Construction Site Erosion and Sediment Controls

Planning, Design and Performance

Second Edition

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Preface

Construction sites have an erosion rate of approximately 20 to 200 tons per acre per year, a rate that is about 3 to 100 times that of croplands. Some areas can experience much higher erosion rates. For example, much of the Piedmont region of the southeast (including parts of Alabama and Georgia) may have some of the highest erosion rates in the nation because of its combination of very high energy rains, moderately erosive soils and steep topography. The high erosion rates mean that even a small construction project may have a significant detrimental effect on local water bodies.

The site-specific factors affecting construction site erosion include:

- Rainfall Energy (the southeast has the highest in the nation)
- Soil Erodibility (fine grained soils are usually the most erosive)
- Site Topography (steep hills undergoing development create the most severe problems)
- Surface Cover (usually totally removed during initial site grading, especially on hilly construction sites)

Because of the highly variable rainfall, soil, and topographic conditions throughout the country, it may not be suitable to use generic erosion and sediment control solutions in all areas; specific local problems and features must be considered when selecting the most appropriate control program for a specific area. This book illustrates how it is possible to design suitable controls using sound engineering principles and site-specific conditions.

This book was conceived and prepared as a "toolbox" to assist planners, watershed managers, and engineers in meeting the erosion control requirements of the EPA's Stormwater Permit Program, and local erosion control ordinances. Specific design examples are given for a variety of basic erosion and sediment controls, including diversion structures, slope mulches, stable channels, detention ponds, and silt fences. The design procedures allow alternative designs corresponding to different design periods, hydraulic failure rates, and pollutant control objectives. The material in this book is unique in that scientific principles and engineering design have been integrated, allowing the prediction of the performance of erosion controls to be made for specific site and rain conditions. Reviews of 95 US and International erosion control guidance manuals were also reviewed to identify common and emerging erosion controls.

This second edition includes many changes that have occurred in the erosion and sediment control field in the 15 years since the first edition was prepared. Many new publications describing the characteristics of construction site erosion are now available, along with numerous publications on field and laboratory monitoring of sediment controls, have been used to update all chapters of the book. Discussions of emerging regulations are also presented, along with information concerning receiving water effects associated with construction site runoff. New sidebar discussions photographs of interesting problems and solutions have also been added to the 2nd edition. Major updates incorporate new rainfall (NOAA Atlas 14) and runoff (proposed changes to NRCS TR-55) processes and examples. Increasing interests in predicting erosion from individual or short series of rains, in contrast to annual total erosion, is also addressed. Updated example specifications from current erosion manuals are also included in the text. Increased discussions reflect the interest and use of chemical controls for construction site erosion.

The chapters and appendices in this book include:

The class for which this material has been developed is traditionally offered to second-semester seniors and graduate students, with basic hydrology as a prerequisite. Each chapter has a set of problems at the end. The problems are separated into concept or thought questions, skill-supporting problems, and project-based problems. When the authors teach this class, they organize the class around single projects based on actual local construction projects for each student with supplemental homework. The project consists of having each student identify a local construction site that the student can monitor and evaluate, with the focus on the student having a firm understanding by the end of the course of the steps required to prepare an acceptable erosion control plan. It is important, but not critical, that the students contact the site engineers to obtain copies of pre-development and final development topographic information, plus their erosion control plan. The purpose of this project assignment is not to criticize the professional plan, but to use the detailed information to make reasonable calculations and decisions. The students also frequently observe the site over the term of the class to note changes that are occurring, along with maintenance activities. Hopefully the students will also have an opportunity to observe the site after large rains to obtain a better appreciation of the damage that may occur on a site and necessary grading and erosion control repairs.

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Chapter 1: Introduction to Erosion and Sediment Control, Problems and Regulations

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Problems Associated with Construction Site Erosion and Sediment Loss

Observed Erosion Rates from Construction Sites

Problems associated with construction site runoff have been known for many years. More than 35 years ago, Willett (1980; Virginia 1980) estimated that approximately five billion tons of sediment reached U.S. surface waters annually, of which 30 percent was generated by natural processes and 70 percent by human activities. Half of this 70 percent was attributed to eroding croplands. Although urban construction accounted for only ten percent of the total, it equaled the combined contributions of forestry, mining, industrial, and commercial activities. While construction occurred on only about 0.007 percent of U.S. land in the 1970s, it accounted for approximately ten percent of the sediment load to all U.S. surface waters (Willett 1980), and the vast majority of the sediment load to urban streams. Increased development in many areas of the US in recent years has only served to increase the need for construction site erosion controls.

Urban areas experience large construction sediment loads from two primary reasons: (1) construction sites have extremely high erosion rates from graded and bare lands; and (2) urban construction sites are efficiently drained by stormwater drainage systems installed early during the construction activities. Some construction sites can have measured erosion rates of approximately 20 to 200 tons per acre per year, 3 to 100 times greater than croplands. These rates are highly variable around the country, and depend on local rain, soil, topographic, and management conditions. As an example, the Birmingham, Alabama, area may have some of the highest erosion rates in the U.S. because of its combination of very high energy rains, moderately to severely erosive soils, and steep slopes. In similar areas, the high erosion rates mean that even a small construction project may have a significant detrimental effect on local water bodies.

In the Chesapeake Bay Basin in the eastern United States, it is estimated that the amount of land under construction annually is 84,500 acres or about 132 square miles each year or about 0.02% of the total Bay watershed area. Models developed for the Chesapeake Bay Program estimate that 16% of the delivered sediment load from the urban sector is from construction sites and construction sites are responsible for 3% of the load from all sectors combined (Sweeney, 2013). Table 1-1 reviews the sediment load delivered from monitored construction sites.

Table 1-1. Measured Sediment Loading Rates for Construction Sites with no Erosion or Sediment Control (Chesapeake Bay Program Expert Panel, 2014).

Study	Region	Tons/acre/year
Yorke and Herb, 1978	Maryland	33
Nelson, 1984	Southeastern US	100 to 300
Cleaves et al., 1970	Southeastern US	218.9
Likens and Borman, 1974	Northeastern US	48.4
Cywin and Hendricks, 1969	Southeastern US	134

Data from the highly urbanized Menomonee River watershed in southeastern Wisconsin illustrate the impact of construction site erosion on water quality. These data indicate that construction sites had much greater potentials for generating sediment and phosphorus than did areas in other land uses (Chesters, *et al*. 1979). The construction sites generate approximately 8 times more sediment and 18 times more phosphorus than industrial sites, which is the 2nd highest contributing land use, and 25 times more sediment and phosphorus than row crops. In fact, these construction sites contributed more sediment and phosphorus to the Menomonee River than any other land use, although at that time, construction occupied only 3.3 percent of the watershed's total land area. Construction sites were found to contribute about 50 percent of the suspended sediment and total phosphorus loading at the river mouth (Novotny, *et al*. 1979).

Similar conclusions were reported by the Southeastern Wisconsin Regional Planning Commission in a 1978 modeling study of the relative pollutant contributions of 17 categories of point and nonpoint pollution sources to 14 watersheds in the southeast Wisconsin regional planning area (SEWRPC 1978). Construction was the first or second largest contributor of sediment and phosphorus in 12 of the 14 watersheds. Although construction occupied only two percent of the region's total land area in 1978, it contributed approximately 36 percent of the sediment and 28 percent of the total phosphorus load to inland waters. The largest source of sediment was estimated to be cropland; livestock operations were estimated to be the largest source of phosphorus. However, comparing the relative contributing areas, cropland comprised 72 percent of the region's land area and contributed about 45 percent of the sediment and only 11 percent of the phosphorus to regional watersheds. This early study again pointed out the high pollution-generating ability of construction sites and the significant water quality impact a small amount of construction may have on a watershed.

A study of construction site runoff water quality in the Village of Germantown (Washington County, Wisconsin) yielded similar results (Madison, *et al*. 1979). During construction of several large subdivisions and after utility construction, including installation of the storm drainage system, the monitoring data showed that sediment leaving the developing subdivisions averaged about 25 to 30 tons per acre per year (Madison, *et al*. 1979). Construction practices identified as contributing to these high yields included the following:

- Removing surface vegetation;
- Stripping and stockpiling topsoil;
- Placing large, highly erodible mounds of excavated soil on and near the streets;
- Pumping water from flooded basement excavations; and
- Tracking mud in the streets by construction vehicles.

If the utility installation sediment source had been included, the total amount of eroded sediment leaving the site would have been substantially greater. The Germantown data also showed that the amount of sediment leaving areas undergoing development was a function of the extent of development and was independent of the type of development. Almost all eroded sediment from the Germantown construction areas entered the receiving waters with nearly 100 percent of the sediment reaching the receiving water when ten percent or more of the watershed was experiencing development. The smallest sediment delivery value obtained during the Germantown monitoring was 50 percent, which was observed when only five percent of the watershed was undergoing development. These high delivery values occurred (even during periods with small amounts of development) because storm drainage systems, which efficiently transport water and its sediment load, were installed early in development. When looking at the Milwaukee River as a whole, the highly-efficiency delivery system installed during urban land development ensures that construction is a major sediment contributor, even though the amount of land under active construction is very low (Figure 1.1).

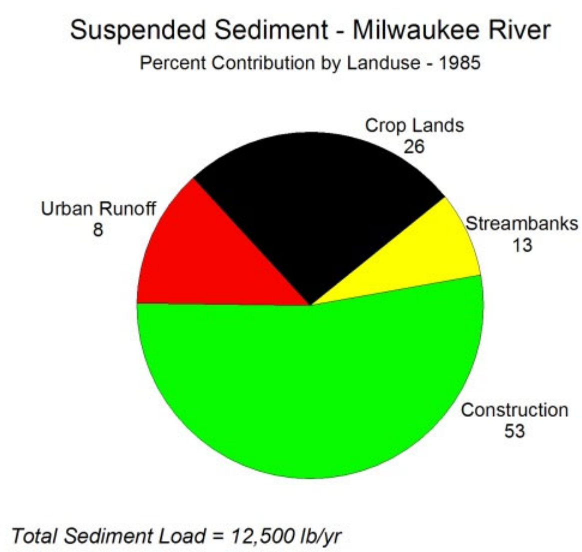


Figure 1-1. Soil Delivery to Streams.

The Chesapeake Bay Expert Panel on Erosion and Sediment Control compiled the results of 10 studies where nutrients were monitored in runoff from urban construction sites. Table 1-2 summarizes these results, which indicate that, especially for nitrogen, construction is a significant source of elevated concentrations of nitrogen in streams below the construction sites.

Table 1-2. Comparison of Nutrient Concentrations in Construction Site Runoff (Expert Panel 2014)

Study	Total Nitrogen (mg/L)	Dissolved Inorganic Nitrogen (mg/L)	Total Phosphorus (mg/L)
Kayhanina et al. 2001	3.5	1.06	0.95
Line 2007	1.7		0.47
Cleveland and Fashokun, 2006		1.26	0.47 (measured as PO_4)
McLaughlin and King 2008	5.18	ND	3.1
McLaughlin and King 2008	19.8		34.6
McLaughlin and King 2008	3.78		0.3
Horner et al. 1990			12.3
Horner et al. 1990			2.25
Horner et al. 1990			0.55

Sediment delivery from agriculture is much smaller per unit area than from urban construction sites (*Sources of Sediment in Milwaukee River*, WI DNR). For example, assuming 4% delivery efficiency for agriculture and 100% delivery efficiency for construction sites, construction generates more sediment while occupying less land.

Agricultural Field (4% efficiency of sediment delivery due to buffer zones, rough surfaces, flat surfaces with sedimentation depressions prior to entering receiving water)

(10 tons/ac/yr) (4%) = 0.4 tons/ac/yr

Construction Site (100% efficiency of sediment delivery due to the direct connection between the construction area, the drainage system, and the receiving water)

(20 tons/ac/yr) (100%) = 20 tons/ac/yr

 Outer harbor at Milwaukee in Lake Michigan frequently shows excessive turbidity from Kinnickinnic, Menomonee, and Milwaukee Rivers discharges during moderate to heavy rains. This has led to numerous investigations to identify the source of the sediment.	 High sediment discharges from Inner to Outer harbor in Milwaukee during heavy rains.

Figure 1-2. Sources of Sediment in Milwaukee River, WI (WI DNR)

Developed in response to the increased awareness of these problems and to the public's demand that they be reduced, the EPA's Stormwater Permit Program includes regulations for the control of construction site erosion discharges. This chapter summarizes these regulations and includes an appendix describing example regulation specifications for many areas in the country.

Construction Site Runoff Characteristics and Treatability

Table 1-3 summarizes TSS and turbidity values from several research locations at construction sites. The values listed on this table were representative of conditions before any erosion and sediment controls. Typical TSS concentrations are about 6,000 mg/L, while typical turbidity values are about 3,500 NTU. These values are much greater than desired, with likely needed reductions of about 90 to 95% to achieve 250 mg/L TSS and 250 NTU turbidity, for example. The TSS and turbidity goals and whether there are numeric effluent limits are dependent on state or local regulations and receiving water objectives such as total maximum daily load (TMDL) requirements. These modest concentration limits are extremely challenging to meet at construction sites.

In some cases, regulatory programs are based on TSS or SSC concentrations. However, it is common to rely on site measurements of turbidity to indicate the severity of sediment problems and for a simple indication of regulatory compliance; this assumes a close relationship between turbidity and TSS or SSC. A study investigating the relationships between turbidity and sediment concentrations was conducted by Perkins, *et al.* (2017) for many different soils obtained from construction sites in Minnesota. Laboratory erosion tests were conducted on 14 soils collected from construction sites representing a range of conditions. The samples were serially diluted and the measured concentrations of turbidity and sediment concentrations were compared. The trends of turbidity with sediment concentrations were well represented by power functions, as shown on Figure 1-3 for these different soils. The exponent of these power functions was relatively constant between soils (similar slopes), but the log-intercept, or scaling parameter, varied substantially among the different soils. Therefore, there are strong linear relationships between turbidity and SSC, but these relationships varied for different soil and site conditions. They found that the percentage of silt (most important), interrill erodibility, and maximum rainfall abstraction best represented the intercept term on the plots.

Table 1-3. Characteristics of Erosion from Construction Sites before any Controls

reference	Erosion control	type of tests and general location	number of events X locations per treatment	TSS influent (mg/L) avg	Turbidity influent (NTU) avg
Faucette, et al. 2009 JSWCS	bare soil control	field test plots and controlled flow - North Georgia	1	4,252	3,628
McLaughlin and Brown 2006 JAWRA	bare soil control	field fescue test plots - North Carolina	5	6,770	2,279
McLaughlin and Brown 2006 JAWRA	bare soil control	lab erosion tray	3		3,530
Roa-Espinosa. et al. 2000 Chicago conf	control	field test trays - Wisconsin	3	6,596	
Soupir, et al. 2004 JAWRA	control	field plots - Virginia	6	6,537	
Wilson, et al. 2010 IECA	control	lab erosion tray	4	n/a	3,500
Roa-Espinosa. Et al. 2000 Chicago conf	solution PAM mulch dry soil	field test trays - Wisconsin	3	6,596	
Soupir, et al. 2004 JAWRA	dry PAM	field plots - Virginia	6	6,537	
McLaughlin and Brown 2006 JAWRA	bare soil with PAM	field fescue test plots - North Carolina	5	6,770	2,279
Soupir, et al. 2004 JAWRA	straw mulch	field plots - Virginia	6	6,537	
Faucette, et al. 2009 JSWCS	8 inch compost filter sock	field test plots and controlled flow - North Georgia	1	4,252	3,628

Table 1-3. Characteristics of Erosion from Construction Sites before any Controls (continued)

reference	Erosion control	type of tests and general location	number of events X locations per treatment	TSS influent (mg/L) avg	Turbidity influent (NTU) avg
McLaughlin, et al. 2009 JSWC	fiber check dam (straw wattles and coir logs)	full size - North Carolina	20	15,201	3,813
Line and White 2001 ASAE	sed trap with rock outlet	full size - North Carolina	34	2,145	
Line and White 2001 ASAE	U-shaped sed trap with rock outlet	full size - North Carolina	42	4,685	
McCaleb, et al. 2008 ASABE	Dry standard 10-yr trap 10ST	full size - Piedmont North Carolina	18	1,665	n/a
McCaleb, et al. 2008 ASABE	Dry pond standard 25-yr trap 25ST	full size - Piedmont North Carolina	29	6,927	n/a
McCaleb, et al. 2008 ASABE	Dry standard trap with silt fence baffles STSFB	full size - Piedmont North Carolina	11	12,200	n/a
		number	17	15	7
		average	12	6,511	3,237
		median	6	6,537	3,530
		min	1	1,665	2,279
		max	42	15,201	3,813
		COV	1.1	0.53	0.20

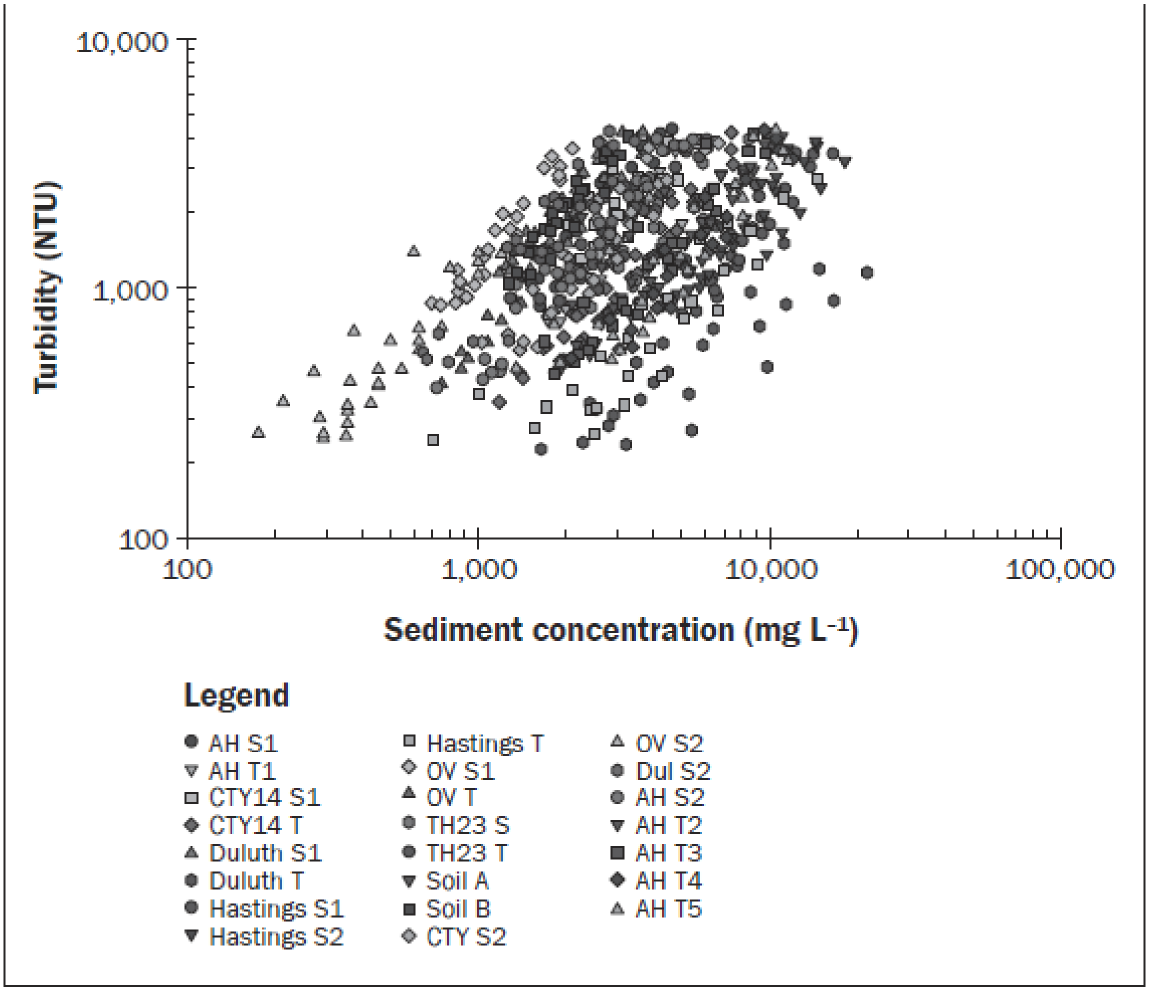


Figure 1-3. Sediment vs. turbidity dilution curves for different soil types (Perkins, *et al.* 2017).

The treatability of sediment-laden runoff from construction sites depends on a number of factors, including the site hydraulics and hydrology (flow rates and volumes of runoff to be treated), erosion rates (dependent on rainfall energy, soil conditions, site topography, surface cover, etc.), and physical and chemical characteristics of the sediment (such as particle size distributions and surface chemistry affecting coagulation with chemical treatment).

During a class research project at the University of Alabama in 2012, students (K. Daly, T. Handley, W. Strickland, and L. Talebi) collected runoff samples from five construction sites in Tuscaloosa, AL, for treatability experiments. The samples represented untreated runoff during rains ranging from 0.18 to 1.25 inches in depth. The samples had initial turbidities ranging from about 900 to 25,000 NTU. Each sample was split using a USGS/Dekaport cone splitter into 10 subsamples. The subsamples were then sieved (425 µm, 250 µm, 106 µm, 45 µm, and 20 µm sieves) or filtered (10 µm, 5 µm, 2 µm, and 0.45 µm membrane filters) to determine the decreasing turbidity as the larger particles were removed. Figure 1-4 is a plot showing the minimal effects on turbidity as particles larger than about 20 µm were removed, with a major decrease in turbidity occurring between the 10 and 20 µm size filtering. For these samples, removing all particles down to about 10 µm would be necessary to reduce the construction site runoff turbidity to less than 100 NTU. The minimum turbidities (<10 NTU) occurred after removing all particles down to about 2 to 5 µm. It is expected that other construction site runoff samples would have different responses to sieving and filtering, but it is likely necessary to remove very small particles in order to meet low turbidity effluent limits.

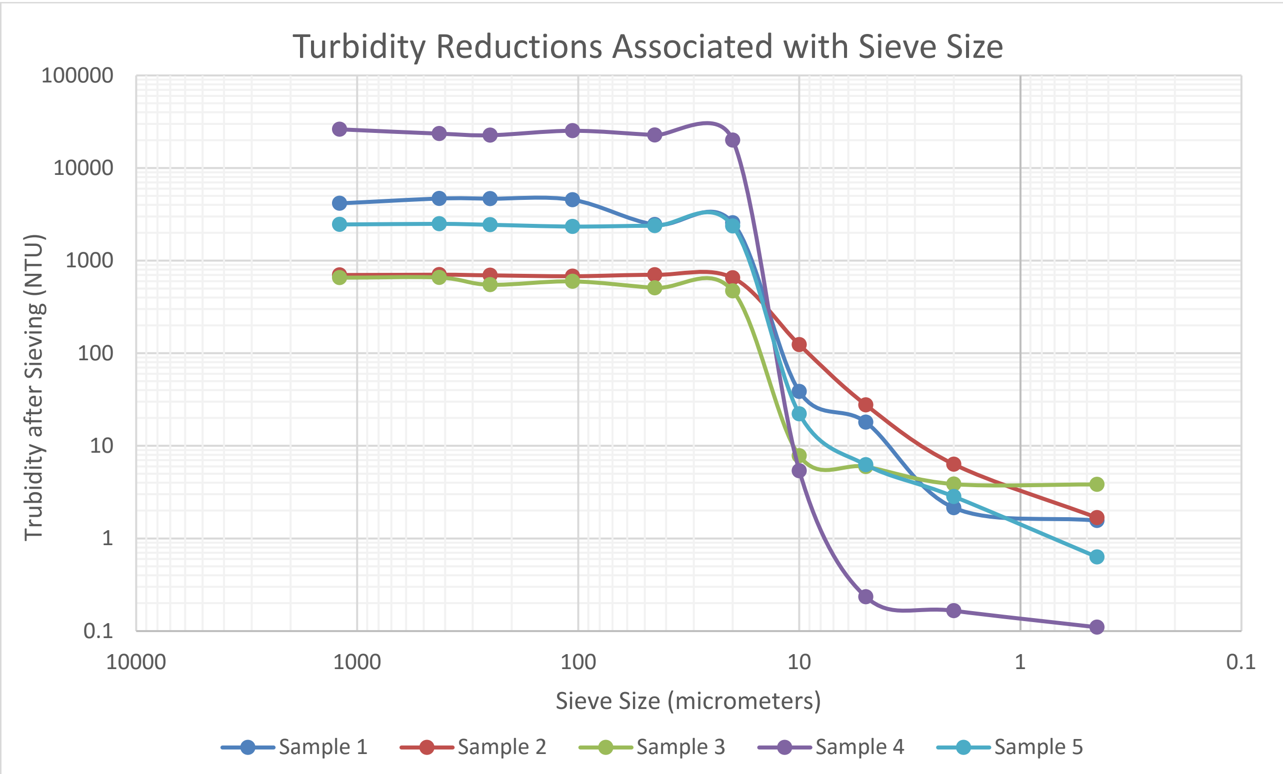


Figure 1-4. Construction site runoff treatability tests.

Clark, *et al.* (2014) reviewed estimates of the sediment and nutrient removal rates associated with erosion and sediment control practices and also evaluated existing nutrient data for construction sites (Table 1-4). They determined that there was no clear evidence that erosion and sediment control (ESC) practices can reduce nutrient discharges from construction sites, while there is some evidence that they may actually become nutrient sources.

Table 1-4. Construction Site Nutrient Loading Rates (Clark, *et al.* 2014)

Source	TN load (lb/ac-yr)	TP load (lb/ac-yr)	Comment
Line and White (2001)	7.2	2.6	Residential, ESC 1
Daniel et al (1979)	12.2 to 49.5	6.7 to 17.9	Residential, ESC 1
Median target selected for CBWM	26.4	8.81	

Why Construction Site Erosion Rates are Comparatively High in the Piedmont and Appalachian Plateaus of the Southeastern Region of the US

Site-specific factors affecting construction site erosion in the Birmingham, Alabama, area include the following:

- Rainfall Energy (Alabama and the southeastern U.S. have amongst the highest in the nation)
- Soil Erodibility (northern part of the state has fine grained, highly erosive soils)
- Site Topography (northeastern part of the state has steep hills under development)
- Surface Cover (usually totally removed during initial site grading on hilly construction sites)

Rainfall energy is directly related to rainfall intensity, and the USLE (Universal Soil Loss Equation, described in Chapter 4) rainfall erosion index varies from 250 to 550+ for Alabama (most of the state is about 350). Nelson (1996) monitored sediment quantity and particle size from 70 construction site runoff samples from the Birmingham area. Suspended solids concentrations ranged from 100 to more than 25,000 mg/L (overall median about 4,000 mg/L), while the turbidity values ranged from about 300 to >50,000 NTU (average of about 4,000 NTU). These sites would be in violation of any future federal numeric effluent limit for turbidity, if these sites fit the requirements for monitoring. They currently violate state permits where effluent turbidity or TSS monitoring is required. About 90% of the particles (by mass) were smaller than about 20 μm (0.02 mm) in diameter, with the median size being about 5 μm (0.005 mm). making them difficult to treat by traditional sedimentation. Local construction site erosion discharges were estimated at approximately 100 tons/acre/year. Table 1-5 summarizes the measured suspended solids and median particle sizes as a function of rain intensity for this study. High intensity rains were found to have the most severe erosion discharges, as expected, with much higher suspended solids concentrations, compared to lower intensity rains. The extreme turbidity values also cause very high in-stream turbidity conditions for great distances downstream of eroding sites.

Table 1-5. Birmingham Construction Site Erosion Runoff Characteristics (Nelson 1996)

	Low intensity rains (<0.25 in/hr)	Moderate intensity rains (about 0.25 in/hr)	High intensity rains (>1 in/hr)
Suspended solids, mg/L	400	2,000	25,000
Particle size (median), μm	3.5	5	8.5

Sidebar: Receiving Water Impacts Associated with Construction Site Discharges

The following summarizes a project that investigated in-stream biological conditions downstream of construction sites having varying levels of erosion controls (none, silt fences, and silt fences plus grass buffers). The project title is *Studies to Evaluate the Effectiveness of Current BMPs in Controlling Stormwater Discharges from Small Construction Sites* and was conducted for the Alabama Water Resources Research Institute, Project 2001AL4121B, by Drs. Robert Angus, Ken Marion and Melinda Lalor of the University of Alabama at Birmingham. The following describes the results of the initial phase (completed in 2002).

Research Objectives

This project examined the effectiveness of low-cost erosion controls, as well as the effects of the discharged silt on the receiving streams' biological communities. The purpose was to determine the tolerable amount of fine sediment that can be discharged to a stream or river without causing serious detrimental conditions to the aquatic ecosystem. A second purpose was to develop or refine metrics that are more sensitive for comparing the level of impairments between sites affected by construction site erosion since current EPA-approved rapid bioassessment procedures were not derived to evaluate the impacts of rapid siltation.

Methods

This study was conducted in the upper Cahaba River watershed in north central Alabama, near Birmingham. The study areas had topography and soil types representative of the upland physiographic regions in the Southeast (i.e., southern Appalachian and foothill areas), making the results relevant to a large portion of the Southeast. The rainfall amounts and intensities in this region are representative of many areas of the Southeast. The expanding suburbs of the metropolitan Birmingham area are rapidly encroaching upon the upper Cahaba River and its tributaries.

The effectiveness of in–place erosion control devices (silt fences and grass buffers) were evaluated at small construction sites during "intense" (≥1 inch/hr) rain events. Runoff samples were collected from sheet flows above silt fences and from points below the fence within the vegetated buffer. Sampling was only carried out on sites with properly-installed and well-maintained silt fences, located immediately upgrade from areas with good vegetative cover. The runoff samples were analyzed for turbidity (using a nephelometer), particle size distribution (using a Coulter Counter Multi-Sizer IIe), and total solids (dissolved solids plus suspended/non-filterable solids).

Six tributary or upper mainstream in-stream sites were studied for the effects of sedimentation from construction sites on both habitat quality and the biological "health" of the aquatic ecosystem (using benthic macroinvertebrates and fish). No other sediment sources, except for the construction areas, affected the study sites. Two sites generated heavy sediment loads, two generated moderate sediment loads, and two (reference sites) had little, or no, sediment inputs. Each site was assessed in the spring to evaluate immediate effects of the sediment, and again during the next late summer or early fall to evaluate delayed effects. The EPA's *Revision to Rapid Bioassessment Protocols for Use in Streams and Rivers* was used to assess the habitat quality at the study sites.

Results

<u>Effectiveness of Silt Fences</u> - Comparisons were made between samples collected immediately below silt fences and samples collected nearby but not below a silt fence (Table 1-6). Silt fences were better than

no control measures, but not substantially. The mean count of small particles below the silt fences were about 50% less than that from areas with no erosion control measures, even though the fences appeared to be properly installed and in good order. However, the variabilities were large and the difference between the means was not statistically significant. This level of control is similar to levels found during controlled laboratory tests. The silt fences did not reduce particle counts to levels comparable to nearby undisturbed sites. For every variable measured (turbidity, total solids, suspended solids, etc.), the mean values of samples taken below silt fences were significantly higher ($p < 0.001$) than samples collected from nearby undisturbed vegetated control sites collected at the same time. These data indicate that silt fences are only marginally effective at reducing small soil particulates in runoff water. Surprisingly, the amount of silt in the runoff (as measured with the variables listed above) was not significantly correlated with slope of the site, or the amount or intensity of rainfall. This may reflect the fact that samples were only collected during intense (>1 inch/hour) rainfall events, the most erosive category.

Table 1-6. Mean values (± std. error) of particle counts in similar samples taken during >1"/hr rain events in unvegetated control sites, below silt fences, and in disturbed areas with no barrier.

	No Barriers (n= 40)	Silt fence (n =23)	Control (n = 34)
Total Particles	$2.18 \times 10^8 \pm 3.28 \times 10^7$	$1.01 \times 10^8 \pm 2.48 \times 10^7$	$2.45 \times 10^6 \pm 3.54 \times 10^5$
Small Particles	$2.13 \times 10^8 \pm 3.21 \times 10^7$	$9.82 \times 10^7 \pm 2.43 \times 10^7$	$2.36 \times 10^6 \pm 3.44 \times 10^5$
Large Particles	$4.37 \times 10^6 \pm 9.20 \times 10^5$	$2.91 \times 10^6 \pm 7.28 \times 10^5$	$8.56 \times 10^4 \pm 1.31 \times 10^4$

Note: In each row, the mean for the Control is significantly lower than for the other cells in the same row (ANOVA on log transformed data, $p << 0.001$). Means for the "No Barriers" and "Silt Fence" treatments were not significantly different for any particle size groups ($p > 0.05$), although the silt fence sites had apparently reduced particle counts.

Effectiveness of Silt Fences with Vegetated Buffers - In addition to sampling immediately below the silt fences, runoff samples were collected after flow over buffers having 5, 10, and 15 feet of dense (intact) vegetation. Again, only sites with silt fences which appeared to be properly installed and maintained were evaluated. Mean total solids in samples collected after passage through the silt fences and a 15 foot vegetated buffer zone were about 20% lower, on average, than those samples collected immediately below the silt fences. The installation of silt fences above an intact, good vegetated buffer removes sediment from construction site runoff more effectively than with the use of silt fences alone. High variations in the effectiveness were observed, likely due to variations in the site microenvironments. Longer buffer lengths (15 feet) generally resulted in greater removals of sediment than shorter buffer lengths (5 feet). An increase in the percent removal of sediment in the vegetated buffer strip appeared to correlate weakly with a decrease in the site slope.

Development of Biological Metrics Sensitive to Sedimentation Effects (Fish) - Analysis of the fish biota indicates that various metrics used to evaluate the biological integrity of the fish community also are affected by highly sedimented streams. As shown in Figure 1-5, the overall composition of the population, as quantified by the Index of Biotic Integrity (IBI) is lower, the proportion and biomass of darters, a disturbance-sensitive group, is lower; the proportion and biomass of sunfish is higher; the Shannon-Weiner diversity index is lower; and the number of disturbance-tolerant species higher.

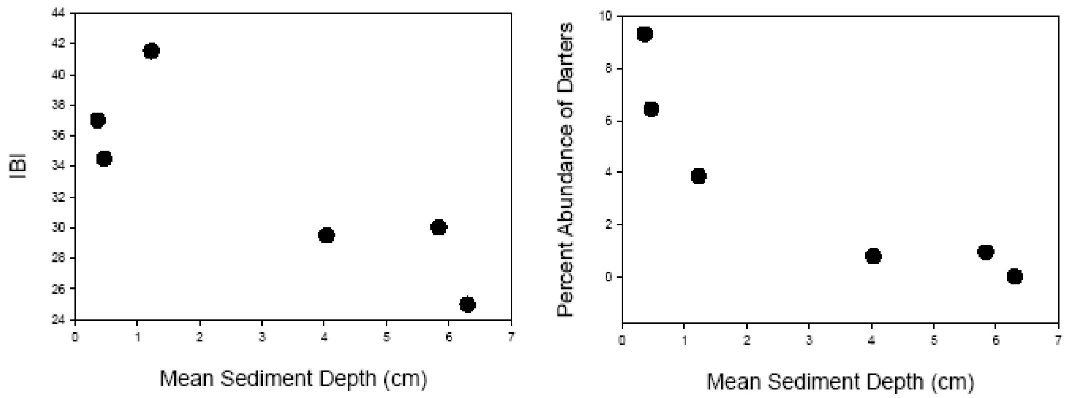


Figure 1-5. Association between two fish metrics and amount of stream sediment.
NOTE: The IBI (Index of Biotic Integrity) is based on numerous characteristics of the fish population. The percent relative abundance of darters is the percentage of darters to all the fish collected at a site.

<u>Benthic Macroinvertebrates</u> – A number of stream benthic macroinvertebrate community characteristics were sensitive to sedimentation. Metrics based on these characteristics differed greatly between sediment-impacted and control sites (Figure 1-6). Some of the metrics that appeared to reflect sediment-associated stresses include the Hilsenhoff Biotic Index (HBI), a variation of the EPT index (%EPT minus Baetis), and the Sorensen Index of Similarity to a reference site. The HBI index is a weighted mean tolerance value; high HBI values indicate sites dominated by disturbance-tolerant macroinvertebrate taxa. The EPT% index is the percent of the collection represented by organisms in the generally disturbance-sensitive orders *Ephemeroptera*, *Plecoptera*, and *Trichoptera*. Specimens of the genus *Baetis* were not included in the index as they are relatively disturbance-tolerant. The HBI and the EPT indices also showed positive correlations to several other measures of disturbance, such as percent of the watershed altered by development.

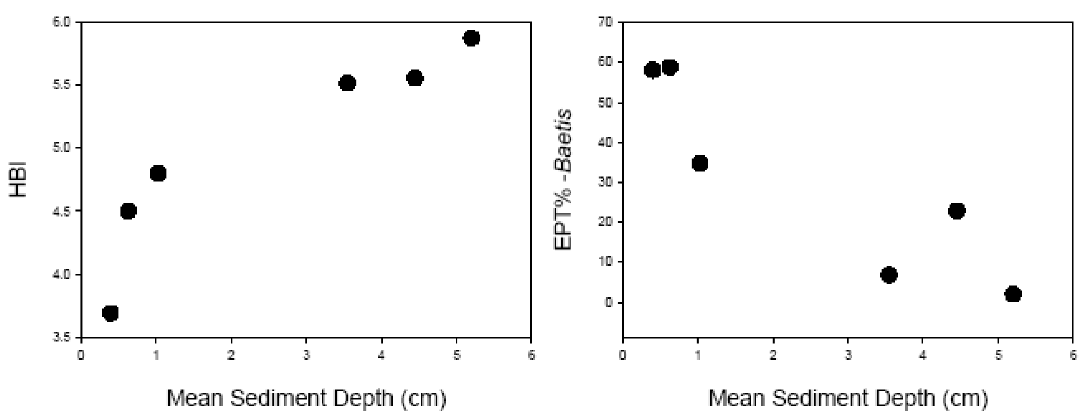


Figure 1-6. Associations between two macroinvertebrate metrics and the amount of stream sediment.

Another receiving water investigation that compared an urbanizing watershed with control watersheds was conducted by Hogan, *et al.* (2014). They measured the stream characteristics in the developing watershed that had used the "best available sediment and erosion control practices." The 5 km^2 watershed test area stream went from an almost complete conversion from forested areas to urban areas between 2003 and 2010. The study mapped the changing landscape topography using high-resolution LIDAR, streamflow, physical geomorphology, benthic microorganism, and habitat characteristics. They concluded that despite using the best available sediment and erosion controls, the streams experienced altered flows, geomorphology, and decreased biotic community health. Figure 1-7 illustrates the declining benthic macroinvertebrate metric scores as the watershed developed, compared to undeveloped control watersheds.

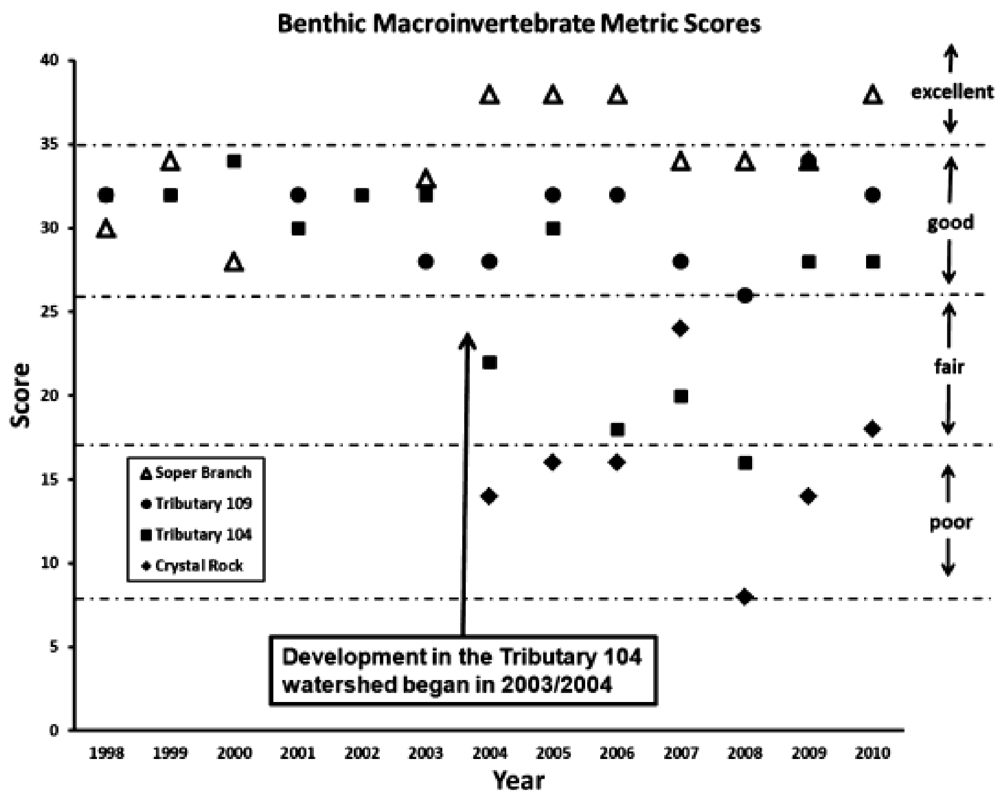
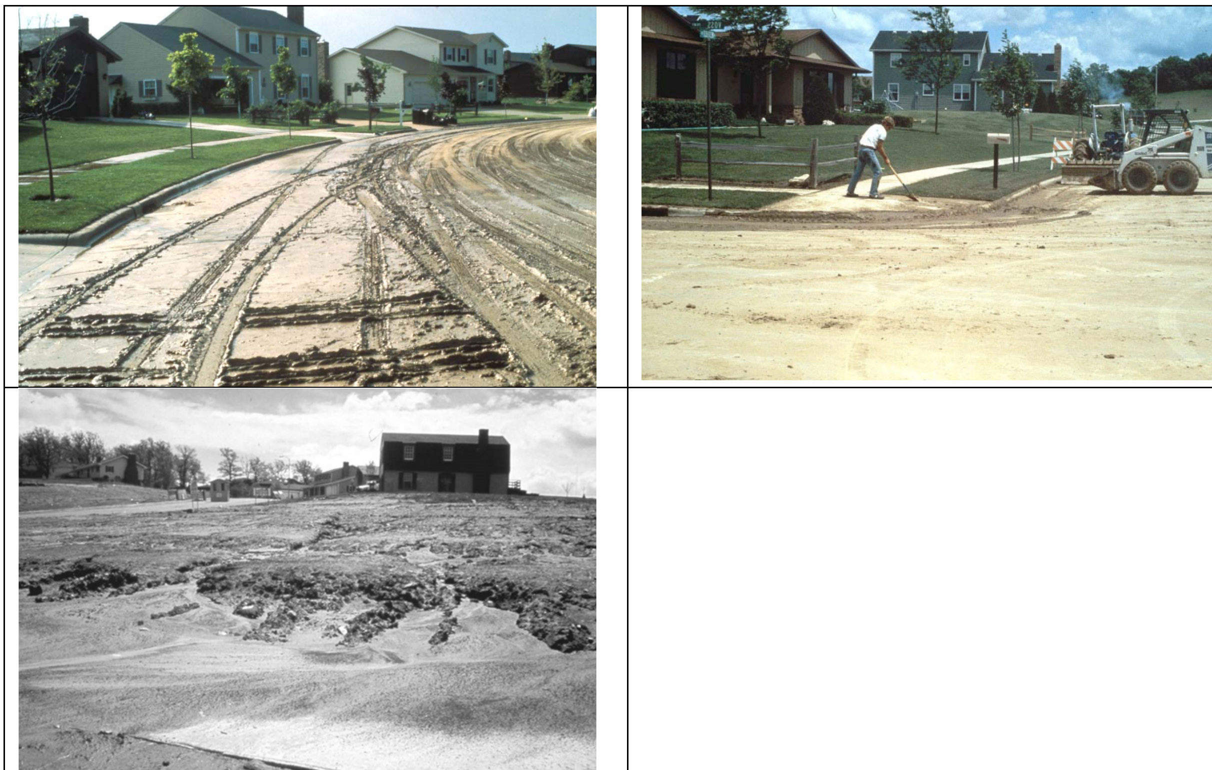


Figure 1-7. Stream benthic macroinvertebrate metric scores in urbanizing watershed (Tributary 104 and Crystal Rock) compared to control watersheds (Soper Brancn and Tributary 109) (Hogan, *et al.* 2014).

They concluded that the mitigation actions were unable to preserve predevelopment landscape and stream conditions and produced detrimental effects such as altered streamflow and hydrology.

Receiving water problem investigations conducted throughout the country have led to increasing local and national regulations, and the development of new technologies and methods, for the reduction of construction site erosion. The rest of this introductory chapter outlines the Phase I and Phase II NPDES stormwater regulations affecting construction sites, plus the 2009 US EPA Federal Construction Numeric Effluent Limitations. The 2009 regulations' discussion reflects the current state of the regulations since at the time of this review the numeric effluent limitation of 280 NTU has been challenged successfully in court.



Trying to Sell Badly Eroded Land (difficult to sell lots and homes in these types of neglected areas)

Figure 1-8. Bad Impression on Neighbors (massive erosion from development extension affecting adjacent property owners)

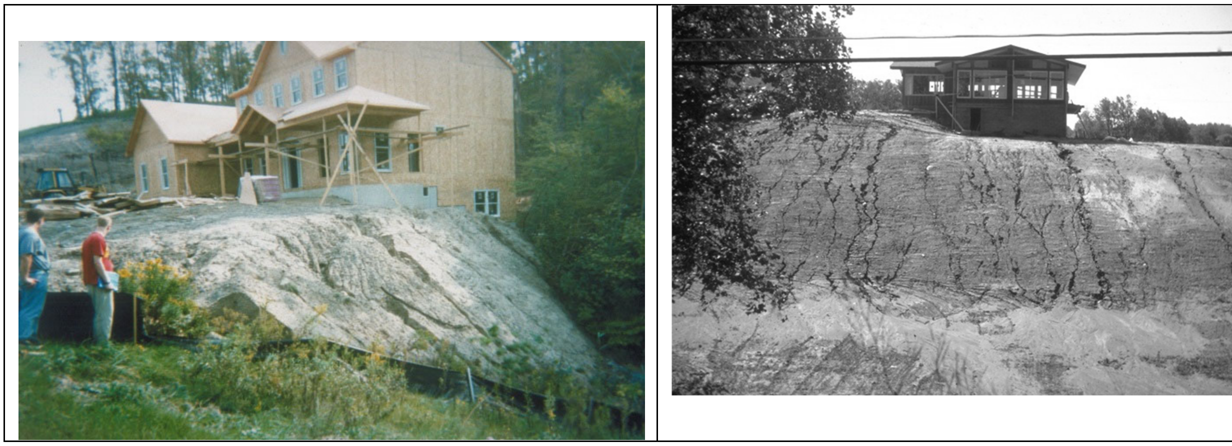


Figure 1-9. Erosion Threatening Homes (This home is being constructed on 12 feet of fill soil. The foundation footers are 14 feet below the groundline. Note the rills draining down to the drainage swale)

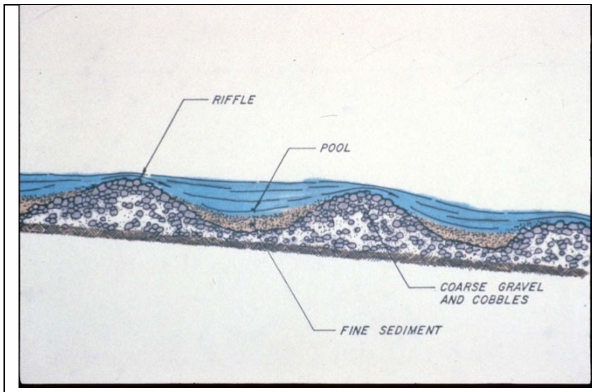
Figure 1-10. Damage from Erosion Requiring Repairs (IECA photo)

Culverts can be haphazardly installed during construction operations. They can provide high energy supercritical velocities at their outlets that need to be reduced to prevent scour.

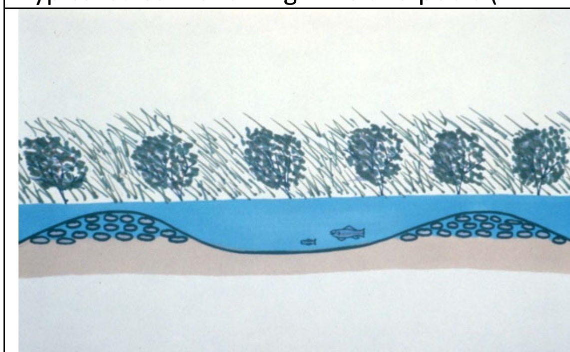
High turbidity is common in urban waters in many locations having excessive erosion.

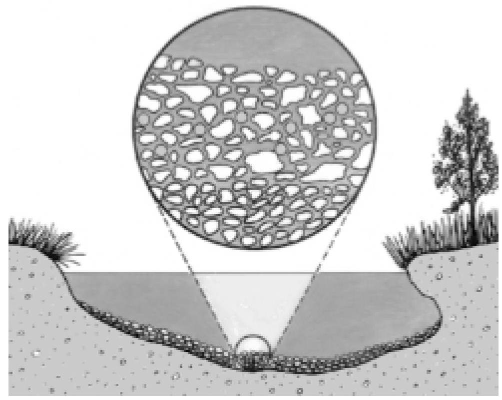
Figure 1-11. Receiving Water Problems Caused by Excessive Erosion

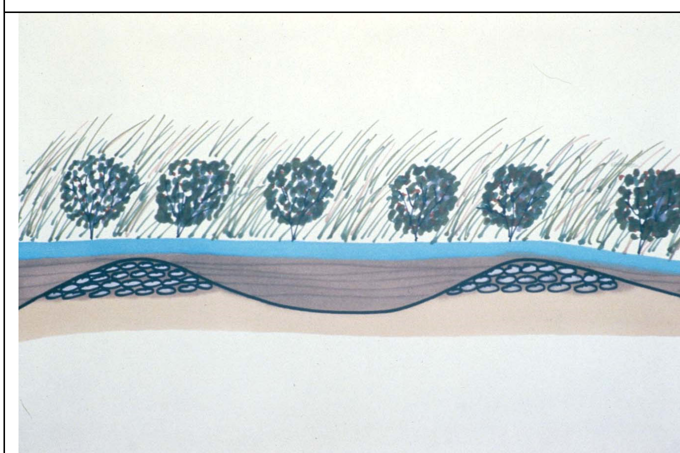
Figure 1-12. Typical Urban Stream Sediment (mostly silts and clays, little coarse material)

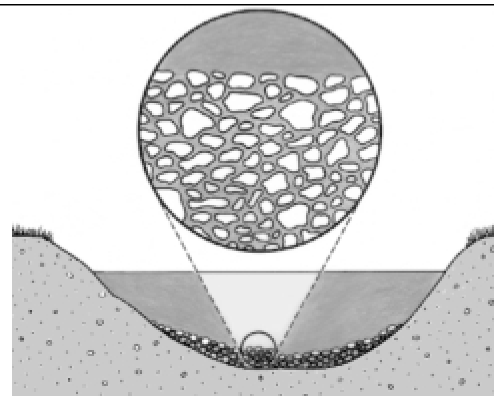


Typical stream showing riffle and pools (WI DNR)


Clean gravel channel bottom: supportive of fish (WI DNR)


Clean gravel channel bottom: supportive of fish


Sediment-laden channel bottom: unsupportive (WI DNR)


Sediment-laden channel bottom: unsupportive

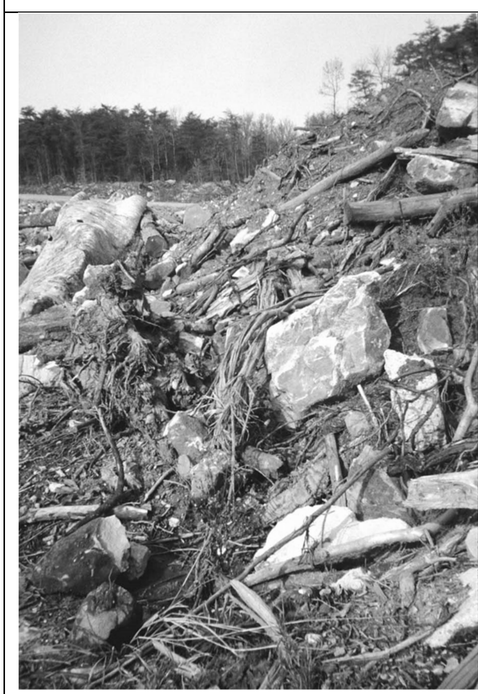
Natural stream showing coarse bottom material in riffle area.

Figure 1-13. Sediment Problems (WI DNR) (Natural streams alternate pools and riffles and have varying stream sediment textures. With erosion impacts, pools are filled, and coarse material becomes covered with fines)

Drainage Ditch Filled with Construction Sediment (J. Voorhees) (Decreased drainage capacity causes increased flooding)

Eroded Streams and Channels (WI DNR) (Eroding banks affect shoreline water quality)

Figure 1-14. Off-site sediment problems caused by construction activity.

 Most stormwater has low turbidity unless affected by eroding soils.	 Local erosion problem affecting turbidity of one drainage branch.
 Eroding soils from bare ground can be responsible for much sediment loss.	 A small utility trench can cause concentrated flow resulting in greater erosion
 Buried debris and other material adversely affects soil structure and future drainage.	 Vast amounts of bare ground exposed for extended periods at construction sites are

	responsible for most of the erosion problems, especially if on a slope.

Figure 1-15. Other problems associated with construction site sediment and debris.

Sidebar: Lack of Following a Good Plan

This site began, at least on paper, with all the promise of a well-planned, phased, and properly designed residential development. The consulting engineering firm had divided this 70 acre site into four construction phases, balancing the cuts and fills for each phase. They had incorporated appropriate erosion and sediment control practices in the stormwater pollution prevention plan that also contained an 8 acre pond for water quality and quantity control.

Unfortunately, once the project began construction in mid-August, the developer instructed the contractor to ignore the plan and build the entire site and infrastructure in one phase, with 65 aces disturbed at one time. In fact, the developer never signed nor submitted the Notice of Intent for the project as required under the state permit regulations. It began raining in mid-October and was still raining in late December. Unfortunately, this site's outlet drains to a tributary only 3,800 feet from a high quality sport fishing recreational lake. It was later determined that the soils that washed off this site destroyed two acres of walleye spawning area. Soil analyses indicated that the site soil contained 75-98 percent material smaller than 0.074 mm, or 74 μm, and was therefore highly erosive.

The site was shut down by state authorities after the sediment plume into the lake was noticed in late December. Remediation included seeding and mulching the entire site for spring thaw conditions, placing stone check dams in all drainage conveyances, installing a rock dam to create a large sediment basin, construction of five rock chutes for gradient control, and six sediment traps at various locations on the site. The cost for this work was approximately $35,000. In addition, the developer paid a $10,000 fine and was placed on a graduated fine scale for any additional water quality violations.

Even though this site was relatively flat, the high content of fine particulates in the soil coupled with the total disregard for erosion control practices and lack of knowledge of the drainage area caused this disaster.

Figure 1-16. This exposed site is under a state shutdown order for destroying 2 acres of walleye spawning area in a nearby lake. 65 acres of the 70 acre site was stripped exposing soil containing 75 – 98 percent fines that could not settle out on site.

Continuous operations at a solid waste landfill require special precautions to prevent excessive erosion. This site has a large sediment pond, with pre-treatment forebays, plus a final sand filter, to meet their 50 NTU discharge permit requirement for turbidity.

End of season construction site shutdowns can also result in excessive erosion during late winter and early spring rains during periodic thaws unless the site is well-stabilized for the season.

.
Control of runoff is critical at the beginning of construction. Here the stormwater infrastructure is in place but the 24 inch storm sewer is 75% plugged with sediment. Note the large size of the material on the catch basin grate.

Cleanup of excessive sediment on roads should not include rinsing the debris to the storm drainage inlet!

Figure 1-17. Sediment sources

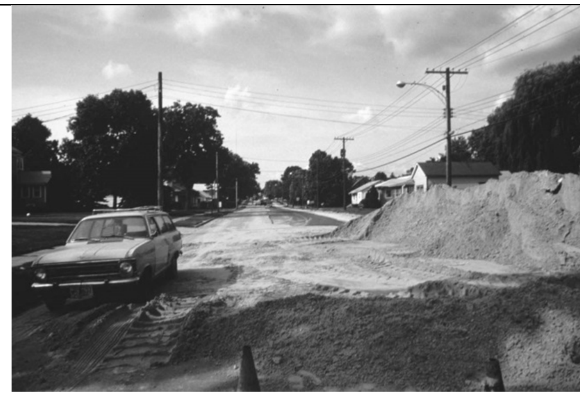
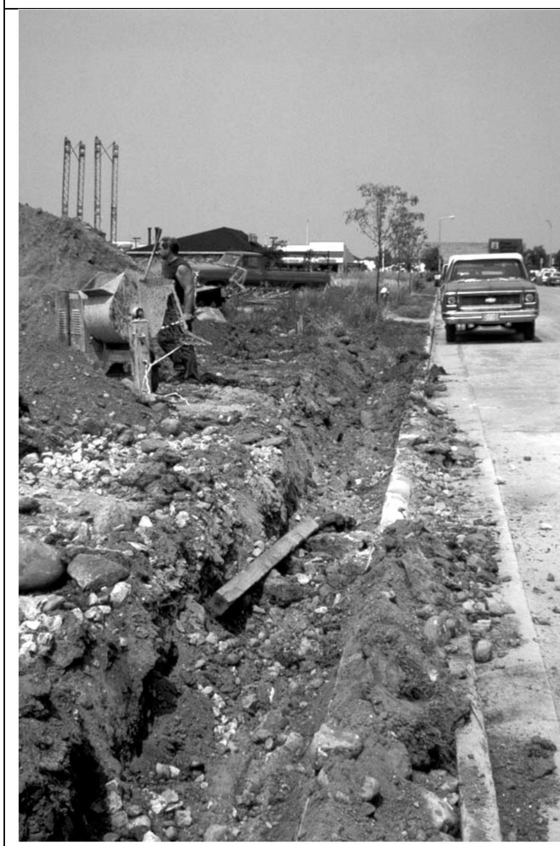
 Stock piles of material can be important sediment sources.	 (especially when located on the road itself, directly connected to the drainage system and receiving water)
 It is very difficult to work close to the road and prevent debris from entering the drainage system.	

Figure 1-18. Stock Pile Problems and Working Close to Roads

Engine repairs and other heavy equipment maintenance should not be allowed on construction sites, unless suitably protected from the elements.

Hazardous materials and other unsafe debris should never be left exposed at construction sites.

Improper waste concrete disposal.

Fuel spillage at re-fueling area is both hazardous and damaging.

Figure 1-19. Improper Disposal of Construction Debris and Improper Equipment Maintenance

Poor grading directed runoff away from drain inlet and to the unprotected slope. Expensive repairs are now needed.

Another unfortunate example of poor grading allowing runoff to miss protected downslope channel.

Figure 1-20. Poor Drainage Construction

In this commercial mall rehabilitation project, dust became a problem even though much of the site area was impervious. Complaints were received from homeowners beyond the work area in the direction of the prevailing winds.

Another example of fugitive dust causing potential traffic safety problems. Construction was halted this day due to high winds at this road-widening project, but unstabilized and exposed ground still allowed excessive dust losses.

Fugitive dust losses and traffic safety problem as heavy equipment was being driven on unprotected construction roads near existing roads during period of high winds.

Figure 1-21. Fugitive Dust Problems

Construction Site Erosion and Sediment Control in the Sustainability Framework

In September 2015, the United Nations adopted the Agenda for Sustainable Development, including 17 Sustainable Development Goals. The reduction of erosion and the control on-site of any sediment generated fulfills several of the UN SDGs, both directly and indirectly. For example, Target 6.3 (in Goal 6 – Clean Water and Sanitation) states that "By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally." Construction site control will reduce water pollution and the release of hazardous chemicals through keeping sediment on the land and reducing opportunities for spills and leaks of hazardous chemicals. Goal 11 on Sustainable Cities and Communities states, in Target 11.6, "By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management." Goal 15 is Life on Land and is the primary goal where construction erosion will provide direct benefits. For example, Target 15.1 states "By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements." Target 15.3 states "By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world." Finally, Target 15.5 states "Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species." The control of construction site erosion, the minimization of disturbed areas, the conscious efforts to minimize impacts on receiving waters are all actions that result in good environmental stewardship while promoting sustainable site development.

While the UN SDGs are goals, three site-specific evaluation frameworks have been developed to directly promote sustainable site development – SITES ®, Leadership in Energy and Environmental Design (LEED®) and Envision. The Sustainable SITES Initiative (Green Business Certification Inc.) advertises that "The central message of the SITES program is that any project—whether the site of a university campus, large subdivision, shopping mall, park, commercial center, or even a home—holds the potential to protect, improve, and regenerate the benefits and services provided by healthy ecosystems." It is a credit-based system where projects can earn points for specific sustainability practices during design, construction, and operation. The three areas where construction site planning and operation can contribute to SITES points are listed in Table 1-7.

Table 1-7. SITES® Areas where Construction Erosion Control May Contribute to Points (NOTE: Baseline activities are not bolded. Activities earning SITES points are in bold type)

1: SITE CONTEXT	
CONTEXT P1.1	Limit development on farmland
CONTEXT P1.2	Protect floodplain functions
CONTEXT P1.3	Conserve aquatic ecosystems
CONTEXT P1.4	Conserve habitats for threatened and endangered species
CONTEXT C1.5	**Redevelop degraded sites**
CONTEXT C1.6	**Locate projects within existing developed areas**
CONTEXT C1.7	**Connect to multi-modal transit networks**

4: SITE DESIGN - SOIL + VEGETATION	
SOIL+VEG P4.1	Create and communicate a soil management plan
SOIL+VEG P4.2	Control and manage invasive plants
SOIL+VEG P4.3	Use appropriate plants
SOIL+VEG C4.4	**Conserve healthy soils and appropriate vegetation**
SOIL+VEG C4.5	**Conserve special status vegetation**
SOIL+VEG C4.6	**Conserve and use native plants**
SOIL+VEG C4.7	**Conserve and restore native plant communities**
SOIL+VEG C4.8	**Optimize biomass**
SOIL+VEG C4.9	**Reduce urban heat island effects**
SOIL+VEG C4.10	**Use vegetation to minimize building energy use**
SOIL+VEG C4.11	**Reduce the risk of catastrophic wildfire**

7: CONSTRUCTION	
CONSTRUCTION P7.1	Communicate and verify sustainable construction practices
CONSTRUCTION P7.2	Control and retain construction pollutants
CONSTRUCTION P7.3	Restore soils disturbed during construction
CONSTRUCTION C7.4	**Restore soils disturbed by previous development**
CONSTRUCTION C7.5	**Divert construction and demolition materials from disposal**
CONSTRUCTION C7.6	**Divert reusable vegetation, rocks, and soil from disposal**
CONSTRUCTION C7.7	**Protect air quality during construction**

LEED® has incorporated many of the credit areas shown in the SITES Sustainable Development Initiative into their program. Because LEED® focuses on the building, including energy systems, there is less specific focus on the steps required in construction sediment and erosion control. Table 1-8 shows the topic areas of LEED® where construction erosion is part of the prerequisite (required of all LEED® new construction sites) or credit process.

Table 1-8. LEED® areas where Construction Site Erosion Control Is Incorporated

Sustainable Sites	
Prereq	Construction Activity Pollution Prevention
Credit	Site Assessment
Credit	Site Development - Protect or Restore Habitat
Credit	Open Space
Credit	Rainwater Management
Credit	Heat Island Reduction
Credit	Light Pollution Reduction
Materials and Resources	
Prereq	Storage and Collection of Recyclables
Prereq	Construction and Demolition Waste Management Planning
Credit	Building Life-Cycle Impact Reduction
Credit	Building Product Disclosure and Optimization - Environmental Product Declarations
Credit	Building Product Disclosure and Optimization - Sourcing of Raw Materials
Credit	Building Product Disclosure and Optimization - Material Ingredients
Credit	Construction and Demolition Waste Management

ENVISION from the Institute for Sustainable Infrastructure promotes a regional framework for sustainability with a particular focus on municipal infrastructure.

RESOURCE ALLOCATION
RA 1.2 Support Sustainable Procurement Practice

Assessment Questions:
Will the project team establish a preference for using manufacturers, suppliers and service companies that have strong sustainable policies and practices?
Will the project team establish a sound and viable sustainable procurement program?
Does the project team intend to source at least 15% of project materials, equipment, supplies and services from these companies?

RA 1.3 Use Recycled Materials

Assessment Questions:
Will the project team consider the appropriate reuse of existing structures and materials and incorporated them into the project?
Will the project team specify that at least 5% of materials with recycled content be used on the project?

RA 1.4 Use Regional Materials
Metric: Percentage of project materials by type and weight or volume sourced within the required distance.

Assessment Questions:
Will the project team work to identify local/regional sources of materials?
Are at least 30% of project materials locally sourced?

RA 1.5 Divert Waste from Landfills

Assessment Questions:
Will the project team identify potential recycling and reuse destinations for construction and demolition waste generated on site?
Will the project team develop an operations waste management plan to decrease and divert project waste from landfills and incinerators during construction and operation?
Will the project divert at least 25% of project waste from landfills?

RA 1.6 Reduce Excavated Materials Taken Off Site

Assessment Questions:
Will the project be designed to balance cut and fill to reduce the amount of excavated material taken off site?
When necessary, will the project team taken steps to identify local sources/receivers of excavated material?
Will the project reuse at least 30% of suitable excavated material onsite?

NATURAL WORLD

NW 1.1 Preserve Prime Habitat

Assessment Questions:
Will the project team take steps to identify and document areas of prime habitat near or on the site?
Will the project avoid development on land that is judged to be prime habitat?
Will the project establish a minimum 300 ft. natural buffer zone around all areas deemed prime habitat?
Will the project significantly increase the area of prime habitat through habitat restoration?
Will the project improve habitat connectivity by linking habitats?

NW 1.2 Protect Wetlands and Surface Water

Assessment Questions:

Will the project avoid development on wetlands, shorelines, and waterbodies?

Will the project maintain soil protection zones (VSPV) around all wetlands, shorelines, and waterbodies?

Will the project restore degraded existing buffer zones to a natural state?

NW 1.3 Preserve Prime Farmland

Assessment Questions:

Will this project avoid development on land designated as prime farmland.

NW 1.4 Avoid Adverse Geology

Assessment Questions:

Will the project team identify and address the impacts of sensitive or adverse geology?

Will the project be designed to reduce the risk of damage to sensitive geology?

Will the project be designed to reduce the risk of damage from adverse geology?

NW 1.5 Preserve Floodplain Functions

Assessment Questions:

Will the project avoid or limit development within the design frequency floodplain?

Will the project maintain pre-development floodplain infiltration and water quality?

Will the project design incorporate a flood emergency operations and/or evacuation plan?

Will the project maintain or enhance riparian and aquatic habitat, including aquatic habitat connectivity?

Will the project maintain sediment transport?

Does the project team intend to modify or remove infrastructure subject to frequent damage by floods?

NW 1.6 Avoid Unsuitable Development on Steep Slopes

Assessment Questions:

Will the project team use best management practices to manage erosion and prevent landslides?

Will the project team minimize or avoid all development on or disruption to steep slopes?

NW 1.7 Preserve Greenfields

Assessment Questions:

Will the project team consider how the project can conserve undeveloped land?

Will at least 25% of the project development be located on previously developed sites, that is, sites classified as greyfields or brownfields?

NW 2.1 Manage Stormwater

Assessment Questions:

Will the project be designed to reduce storm runoff to pre-development conditions?

Will the project be designed to significantly improve water storage capacity?

NW 2.2 Reduce Pesticides and Fertilizer Impacts

Assessment Questions:

Will operational policies be put in place to control and reduce the application of fertilizers and pesticides?

Will the project include runoff controls to minimize contamination of ground and surface water?

Will the project team select landscaping plants to minimize the need for fertilizer or pesticides?

Will the project team select fertilizers and pesticides appropriate for site conditions with low-toxicity, persistence, and bioavailability?

Will the project be designed to eliminate the need for pesticides or fertilizers?

NW 2.3 Prevent Surface and Groundwater Contamination

Assessment Questions:

Will the project team conduct or aquire hydrologic delineation studies?

Will spill and leak prevention and response plans and design be incorporated into the design?

Will the project design reduce or eliminate potentially polluting substances from the project?
Will the project team seek to reduce future contamination by cleaning up areas of contamination and instituting land use controls to limit the introduction of future contamination sources?

NW 3.1 Preserve Species Biodiversity

Assessment Questions:

Will the project team identify existing habitats on and near the project site?
Will the project protect existing habitats?
Will the project increase the quality or quantity of existing habitat?
Will the project preserve, or improve, wildlife movement corridors?

NW 3.2 Control Invasive Species

Assessment Questions:

Will the project team specify locally appropriate and non-invasive plants on the site?
Will the project team implement a comprehensive management plan to identify, control, and/or eliminate, invasive species?
Will the project team implement a comprehensive management plan to prevent or mitigate the future encroachment of invasive species?

NW 3.3 Restore Disturbed Soils

Assessment Questions:

Will the project restore 100% of soils disturbed during construciton?
Will the project restore 100% of soils disturbed by previous development?

NW 3.4 Maintain Wetland and Surface Water Functions

Assessment Questions:

Will the project maintain or enhance hydrologic connetion?
Will the project maintain or enhance water quality?
Will the project maintain or enhance habitat?

Will the project maintain or restore sediment transport?
Will wetlands and surface water be maintained or restored so as to have a fully functioning aquatic and riparian ecosystem?

As each of these sustainable development initiatives note, development and construction are not antithetical to sustainability. They are not advocating for no development. They are promoting the minimization of disturbance, especially of critical habitat, and the restoration of disturbed areas.

Construction Site Erosion and Sediment Control Regulations

The NPDES (National Pollutant Discharge Elimination System) was established as part of the Clean Water Act amendments of 1972. It was intended to control and regulate point sources of water pollution throughout the US, with the eventual objective of totally eliminating these discharges and ensuring all US receiving waters were "fishable" and "swimmable." Over the years, these lofty objectives have been scaled back, but these regulations have done much to improve the quality of US waters.

These initial regulations affected municipal sewage treatment plants (or "publicly owned treatment works," POTWs) and industrial discharges. Stormwater was initially considered an exempt point source and was not included in the initial regulations. After reviewing the water quality data showing stormwater caused receiving water quality and habitat degradation, the EPA finally established separate regulations for stormwater in 1987. The original Phase I regulations for stormwater (implemented in 1990) applied to large municipalities (generally population >250,000) and certain industries. Medium-sized municipalities (100,000 to 250,000 in population, plus other industries) were regulated several years later. The Phase II regulations are intended to be applied to all urban areas in the US. The Phase I regulations included construction activity as an industry and were applied to all construction sites greater than 5 acres, while the Phase II regulations apply all construction sites larger than 1 acre.

Many municipalities and some states have had local regulations affecting construction sites for many years, independent of the federal regulations. Some features of these are included in Appendix 1A.

CWA 402(p)(6) Initial Phase II Rule (for small municipalities)

The purpose of the initial Phase II regulations was to designate additional sources of stormwater beyond Phase I that needed to be addressed to protect receiving water quality. These regulations required that all unregulated dischargers of stormwater apply for NPDES permits by March 10, 2003. According to the EPA, this regulation would apply to millions of industrial/commercial facilities and over 22,000 municipalities.

The final Phase II rule was signed on December 8, 1999. Phase II NPDES permit applications were due starting March 10, 2003, but the specific compliance dates were set by each state regulatory agency.

Two new classes of facilities were established for automatic coverage on a nationwide basis:

1. Small municipal separate storm sewer systems located in urbanized areas (about 3,500 municipalities) [Phase I included medium and large municipalities]
2. Construction activities that disturb less than 5 acres of land (about 110,000 sites a year) [Phase I included construction sites larger than 5 acres]

A “no exposure” incentive for Phase I sites was also proposed for industrial activities (excludes about 70,000 facilities).

Permit Requirements for each Regulatory Agency
The following are the required elements for each plan to be prepared by the local regulatory agencies:

- Develop, implement, and enforce a program to reduce the discharge of pollutants and protect water quality to the “maximum extent practicable”
- Include six minimum control measures:
    - Public education and outreach
    - Public involvement and participation
    - Illicit discharge detection and elimination
    - Construction site stormwater runoff control
    - Post-construction stormwater management in new development and redevelopment
    - Pollution prevention and good housekeeping for municipal operations
- Submit a notice of intent (NOI), or permit application, and identify for each minimum control measure:
    - Best management practices to be used
    - Measurable goals
    - Timeframe for implementation
    - Responsible persons
- Evaluate program and submit reports

The objective is to include greater flexibility in the Phase II rule by encouraging the use of general permits, encouraging municipalities to determine appropriate stormwater controls, not requiring extensive monitoring by permittees, and recognizing the use of existing programs, including existing structures and mechanisms for public participation.

Construction Site Regulations
The Phase II regulations extended existing Phase I regulations for construction to the following sites:

- All sites that result in the disturbance of 1 acre or more, but less than 5 acres (designated nationwide)
- Sites that result in disturbance of less than 1 acre (potential designation by permitting authority).

The regulations encourage the use of local regulations that control erosion and sediment to the “maximum extent practicable,” control other waste at construction sites, and allow the granting of waivers by the permitting authority and to qualifying local and state programs.

The EPA allows the local agencies to waive coverage for construction sites that meet the following criteria:

- Rainfall erosivity factor (NRCS RUSLE rainfall factor “R”) less than 5 (during the period of construction) (“low rainfall”), if construction site is <5 acres in size
- Annual soil loss of less than 2 tons/acre/year (“low erosion potential”)

- A watershed plan or TMDL assessment that addresses the pollutants of concern

The rule requires the following:

1. Control of other wastes at construction sites (discarded building materials, concrete truck washout, sanitary wastes, etc.)
2. Appropriate best management practices (such as silt fences, temporary detention ponds, etc.)
3. Pre-construction reviews of site management plans
4. Receipt and consideration of public information
5. Regular inspections during construction
6. Penalties to ensure compliance

If local regulations incorporate the following erosion-preventing principles and elements into its stormwater program, then it would be considered as a "qualifying" program that meets Federal requirements:

Five Principles

1. Good site planning
2. Minimize soil movement
3. Capture sediment
4. Good housekeeping practices
5. Mitigation of post-construction stormwater discharges

Eight Elements

1. Program description
2. Coordination mechanism
3. Requirements for nonstructural and structural BMPs
4. Priorities for site inspections
5. Education and training
6. Exemption of some activities due to limited impacts
7. Incentives, awards, and streamlining mechanisms
8. Description of staff and resources

Effluent Limit Guidelines Schedule - 2004

The following discussion is summarized from the EPA reports (USEPA 2002 and 2004) describing the effluent guidelines for the construction and development (C&D) NPDES categories.

Section 304(m) of the Clean Water Act (CWA) requires the U.S. Environmental Protection Agency (EPA) to publish a plan every two years that consists of three elements. First, under section 304(m)(1)(A), the EPA is required to establish a schedule for the annual review and revision of existing effluent guidelines in accordance with section 304(b). Section 304(b) applies to effluent limit guidelines (ELGs) for direct dischargers and requires the EPA to revise such regulations as appropriate. Second, under section 304(m)(1)(B), the EPA must identify categories of sources discharging toxic or nonconventional pollutants for which the EPA has not published Best Available Technology (BAT) ELGs under section 304(b)(2) or new source performance standards under section 306. Finally, under section 304(m)(1)(C), the EPA must establish a schedule for the promulgation of BAT and New Source Performance Standards (NSPS) for the categories identified under subparagraph (B) no later than three years after being identified in the 304(m) plan. Section 304(m) does not apply to pretreatment standards for indirect dischargers, which the EPA promulgates pursuant to sections 307(b) and 307(c) of the CWA.

On October 30, 1989, the Natural Resources Defense Council, Inc. (NRDC), and Public Citizen, Inc., filed an action against EPA in which they alleged, among other things, that EPA had failed to comply with section 304(m). Plaintiffs and the EPA agreed to a settlement of that action in a consent decree entered on January 31, 1992. (*Natural Resources Defense Council et al v. Whitman,* D.D.C. Civil Action No. 89-2980). The consent decree established a schedule by which the EPA is to propose and take final action for eleven point source categories identified by name in the decree and for eight other point source categories identified only as new or revised rules, numbered 5 through 12. The EPA selected the Construction and Development (C&D) category as the subject for New or Revised Rule #10. The decree, as modified, called for the Administrator to sign a proposed ELG for the C&D category no later than May 15, 2002, and to take final action on that proposal no later than March 31, 2004. A settlement agreement between the parties, signed on June 28, 2000, required that the EPA develop regulatory options applicable to discharges from construction, development and redevelopment, covering site sizes included in the Phase I and Phase II NPDES stormwater rules (i.e., one acre or greater). The EPA was required to develop options including numeric effluent limitations for sedimentation and turbidity; control of construction site pollutants other than sedimentation and turbidity (e.g. discarded building materials, concrete truck washout, trash, etc.); controls for reducing post-construction runoff; controls for construction sites; and requirements to design stormwater controls to maintain pre-development runoff conditions, where practicable. The settlement also required the EPA to issue guidance to Municipal Separate Storm Sewer Systems (MS4s) and other permittees on maintenance of post-construction controls identified in the proposed ELGs.

The EPA therefore proposed Effluent Limitation Guidelines for discharges associated with construction and development activities under the authority of Sections 301, 304, 306, 308, 402, and 501 of the Clean Water Act (CWA) (the Federal Water Pollution Control Act), 33 United States Code (U.S.C.) 1311, 1314, 1316, 1318, 1342, and 1361. The proposed rule contained three options for controlling stormwater discharges from construction sites (USEPA 2002):

> Option 1: Establish inspection and certification provisions to ensure proper implementation of controls and obtain NPDES permits at sites one acre or greater. This option would not create effluent limitation guidelines.
>
> Option 2: Add minimum requirements for preparing of a Stormwater Pollution Prevention Plan (SWPPP), sizing sediment basins, installing erosion and sediment controls, providing temporary stabilization to exposed soils, and conducting regular inspections, and would apply to all sites that disturb five or more acres of land.
>
> Option 3: No new requirements.

The EPA estimated that Option 1 would cost approximately $130 million annually, while preventing the annual discharge of approximately 5.25 million tons of Total Suspended Solids (TSS) and associated turbidity to surface waters. The estimated annual monetized benefits of this option are $10.4 million. Option 2 was estimated to cost approximately $505 million annually, while preventing the discharge of approximately 11.1 million tons of TSS and associated turbidity to surface waters annually. The estimated annual monetized benefits of Option 2 are $22.0 million. Option 3 was not expected to have any costs or benefits.

On March 31, 2004, the EPA Administrator signed a Federal Register notice (published on April 4, 2004) opting for Option 3 and relying on the range of existing programs, regulations, and initiatives at the federal, state, and local levels for the control of runoff from construction sites rather than establish a new effluent guideline.

Effluent Limit Guidelines – 2009

In December 2009, the EPA published in the Federal Register which provided notice of the intent to implement additional non-numeric rules on C&D sites subject to NPDES permits and numeric effluent rules for turbidity on C&D sites of a specific size. The C&D sites for which the new rules are applicable include North American Industry Classification Systems (NAICS) 236 (Construction of Buildings) and NAICS 237 (Heavy and Civil Engineering Construction). Turbidity was selected as the surrogate measure of other pollutants in construction site runoff, such as TSS, phosphorus, metals and organics. As the Federal Register notice states,

> "…According to ATTAINS (as of September 17, 2009), turbidity contributes to impairment of 26,278 miles of assessed rivers and stream, 1,008,276 acres of assessed lakes and reservoirs, and 240 square miles of assessed bays and estuaries…. According to the survey, excess streambed sedimentation is one of the most widespread stressors, with 25 percent of streams in "poor" streambed sediment condition…."

As noted above, when the Phases I and II rulemaking occurred, EPA interpreted industrial discharges to include discharges from C&D sites. The non-numeric effluent guidelines required installation of best management practices to control sediment discharges, as well as control measures for other pollutants such as litter, construction debris, and chemicals. The 2008 Construction General Permit (CGP) also required permittees to develop and implement a stormwater pollution prevention plan (SWPPP). The SWPPP requires a description of the site, including drainage maps, locations of discharge controls, descriptions of the control measures, and the inspection procedures for the control practices. Federal and state CGPs were required to be technology-based, e.g., the technology implemented to control permitted discharges must be deemed sufficient to meet the requirements of the rules. If necessary, water-quality based effluent limitations could be implemented in the permit. In certain states, these numeric limits were implemented for sites in high-value waters. Other states interpreted the rule as a means to implement monitoring and benchmark levels for maintaining/replacing control measures.

The non-numeric effluent limitations listed in the 2009 Final Rule include the following and are applicable to all permitted sites:

- Control stormwater volume and velocity with the sites
- Control peak flowrates and total stormwater volume at discharge locations
- Minimize soil exposure during construction
- Minimize disturbance of steep slopes

Erosion and sediment controls must be designed, installed and maintained to meet the following requirements:

- Minimize sediment discharges through designs that account for "amount, frequency, intensity and duration of precipitation, the nature of resulting stormwater runoff, and soil characteristics, including the range of particle sizes expected to be present on the site;
- Provide natural buffers around surface waters, with stormwater directed to vegetated buffers or infiltration areas (unless not feasible).
- Minimize soil compaction and preserve topsoil.
- Dewater trenches and basins from the top.

The new regulations heavily emphasize activities that stabilize soil immediately after clearing unless the area is an active construction zone or will be an active zone within 14 calendar days. Provisions are made for arid, semi-arid and drought areas to require vegetative stabilization only when practical. The new regulations also prohibit discharges of dewatering and vehicle washing waters/pollutants unless appropriately treated first (see below where soaps and solvents from vehicle washing are prohibited discharges). The rules require that building materials, wastes, landscape materials and fertilizers, etc., have minimal exposure to rainfall prior to installation and that there be a chemical spills and leak prevention program with appropriate response procedures.

Finally, as stated by the Final Rule, the following C&D discharges are prohibited:

- Concrete washout wastewater unless treated appropriately
- Stucco, paint, form release oils, curing compounds, and other construction materials washout and wastewater
- Fuels, etc., used in vehicle and equipment operation and maintenance
- Soaps and solvents used in vehicle washing

The ELGs and NSPSs are being implemented in two parts and include monitoring of discharges to meet a numeric limit. In the Final Rule, the limit was set at 280 NTU; however, this limit has been challenged successfully in court. EPA was to develop a new turbidity ELG, publish it, receive public comments and return to the courts with the new number. The concept of a numeric ELG is still valid, but the 280 NTU as a defensible standard has been withdrawn by EPA. To highlight how the ELG could be implemented, the 2009 rule stated that the ELG would be a maximum daily discharge, based on an average of samples collected over a calendar day (or other 24-hour period defined for the project). The ELGs would be applicable first to sites with 20 or more acres of exposed soil in total on the project. Appropriately stabilized soils would not be included in the calculation of the exposed acreage. Approximately 18 months after the 20-acre rule is implemented, sites with 10 acres or more of exposed soil would be subject to the ELGs and NSPSs, including monitoring.

On March 6, 2014, as part of the settlement, EPA amended the rule and withdrew the numeric turbidity limitation and monitoring requirements, and also provided clarification regarding several other requirements of the rule (79 Fed. Reg. 12661 and 80 Fed. Reg. 25235). The permit in effect at the time of this writing – the 2017 Construction General Permit, CGP) – was issued after the effective date of the 2014 amendments. The EPA was required to incorporate those requirements into the 2017 permit. Therefore, the 2017 CGP included the revisions that reflected the 2014 C&D rule amendments, as well as maintained changes that were made to the 2012 CGP to incorporate the other portions of rule requirements not affected by the 2014 amendments.

EPA also has not published monitoring guidance at this time; however, several states have. The Final Rule states that "the permit must specify the type, interval and frequency of sampling sufficient to yield data which are representative of the monitored activity and must require monitoring for specific pollutants that are limited in the permit…." In the Monitoring Guidance section of the Final Rule, the Final Rule does not dictate the specific requirements for monitoring turbidity (frequency, location, etc.); they expect the permits to contain that information for specific sites or categories of sites. EPA does discourage non-routine monitoring during a discharge event simply to meet the maximum daily discharge limit and encourages a minimum of three samples per day during discharges from the site. EPA encourages monitoring of all discharge event days smaller than the 2-year, 24-hour storm event, although permitting authorities may require monitoring of a representative number of events. For days where the total rainfall exceeds the 2-year, 24-hour storm event size for the area, monitoring is not required for that day only, but all other measures are required. For days where the rainfall total is less than the 2-year, 24-hour storm event, monitoring is required in accordance with the permit. This includes days in a single storm event where the rainfall is less than the 2-year, 24-hour event or where discharge is occurring from the site as a result of a large storm but it is not raining during that day. It is assumed that discharges to vegetated buffers and infiltration areas off site and that do not end up in the receiving water would not need to be monitored. Linear construction projects, such as highway and large utility projects are specifically mentioned in this section since, for safety reasons, only a select number of discharges may be accessible for monitoring.

Existing State Programs - In March 2003, Phase II of EPA's NPDES regulations for stormwater went into effect and required that permitting authorities establish programs to regulate runoff from construction sites of one to five acres in size. These new requirements were expected to affect approximately 200,000 construction sites annually. Larger construction sites have been regulated under the NPDES program since 1992. The authorized states and EPA implemented these requirements (Phase II) with the presumption that they would result in significant reductions of pollutants from well-designed and maintained construction sites.

The EPA's analyses concluded that every state had regulations and programs in place that incorporate most of the provisions of the most stringent proposed option (#2). The following lists how states are already addressing these key requirements of the proposed effluent guideline:

> Stormwater Pollution Prevention Plans – All 50 states require site managers to prepare a stormwater pollution prevention plan, erosion and sediment control plan, or an equivalent document.
>
> Inspections by Construction Site Operator – All 50 states require construction site operators to inspect their sites on a regular basis.
>
> Erosion and Sediment Control – All 50 states require site managers to implement a combination of erosion and sediment controls to prevent soil erosion and to manage construction site runoff. The EPA's earlier proposed option of establishing effluent guidelines would have mandated sediment basins of a particular size across the country. Currently, states base their technical requirements for basins or other erosion control techniques on local rainfall patterns and other considerations.
>
> Stabilization of Soils After Construction – All 50 states require stabilization of soils after construction activities have temporarily or permanently ceased. The EPA's proposed effluent guidelines mandate this step within 14 days and that all exposed acreage be calculated to

determine whether the site has to implement turbidity monitoring and reporting at its discharges. Currently, states set their own requirements based on local conditions. In dry areas, for instance, 14 days may not be necessary because of low rainfall. The 2009 EPA Final Rule accepts this concept and states that vegetative stabilization in arid, semi-arid and drought areas should be implemented as soon as feasible.

The Final Rule, issued in December 2009, enhanced the earlier construction erosion regulations by mandating turbidity monitoring for, at first, sites with 20 acres or more of exposed, unstablized soil, and, within three years, sites with 10 acres or more of exposed soil. Unlike the earlier proposal, control practices and their sizing are not mandated, as long as the turbidity ELGs are being met. As noted above, the turbidity ELG was withdrawn in 2014.

Existing Local Programs - Many local governments also have long-standing programs in place to control sediment and erosion from construction sites within their jurisdiction. EPA's stormwater regulations (Phase I and Phase II) set minimum requirements for these programs. Approximately, 6,000 municipalities are covered by these regulations. Many of the approximately 5,000 communities covered by Phase II are currently developing or upgrading their programs to meet these requirements. These are some of the minimum requirements for these programs:

- Ordinances or other regulatory mechanisms requiring the implementation of proper erosion and sediment controls
- Review of site plans to ensure proper design and installation of sediment and erosion controls
- Site inspections and enforcement of control measures
- Sanctions to ensure compliance
- Procedures for public review and comment
- Review of site plans

The NPDES regulations require that municipalities set up procedures for review of site plans to ensure proper implementation of sediment and erosion controls. Many states and municipalities have chosen to require certification of the erosion control designs.

EPA Resources for Construction Site Stormwater Management
A range of regulatory programs and resources are currently in place and being implemented at the federal, state and local levels address construction site stormwater runoff:

Regulatory Programs - NPDES Regulations – The NPDES regulations for stormwater cover construction sites in two ways. First, authorized states and EPA (in non-authorized states) must develop programs and permits for sites disturbing one or more acres of land. Second, municipalities in urbanized areas must develop comprehensive programs to regulate stormwater from construction activities within their jurisdiction.

Construction: The NPDES Phase I and Phase II stormwater regulations require permits for construction sites that disturb one or more acres of land. Phase I became effective in 1992 and regulates construction sites five acres or larger in size. Authorized states and EPA developed detailed permit requirements for these sites and refined those requirements as permits are reissued (NPDES permits are reissued every 5 years). Effective in March 2003, Phase II extends these requirements to also cover sites of one to five acres.

Municipal: Approximately 6000 municipalities with separate storm sewer systems are covered by EPA's NPDES stormwater regulations (Phase I and II). They are required to develop programs to regulate stormwater from sites within their jurisdiction that are one acre or larger. Most municipalities have programs that cover construction sites. The NPDES regulations outline a set of minimum controls and many cities are enhancing their current programs to meet these requirements. Municipal programs must include local enforceable ordinances, review of site plans, inspections, and enforcement procedures. Effective March 2003, the Phase II regulations cover municipalities in urban areas with populations up to 100,000 (the earlier Phase I regulations addressed larger municipalities). These communities have five years to develop and fully implement these programs.

EPA Resources for the Control of Construction Site Runoff - The following are listed by the EPA as main sources of information and technical assistance that they provide to state and local agencies, and to contractors and others involved in construction site erosion control:

State Water Pollution Control Program Grants Program (Section 106) provides funding to state programs to implement the programs under the Clean Water, including stormwater programs.

Stormwater Website contains comprehensive reference and guidance materials for control of construction site runoff.

Construction Industry Compliance Assistance Center (http://cicacenter.org/) contains information and links to a wide variety of information, including state regulatory programs and manuals for sediment and erosion controls.

Electronic Notice of Intent System is an online, electronic application system for obtaining coverage under EPA's Construction General Permit. This system also provides construction site operators with comprehensive information on controlling runoff and meeting permit requirements.

National Management Measures to Control Nonpoint Source Pollution from Urban Areas (http://www.epa.gov/owow/nps/urbanmm/) is a technical guidance and reference document on best management practices to control urban runoff

Smart Growth Program (http://www.epa.gov/livability/) provides tools, technical and financial assistance, and training on complying with stormwater requirements while also encouraging innovation in land development.

Section 319 Nonpoint Source Management Program (http://www.epa.gov/owow/nps/cwact.html) provides grants to states, territories and tribes to support a variety of nonpoint source implementation projects including those addressing stormwater runoff.

Copies of the final Federal Register notice and supporting materials are available at: http://www.epa.gov/guide/construction.

Proposed EPA Effluent Guidelines for Construction and Development Category

The following discussion is summarized from the EPA's guidance document prepared for the proposed effluent guidelines (USEPA 2002) and from the fact sheet describing the final ruling (USEPA 2004). The proposed effluent guidelines contained three options. Option 2 would have required the permittee to prepare a stormwater pollution prevention plan (SWPPP) and implement the erosion and sediment controls contained in the EPA's Construction General Permit (CGP). In addition, the permittee would have been required to conduct periodic site inspections and provide certifications in a site log book. The final rule published in early April 2004 accepted the third option, which was to rely on the range of existing programs for the control of runoff from construction sites, rather than establish a new effluent guideline. Their rational was that provisions contained in the most demanding option (#2) were already included in almost all state and local regulations. Therefore, the originally proposed option 2 may be considered a basic benchmark, and is summarized below:

General Erosion and Sediment Controls

Each SWPPP would have been required to include a description of appropriate controls designed to retain sediment on site to the extent practicable. These general erosion and sediment controls would be required to be included in the SWPPP described below. The SWPPP would be required to include a description of interim and permanent stabilization practices for the site, including a schedule of when the practices would be implemented. Stabilization practices could include the following:

1. Establishment of temporary or permanent vegetation;
2. Mulching, geotextiles, or sod stabilization;
3. Vegetative buffer strips;
4. Protection of trees and preservation of mature vegetation.

The EPA recommended that all controls be properly selected and installed in accordance with sound engineering practices and, manufacturer's specifications.

Sediment Controls

Operators would be required to design and install structural controls to divert flows from exposed soils, to store flows, or otherwise to limit runoff and the discharge of pollutants from exposed areas, and to describe controls in the SWPPP. The controls required are as follows:

1. For common drainage locations that serve an area with 10 or more acres disturbed at one time, the operator would be required to provide a temporary (or permanent) sediment basin that provides storage for a calculated volume of runoff from a 2 year, 24-hour storm from each disturbed acre drained, or equivalent control measures, where attainable, until final stabilization of the site. Where no such calculation has been performed, the operator would be required to provide a temporary (or permanent) sediment basin providing 3,600 cubic feet of storage per acre drained, or equivalent control measures, where attainable, until final stabilization of the site. When computing the number of acres draining into a common location, it would not be necessary to include flows from off-site areas and flows from on-site areas that are either undisturbed or have undergone final stabilization where such flows are diverted around both the disturbed area and the sediment basin.

2. In determining whether a sediment basin is attainable, the operator may consider factors such as site soils, slope, available area on site, etc. In any event, the operator would be required to consider public safety, especially as it relates to children, as a design factor for the sediment

basin. Use of alternative sediment controls would be required where site limitations preclude a safe basin design.

3. For portions of the site that drain to a common location and have a total contributing drainage area of less than 10 acres, the operator would be required to consider installation of sediment traps or other sediment control devices.

4. Where neither a sediment basin nor equivalent controls are attainable due to site limitations, the operator would be required to install silt fences, vegetative buffer strips or equivalent sediment controls for all downslope boundaries of the construction area and for those side slope boundaries deemed appropriate for individual site conditions.

Pollution Prevention Measures
The operator would be required to implement the following pollution prevention measures:

1. The operator would be required to prevent litter, construction chemicals, and construction debris from becoming a pollutant source in stormwater discharges; and

2. The operator would be required to contain construction and building materials in appropriate storage areas and manage the materials to prevent contamination of stormwater runoff.

Stormwater Pollution Prevention Plan
Permittees would be required to develop and implement Stormwater Pollution Prevention Plans (SWPPPs) prior to groundbreaking at any construction site. In areas where EPA is not the permit authority, operators may be required to prepare documents that may serve as the functional equivalent of a SWPPP. Such alternate documents would satisfy the requirements for a SWPPP so long as they contain the necessary elements of a SWPPP. A SWPPP would be required to incorporate the following information:

1. A narrative description of the construction activity, including a description of the intended sequence of major activities that disturb soils on the site (Major activities include any clearing, grubbing, excavating, grading, soil stockpiling, and utilities and infrastructure installation, or any other activity that results in significant disturbance of soils.);

2. A general location map (e.g., portion of a city or county map) and a site map. The site map shall include descriptions of the following:

    a. Drainage patterns and approximate slopes anticipated after major grading activities;

    b. The total area of the site and the area of the site that is expected to be disturbed by excavation, clearing, grading and other construction activities during the life of the permit;

    c. Areas that will not be disturbed;

    d. Locations of erosion and sediment controls identified in the SWPPP;

    e. Locations where stabilization practices are expected to occur;

f. Locations of off-site material, waste, borrow or equipment storage areas;

g. Surface waters (including wetlands); and

h. Locations where stormwater discharges to a surface water;

3. A description of available data on soils present at the site;

4. A description of the controls to be used to reduce pollutant discharges during construction

5. A description of the general timing (or sequence) in relation to the construction schedule when each erosion and sediment control is to be implemented;

6. An estimate of the pre-development and post-construction runoff coefficients of the site;

7. The name(s) of the receiving water(s);

8. Delineation of SWPPP implementation responsibilities for each site owner or operator;

9. Any existing data that describe the stormwater runoff characteristics at the site (such as data that may be collected during a site assessment).

Updating the SWPPP

The operator would be required to amend the SWPPP and corresponding erosion and sediment control practices whenever:

1. There is a change in design, construction, or maintenance that is expected to have a significant effect on the discharge of pollutants; or

2. Inspections or investigations by site operators, local, State, Tribal or Federal officials indicate that any erosion and sediment controls described in the SWPPP are ineffective in eliminating or significantly minimizing pollutant discharges.

Site Log Book/Certification

The operator would be required to maintain a record of site activities in a site log book, as part of the SWPPP. The site log book shall be maintained as follows:

1. A copy of the site log book would be required to be maintained on site and be made available to the permitting authority upon request. EPA recommends that the operator make a copy of the site log book available to the public upon request within a reasonable period;

2. In the site log book, the operator would be required to certify, prior to the commencement of construction activities, that the SWPPP meets all Federal, State and local erosion and sediment control requirements and is available to the permitting authority;

3. The operator would be required to have a qualified professional conduct an assessment of the site prior to groundbreaking and certify that the appropriate erosion and sediment controls described in the SWPPP have been adequately designed, sized and installed to ensure overall

preparedness of the site for initiation of groundbreaking activities. The operator would be required to record the date of initial groundbreaking in the site log book. The operator would be required to certify that the site inspections, soil stabilization activities, and maintenance activities required by the proposed rule have been satisfied within 48 hours of actually meeting such requirements;

4. The operator would be required to post at the site, in a publicly-accessible location, a summary of the site inspection activities on a monthly basis. EPA recommends that the operator provide contact information for obtaining a copy of the SWPPP and a copy of the site inspection log book.

Site Inspections
The operator or designated agent of the operator (such as a consultant, subcontractor, or third-party inspection firm) would be required to conduct regular inspections of the site and record the results of such inspection in the site log book. The specific activities that would require inspection and certification are:

1. After initial groundbreaking, operators would be required to conduct site inspections at least every 14 calendar days and within 24 hours of the end of a storm event of 0.5 inches or greater. These inspections would be required to be conducted by a qualified professional. During each inspection, the operator or designated agent would be required to record the following information:

    a. On a site map, indicate the extent of all disturbed site areas and drainage pathways. Indicate site areas that are expected to undergo initial disturbance or significant site work within the next 14-day period;

    b. Indicate on a site map all areas of the site that have undergone temporary or permanent stabilization;

    c. Indicate all disturbed site areas that have not undergone active site work during the previous 14-day period;

    d. Inspect all sediment control practices and note the approximate degree of sediment accumulation as a percentage of the sediment storage volume (for example 10 percent, 20 percent, 50 percent, etc.). Record all sediment control practices in the site log book that have sediment accumulation of 50 percent or more; and

    e. Inspect all erosion and sediment controls and record all maintenance requirements such as verifying the integrity of barrier or diversion systems (earthen berms or silt fencing) and containment systems (sediment basins and sediment traps). Identify any evidence of rill or gully erosion occurring on slopes and any loss of stabilizing vegetation or seeding/mulching. Document in the site log book any excessive deposition of sediment or ponding water along barrier or diversion systems. Record the depth of sediment within containment structures, any erosion near outlet and overflow structures, and verify the ability of rock filters around perforated riser pipes to pass water.

2. Prior to filing of the Notice of Termination, or the end of the permit term, a final site erosion and sediment control inspection would be required to be conducted by the operator or designated agent. The inspector would be required to certify that the site has undergone final stabilization using either vegetative or structural stabilization methods and that all temporary erosion and sediment controls (such as silt fencing) not needed for long-term erosion control have been removed.

Stabilization
The operator would be required to initiate stabilization measures as soon as practicable in portions of the site where construction activities have temporarily or permanently ceased, but in no case more than 14 days after the construction activity in that portion of the site has temporarily or permanently ceased. This provision would not apply in the following instances:

1. Where the initiation of stabilization measures by the 14^{th} day after construction activity temporarily or permanently ceased is precluded by snow cover or frozen ground conditions, the operator shall initiate stabilization measures as soon as practicable;

2. Where construction activity on a portion of the site is temporarily ceased, and earth disturbing activities will be resumed within 21 days, temporary stabilization measures need not be initiated on that portion of the site.

3. In arid areas (areas with an average annual rainfall of 0 to 10 inches), semi-arid areas (areas with an average annual rainfall of 10 to 20 inches), and areas experiencing droughts where the initiation of stabilization measures by the 14^{th} day after construction activity has temporarily or permanently ceased is precluded by seasonably arid conditions, the operator shall initiate stabilization measures as soon as practicable.

Maintenance
The operator would be required to remove accumulated sediment from sediment traps and ponds identified as having sediment accumulations greater than 50 percent to restore the original design capacity.

State Regulations
States and municipalities have been regulating discharges of runoff from the construction and land development industry to varying degrees for some time. A compilation of state and selected municipal regulatory approaches was prepared by the EPA (USEPA 2002) to help establish the baseline for national and regional levels of control. They collect data by reviewing state and municipal web sites, summary references, state and municipal regulations, and stormwater guidance manuals. All states (and the selected municipalities) were contacted to confirm the data collected and to fill in data gaps. Eighty-seven percent of the state agencies, but a much smaller percentage of municipalities, responded. The state and municipal regulatory data are described below and the complete data summaries are included in Appendix A. Table 1A-1 lists example exemptions and waivers, Table 1A-2 shows some preferred practices, and Table 1A-3 lists allowed practices. These three tables include information for both local regulations and some state regulations. Table 1A-4 was prepared by the EPA (USEPA 2002) and lists some specific requirements (numeric standards, design storm frequency, soil stabilization requirements, and inspection frequencies). It is expected that all of the information on these tables may not be currently accurate, but they do show a good distribution of information. It is always necessary to contact

the local planning departments and the regional NPDES authority to obtain the most recent compliance requirements.

State and Municipal Existing Control Strategies, Criteria, and Standards
In 2002, the EPA (USEPA 2002) concluded that State requirements are generally equal to, or less stringent, than municipalities that are covered under the federal Clean Water Act NPDES Stormwater Program because State requirements apply to all developments within their boundaries including single site development and low-to-high density developments. NPDES Stormwater Program-designated municipalities generally have a population of 100,000 or more and can collect and fund the resources necessary to design, implement, and monitor separate and potentially more stringent stormwater management programs.

The following key erosion and sediment control measures are being employed by States and municipal/regional authorities to implement the NPDES Stormwater Program:

- Stormwater controls designed for peak discharge control
- Stormwater controls designed for water quality control
- Stormwater controls designed for flood control
- Specified depths of runoff for water quality control
- Percent reduction of loadings for water quality control (primarily solids and sediments)
- Numeric effluent limits for water quality control (primarily total suspended solids, settleable solids, or turbidity)
- Control measures for biological or habitat protection
- Control measures for physical in-stream condition controls (primarily streambed and streambank erosion).

The water quantity control measures for peak discharge and runoff volume controls that apply to the post-development conditions typically are not applicable during the construction phase when the site is disturbed. Pollutant control measures are commonly required during the construction phase, though the requirements for post-development stormwater management are broader and potentially more stringent.

A variety of manuals and documents were used by the EPA (USEPA 2002) to obtain information on design and effectiveness of various erosion and sediment controls, including:

1. State design manuals such as the:
Virginia Erosion and Sediment Control Handbook
Maryland Stormwater Design Manual
Denver Urban Drainage Criteria Manual

2. Guidance documents such as the
Texas Nonpoint Source Book
EPA's National Menu of BMPs

3. Consensus design manuals such as manuals of practice on stormwater design developed by ASCE and the Water Environment Federation (ASCE and WEF, 1992 and 1998) have been used to determine various management strategies.

Links to on-line manuals and guidance documents are provided on EPA's website at http://www.epa.gov/waterscience/guide/construction/. In most cases, the URLs for these government websites change frequently and it is recommended to use an Internet search program to locate the most recent documents and guidance materials for the areas of interest. Also, many of the states have specific construction sediment and erosion control design manuals adopted by their Departments of Transportation.

State Erosion Control Handbooks Available on the Internet

Alabama
Alabama Handbook for Erosion Control

Alaska
Alaska Stormwater Guide

Arizona
Arizona Pollutant Discharge Elimination System (AZPDES) Fact Sheet: Construction General Permit (CGP) for Stormwater Discharges Associated with Construction Activity

California
California Storm Water BMP Construction Handbook

Colorado
Denver Urban Drainage Criteria Manual
http://www.udfcd.org

Connecticut
2002 Connecticut Guidelines for Soil Erosion and Sediment Control

Delaware
Delaware Erosion and Sediment Control Handbook

Florida
Florida Development Manual: A Guide to Sound Land and Water Management

Georgia
Georgia Storm Water Management Manual

Idaho
Catalog of Storm Water BMPs for Idaho Cities & Counties

Illinois
Illinois Urban Manual

Indiana
Indiana Storm Water Quality Manual

Iowa
Iowa Construction Site Erosion Control Manual

Kentucky
Best Management Practices (BMPs) for Controlling Erosion, Sediment, and Pollutant Runoff from Construction Sites

Louisiana
State of Louisiana Nonpoint Source Pollution Management Program - Construction

Maine
Maine Erosion and Sediment Control Practices Field Guide for Contractors

Maine Erosion and Sediment Control Best Management Practices (BMPs)

Maryland
Maryland Stormwater Design Manual
Maryland Storm Water Design Manual, Volumes I & II

Massachusetts
Erosion and Sedimentation Control Guidelines: a guide for planners, designers, and municipal officials

Michigan
Soil Erosion and Sediment Control Authorized Public Agencies Procedures Manual

Minnesota
Protecting Water Quality in Urban Areas: A Manual
Urban Small Sites Best Management Practice Manual

Missouri
Protecting Water Quality: A Construction Site Water Quality Field Guide

Montana
Erosion and Sediment Control Best Management Practices

Nevada
Best Management Practices Handbook

New Hampshire
Managing Storm Water as a Valuable Resource

New Jersey
Revised Manual for New Jersey: BMPs for Control of Nonpoint Source Pollution from Storm Water

New York
New York State Stormwater Management Design Manual

North Carolina

North Carolina Erosion and Sediment Control Planning and Design Manual

Ohio
Storm Water Program – Factsheets, Forms, & Check Lists

Oregon
BMPs & Storm Water Pollution Control Plan

Pennsylvania
Erosion and Sediment Pollution Control Program Manual

South Carolina
Sediment, Erosion, & Storm Water Management

Tennessee
Tennessee Erosion and Sediment Control Handbook
Knoxville BMP Manual

Texas
Texas Nonpoint Sourcebook – Interactive BMP Selector

Utah
UPDES Storm Water Home Page

Vermont
The Vermont Standards and Specifications for Erosion Prevention & Sediment Control

Virginia
Virginia Erosion and Sediment Control Handbook
Northern Virginia BMP Handbook: A Guide to Planning and Designing BMPs in Northern Virginia

Washington
Storm Water Management Manual for Western Washington
Eastern Washington Erosion Prevention and Sediment Control Field Guide
King County Storm Water Pollution Control Manual

Wisconsin
Wisconsin Construction Site Best Management Practice Handbook

Basic Control of Construction Site Runoff to Meet Regulatory Requirements

There are many different types of construction activities taking place on the landscape. These include massive grading projects such as large residential subdivisions, commercial and industrial sites, municipal projects such as sewage treatment plants and parks and recreational facilities, and institutional construction such as academic campus development and incarceration facilities. Also included are linear construction activities such as highway construction, oil and gas pipeline projects, transmission and utility power lines, wind farm construction, and streambank restoration and stream corridor stabilization.

We usually of residential or commercial development projects when we look at erosion control issues and they do make up a large portion of the nation's construction activity. However, smaller scaled projects such as dam embankment construction and re-habilitation, wetland mitigation, and reclamation projects from storm damage or long-term accumulation of hazardous materials, bring their own unique challenges to protect our water resources while completing these projects.

These varied types of construction projects require a wide range of different construction techniques to manage site specific challenges and meet the projects economic and environmental protection goals. The construction phasing and the sequence of construction within each phase must be carefully evaluated based on the overall design and the physical attributes of the site. Construction phasing should consider when and where access to the project should occur, the storage and handling of construction materials, the routing of excavated materials, placement of fill materials and the disposal of waste. Site characteristics such as steep slopes, narrow rights of way and limited construction easements, and the presence of a stream or wetland will require careful design of erosion control practices. If the site has additional physical attributes that include perched or high-water tables, fine soil types, and significant areas draining onto the construction site, the sequence of operations must include appropriately designed erosion and sediment control practices that should be tailored for each individual phase of construction.

One of the main problems associated with the control of construction site runoff is that the actual monitored field performance of most construction site erosion controls has been disappointingly low, and thus the control of sediment from construction sites has not been as effective as preferred. Therefore, meeting the goals of the regulations, i.e., preventing of substantial eroded sediment from leaving the site, is difficult to do inexpensively. Excellent silt fence installations (well-constructed/installed and well maintained) provide only about 50% reduction in sediment discharges, at a maximum, with the best control for larger particles, and little benefit to runoff turbidity. Typical monitored performance has shown negligible benefits due to installation and maintenance problems, such as no entrenchment or not removing trapped sediment after a rain event. The use of rock berms in channels are more robust, but still provide less than about 25% suspended solids control. Sediment ponds can be designed to provide good control (>50%) of suspended solids, but they would have to be very large (about 2% of the drainage area) to provide significant removal of fine sediment, and also need to be cleaned out regularly. The effluent turbidity from sediment control ponds at construction sites is still high, unless additional controls such as coagulation with chemical polymers, or post-detention filtration, are used.

When designing erosion and sediment control to meet regulations, prevention is the best and typically least expensive control solution. Typical preventative measures include the following:

1. Divert flows around exposed soils
2. Schedule site activities to minimize amount of exposed soil
3. Use temporary seed and mulch
4. Use erosion control blankets in sensitive areas (concentrated flow channels, steep slopes)


A small berm and sodded swale divert flows from newly graded and mulched hillside.


A diversion downslope pipe at a highway construction site (during installation) to prevent erosive flows from damaging an unprotected slope.

Figure 1-22. Diversion of Flows


Most construction sites are characterized with large expanses of unprotected soil, even after utilities are installed (WI DNR photo)


Large unprotected area at new commercial site.

	 Unprotected newly graded area at highway expansion project.

Figure 1-23. Minimize Exposed Soil

 Spray mulch blown to protect exposed soil.	 Complete ground cover after hydro-mulching.
 Hydro-mulch and blown-on straw applied to slope to repair eroded areas.	

Figure 1-24. Temporary Mulch (Minimal tacking and no netting to retain material on site for long periods)

Vegetation starting to grow through erosion control netting at highway construction site.

Newly installed erosion control mats on steep highway embankment.

Stored erosion mats at construction site.

Figure 1-25. Erosion Control Blankets

Basic Goals and Performance Standards for Erosion and Sediment Control

The most common goal of jurisdictions implementing an erosion and sediment control program is protection of public safety, water resources, or other aquatic related resources such as habitat or fisheries. A more realistic goal is minimization, "to the extent practical," of off-site impacts. That is because, even with the best designs, the process of site development with its associated earth disturbance can still create adverse downstream impacts, especially when severe storm events exceed the design capacity for these practices. The intent of erosion and sediment control programs should be to minimize the potential for off-site impacts by reducing the aerial extent and time duration of impacts.

In defining how a program can minimize impacts, a dual strategy is recommended. The program should seek first to prevent erosion from occurring and, failing that, to seek to reduce the associated sedimentation. <u>Prevention</u> practices include sequencing construction to reduce areas of disturbance, conducting land disturbance during the dry season, establishing limits on areas of disturbance during the wet season, and timely stabilizing (temporary or permanent) disturbed areas. <u>Reduction</u> of impacts would follow using traditional erosion and sediment control practices such as stabilized construction entrances, silt fences, diversion dikes, sediment traps and basins. Reduction practices are most effective at removing coarser sediments, while preventive practices are more effective at controlling silt or clay particles by preventing their initial movement. In summary, a basic goal of erosion and sediment control programs should be to minimize off-site impacts by following a philosophy of first preventing erosion and then maximizing control of sedimentation on-site.

Once the program's goal is determined, it is necessary to establish an achievable performance standard. This will form the basis for the development of design criteria for the various erosion and sediment control practices. Performance standards can be either technology-based or water-quality based. Technology-based standards are the most common. They typically are related to a reduction in the level of suspended solids (e.g. 80%) leaving a site or may be expressed in terms of retaining sediment on-site. The former standard is appropriate because there is a good understanding of the processes involved in the reduction of suspended solids. The latter performance standard addresses potential adverse impacts beyond water quality such as public safety concerns associated with tracking sediments onto public streets or sediment clogging of runoff conveyances with sediment which can increase flooding. Water quality-based standards often are a "backstop" since most environmental laws prohibit violations of water quality standards. The effluent limit guidelines (ELGs) contained in the 2009 Final Rule are water quality-based standards. The ELG for turbidity was withdrawn and is not included in the 2017 permit. The initial proposal by EPA was 280 NTU for all discharges from sites with a minimum of 10 acres of exposed, unstabilized soil.

Design Criteria

Once a performance standard has been established, then design criteria need to be developed for the individual erosion and sediment controls. Only then can site planners and engineers design those practices which will work best on a given site because of its specific soils, topography, slopes, geology, and hydrology characteristics. Design criteria need to be specified for both prevention and reduction practices.

Specific design criteria have been defined by EPA for at least two prevention practices. First, a maximum area of disturbance at any one time is specified as no more than 10 acres of exposed, unstabilized soil. If this acreage is exceeded, discharge turbidity monitoring is required for the site with all discharges required to meet the ELGs. Second, EPA established a 14-day time frame for temporary or permanent stabilization on areas where construction is not ongoing. Vegetative stabilization is preferred unless in a drought, semi-arid or arid area, where establishing vegetation may not be feasible. States and municipalities may choose to use more stringent design criteria for these two preventive measures. The 14-day guideline was very common already and has been adopted by EPA. Typically, more stringent criteria are found for sites that discharge into high value, exceptional, outstanding receiving waters, such as fisheries or public water supplies. For some localities that have implemented more stringent design criteria, there is a defined seasonality to the rainfall, and, therefore, the criteria may be directed primarily towards activities conducted during the wetter seasons. This approach is used by the Puget Sound Water Quality Management Program which establishes seasonal limits on disturbed area.

Design criteria for reduction practices often are based on sizing criteria, either in terms of contributing drainage area or storage volume, or both. Most programs establish a minimum size for sediment traps and basins, such as 1,800 cubic feet per acre of drainage area. This volume value was developed years ago by the Natural Resources Conservation Service (then the Soil Conservation Service) to achieve a 70% reduction in suspended solids on a Piedmont hydrologic soil group C soil. This volume was then used as a design criterion as a minimum standard for site design.

Exemptions and Waivers

If the erosion and sediment control program is integrated with the stormwater management program, the exemptions and waivers should be consistent, but not necessarily identical. There are activities which, due to their limited size, should not be required to provide permanent stormwater management, but which should be required to implement erosion and sediment control. An example is single family home construction that is not part of a larger development.

The most common and simplest approach for establishing exemptions and waivers is based on the amount of disturbed area. This approach is easily implemented since determining the amount of disturbed area is simple. The size of the disturbed area for an exempt activity will depend to some extent on local conditions such as rainfall patterns, soil types, and topography. It is recommended that the threshold size of disturbance be relatively small, such as 5,000 square feet. This emphasizes that erosion and sediment control are integral components of site development. It also helps to minimize potential cumulative impacts if many construction projects are on-going within a watershed. However, waiver opportunities in many states are limited if the construction project is located in a high-value watershed, such as those containing cold water fisheries.

There also has to be some flexibility for unforeseen types of activities for which pre-construction review and approval would be an undue hardship and not be in the best public interest. These activities typically are of an emergency nature, such as those required after an extreme storm event which creates situations needing an immediate response. Such activities must still implement erosion and sediment controls, but implementation should be based on requirements defined on-site. Alternatively, a special process can be established that calls for plan submission and review of plans within an appropriate time frame.

Design Assistance and Guidance

To maximize program effectiveness and the proper use, design, construction, and maintenance of erosion and sediment controls, it is essential to have a design guidance document available for designers, developers, and contractors. Most areas of the country already have one available. To a large extent, the manuals are very similar to one another, either based on the early Virginia manual, or the manuals prepared by the SCS (NRCS) for various states. In some cases, special local practices have been developed and the manuals are more unique. For each practice, the design manual should specify the purpose, applicability in different site situations, sizing, materials, construction standards, maintenance needs, and operational information. The manual must include both structural and vegetative practices. Many of the structural practices, except for storage volumes of sediment traps or basins, tend to have universal design criteria. Vegetative practices must include local considerations such as the types of plant materials and how they are best established and maintained. It is critical in all locales that design manuals consider local conditions, especially rain characteristics, typical soils, and topography. This hinders the simple transfer of design manuals throughout the country.

Federal Technical Guidance for Preparing Stormwater Pollution Prevention Plans (SWPPP) for Construction Projects

The EPA has published many resources to assist construction site planners and designers. The following web page (visited in February 2019) separates the lists and links of resources into Professional Resources, SWPPP templates, and Inspection and Corrective Action Templates: https://www.epa.gov/npdes/construction-general-permit-resources-tools-and-templates). Under the SWPPP templates, EPA has the *Developing Your Stormwater Pollution Prevention Plan: A Guide for Construction Sites* (EPA 833-R-060-04). Figure 1-26 shows the outline of the guidance document, which follows the design order described in the regulations and in this chapter. The guidance starts with understanding the regulations and objectives of sediment and erosion control activities. It contains several sets of questions that should be answered and documented in the SWPPP, including who has responsibility for installing and maintaining the control measures. In addition, examples are provided throughout which emphasizes the principles behind erosion and sediment control and how these control measures meet them.

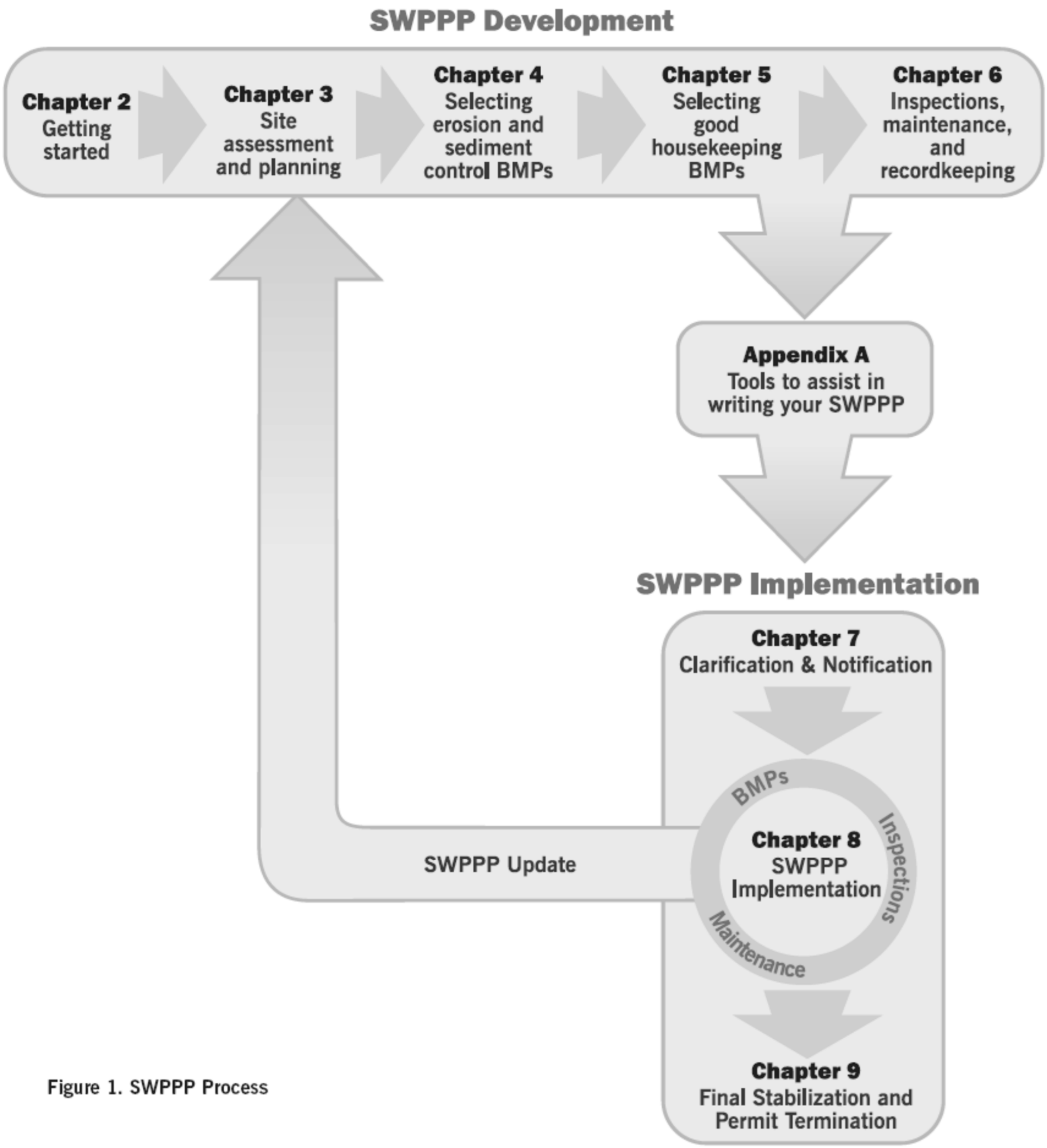


Figure 1-26. Outline of Federal Guidance Document *Developing Your Stormwater Pollution Prevention Plan: A Guide for Construction Sites*.

Checklists to Ensure Plan Completeness and to Aid in Regulatory Review
Some regulatory agencies responsible for erosion and sediment control plan review have developed a series of checklists to aid in quickly determining whether the required plan components were included in the submitted package. Pennsylvania has developed two checklists to fulfill this purpose, and a third checklist for training purposes. Use of these checklists in conjunction with other guidance during plan development help the designer to ensure that he/she has addressed the pertinent issues and demonstrated how the plan has met the regulations. According to the PA Department of Environmental Protection (DEP), "the Complete Plan Checklist is used to determine if an erosion and sediment control plan includes all required elements. This checklist is intended to serve as a tool to determine whether an erosion and sediment control plan addresses all eleven items required by Section 102.4(b)(5). It need not be included as part of the plan submittal.

The E&S Control Plan Technical Review Checklist is used in the PA DEP manual to determine the technical adequacy of an erosion and sediment control plan." "This checklist is to be used by the reviewing agency to ensure the erosion and sediment control plan meets the requirements of Chapter 102 and the standards of the Department's Erosion and Sediment Pollution Control Program Manual, No. 363-2134-008 (January 2000), as amended and updated. It should not be included as part of the plan submittal."

The third checklist was designed by the Pennsylvania Department of Environmental Protection as an instructional checklist for new plan developers and plan reviewers. It outlines the expected items under each section of the Control Plan Technical Review Checklist.

COMPLETE PLAN CHECKLIST

Project: ________________

A. Written Narrative (Labeled “E&S” or “Erosion and Sediment Control Plan” and the final plan for construction). Written Narrative Includes the following:

1. 8.5” X 11” USGS map with outline of project area ☐
2. Soils information (including hydric soils) types, depth, slope, and locations of soils ☐
3. Physical characteristics and limitations of soils ☐
4. Supporting calculations to show anticipated peak flows for the design storms ☐
5. Analysis of the impact that runoff from the project site will have on existing downstream watercourses resistance to erosion. ☐
6. Supporting calculations, standard worksheets, narrative description of the location(s) for all proposed E&S Control BMPs used before, during and after earth disturbance including but not limited to the following:
   a. Channels ☐
   b. Sediment Basins ☐
   c. Sediment Traps ☐
   d. Filter Fabric Fencing ☐
   e. Outlet Protection ☐
   f. Other BMPs (Specify)________________ ☐
   g. Other BMPs (Specify)________________ ☐
   h. Other BMPs (Specify)________________ ☐
7. Analysis of geologic formation and soil conditions to cause pollution to surface waters where potential for such conditions is known to exist. ☐

B. Plan drawings labeled “E&S” or “Erosion and Sediment Control Plan” and the final plan for construction. Drawings include the following:

1. Legend for any symbols that may be used on the drawing ☐
2. Topographic features including existing contours, improvements, streams, wetlands, watercourses, etc. and sufficient surrounding area ☐
3. Soil types and locations ☐
4. Construction techniques or special considerations to address soil limitations ☐
5. Limits of project area (NPDES boundary for permitted sites) ☐
6. Limits of earth disturbance ☐
7. Proposed alteration including proposed contours and proposed improvements ☐
8. Maximum drainage areas to hydraulic BMPs during construction ☐

9. Location of water which may receive runoff and receiving water classification pursuant to Chapter 93 and the “statewide existing use listing” ☐

10. Standard Construction Details for all proposed E&S Control BMPs used before, during and after earth disturbance ☐

11. Location of BMPs showing final contours ☐

12. Complete and site specific sequence of BMP installation and removal including activities planned to limit exposed areas ☐

13. Procedures or note requiring the proper recycling or disposal of waste materials associated with the project site ☐

14 Maintenance Program including inspection schedule, sediment cleanout levels, repair parameters and time frames, and directions for sediment removal ☐

15. Note explaining responsibilities for materials including definition of environmental due diligence and clean fill ☐

16. If identified in item A.7 above, the locations of all bedrock or soil materials with potential to cause pollution to surface waters during earth moving operations (if such are identified in item A.7 above). ☐

17. Evaluation of potential thermal impacts to surface waters from the earth disturbance activity and use of BMPs that avoid, minimize or mitigate potential pollution from thermal impacts ☐

18. E&S Plan consistent with PCSM plan ☐

19. Existing and proposed riparian forest buffers identified ☐

Figure 1-27. Complete Plan Checklist for Pennsylvania Erosion and Sediment Control Plans (PA DEP 2012)

STANDARD E&S CONTROL PLAN TECHNICAL REVIEW CHECKLIST

Project: ______________________ NPDES/Project No. ______________

Project Location: ______________________ Date: ______________________

Check-off: c = Complies, d = Deficient, na = Not applicable
Item Location: D = E&S Drawings, N = E&S Narrative, D&N = Drawings and Narrative

"The E&S Plan shall be prepared by a person trained and experienced in E&S control methods and techniques applicable to the size and scope of the project being designed"

Name ____________ Address ______________ Telephone No. __________ D&N

"The existing topographic features of the project site and the immediate surrounding area"

Check-off	Item	Location
______	Legible mapping	D
______	Existing contours	D
______	Type of cover	D
______	Existing improvements, i.e. roads, buildings, utilities, etc.	D
______	Sufficient surrounding area	D
______	Complete mapping symbols legend and north arrow	D
______	Location map, i.e. USGS	D or N

"The types, depth, slope, locations and limitations of the soils"

Check-off	Item	Location
______	Types, slopes, and locations of soil types	D
______	Soil type use limitations and resolutions	N
______	Hydric soils	N

"The characteristics of the earth disturbance activity, including the past, present, and proposed land uses and the proposed alteration to the project site"

Check-off	Item	Location
______	Proposed NPDES boundary and limits of construction	D
______	Proposed contours/grades	D
______	Proposed waterways and stormwater management facilities	D
______	Proposed improvements, i.e., roads, buildings, utilities, etc.	D
______	Past, present and proposed land uses	N

"The volume and rate of runoff from the project area and its upstream watershed area"

Check-off	Item	Location
______	Maximum during construction drainage areas	D
______	Offsite drainage area(s) on USGS quadrangle map	N
______	Discharge analysis provided for non-surface water discharges	N

"The location of all surface waters of this Commonwealth that may receive runoff within or from the project site and their classification under Chapter 93"

Check-off	Item	Location
______	Existing streams, wetlands, floodway, etc.	D
______	Receiving watercourses	D
______	Chapter 93 classification of streams or other waterbodies	N

"A narrative description of the location and type of perimeter and onsite BMPs used before, during and after the earth disturbance activity"

____________ Description provided in the narrative N

"A sequence of BMP installation and removal in relation to the scheduling of earth disturbance activities, prior to, during and after earth disturbance activities that ensure the proper functioning of all BMPs"

____________ Complete and site specific sequence of BMP installation D
____________ Activities planned to limit exposed areas D
____________ Removal of temporary BMPs D

"Supporting calculations and measurements" and "Plan Drawings"

Stabilized Construction Entrance
____________ Locations ____________ Complete Details D
Silt Fencing
____________ Locations ____________ Slope Length ____________ Complete Details D
Channels
____________ Locations ____________ Drainage Areas ____________ D
____________ Contours and Grades ____________ Complete details D
____________ Peak flow calculations ____________ Capacity and freeboard calculations N
____________ Protective lining calculations N
Sediment Basins
____________ Locations ____________ Contours ____________ Drainage Areas D
____________ Complete berm & outlet details ____________ Cleanout information D&N
____________ Discharge to surface waters or approved alternative D
____________ Structurally sound D&N
____________ Capacity calculations ____________ Discharge calculations N
____________ Dewatering calculations N
Sediment Traps
____________ Locations ____________ Contours ____________ Drainage Areas D
____________ Complete berm & outlet details ____________ Cleanout information D&N
____________ Discharge to surface waters or approved alternative D
____________ Capacity information ____________ Discharge calculations N
Outlet Protection
____________ Locations ____________ Complete Details D
____________ Design Calculations N
Inlet Protection
____________ Locations ____________ Complete Details D
Other BMPs (specify) ____
____________________ Locations ____________________ Complete Details D
____________________ Design Calculations N
Temporary Stabilization

	Seed	Lime	Fertilizer	Mulch	Others	
Types	______	______	______	______	______	D
Rates	______	______	______	______	______	D

Permanent Stabilization
____________ Topsoil replacement D

	Seed	Lime	Fertilizer	Mulch	Others	
Types	______	______	______	______	______	D
Rates	______	______	______	______	______	D

"A maintenance program, which provides for the operation and maintenance of BMPs and the inspection of BMPs on a weekly basis and after each stormwater event, including the repair or replacement of BMPs to ensure effective and efficient operation. The program must provide for completion of a written report documenting each inspection and all BMP repair, or replacement and maintenance activities"

____________	Inspection schedule	D
____________	Maximum sediment storage elevation/level in BMPs	D
____________	Time frames for completing specific maintenance and repairs for each type of BMP proposed.	D
____________	Site stabilization repair parameters and directions	D
____________	Disposal directions for sediment removed from BMPs	D
____________	Note provided requiring written documentation of inspection & repair/replacement of BMPs by contractor	D

"Procedures which ensure that the proper measures for the recycling or disposal of materials associated with or from the project site will be undertaken in accordance with this title"

____________	Project construction wastes are identified	N
____________	Directions for recycling/disposal of construction wastes	D
____________	Soil/rock disposal areas provided with BMPs	D

"Identification of naturally occurring geologic formations or soil conditions that may have the potential to cause pollution during earth disturbance activities and include BMPs to avoid or minimize potential pollution and its impacts from the formations"

____________	Potential for geologic or soil conditions to cause pollution during construction is addressed	N
____________	Instructions for proper handling and/or disposal of all materials that could cause pollution are provided	D
____________	Typical details are provided for proper handling and/or disposal of all such materials	D
____________	The locations of all such materials are clearly shown on the plan maps	D

"Identification of the potential thermal impacts to surface waters of this Commonwealth from the earth disturbance activity including BMPs to avoid, minimize or mitigate potential pollution from thermal impacts"

____________	Analysis of how thermal impacts associated with the project will be avoided is provided	N
____________	If impacts cannot be avoided, impacts are minimized and BMPs provided to mitigate impacts and protect and maintain surface water quality	D&N

"The E&S Plan shall be planned, designed, and implemented to be consistent with the PCSM Plan under 25 Pa. Code § 102.8 (relating to PCSM requirements). Unless otherwise approved by the Department, the E&S Plan must be separate from the PCSM Plan and labeled "E&S" or "Erosion and Sediment Control Plan" and be the final plan for construction"

____________	Overall plan supports the managing of stormwater for erosion and sediment control during earth disturbance activities	D&N
____________	BMPs are compatible with, and can be integrated into, structural and non-structural PCSM practices	D&N

"Identification of existing and proposed riparian forest buffers"

____________	Existing and/or proposed buffers are shown on the plan drawings.	D

Figure 1-28. Pennsylvania E&S Control Plan Technical Review Checklist (PA DEP 2012)

EXPANDED E&S CONTROL PLAN TECHNICAL REVIEW CHECKLIST

This checklist is intended for instructional purposes only
(For use by new technicians or to illustrate check items in standard technical review checklist)

Project: ________________________________ NPDES/Project No. ________________

Project Location: ________________________ Date: ___________________________

Check-off: c = Complies, d = Deficient, na = Not applicable
Item Location: D = E&S Drawings, N = E&S Narrative, D&N = Drawings and Narrative

"The E&S Plan shall be prepared by a person trained and experienced in E&S control methods and techniques applicable to the size and scope of the project being designed"

	Item Location
Name of Plan Designer Provided ___ Business Address ___ Telephone No. ____	**D&N**

"The existing topographic features of the project site and the immediate surrounding area"

	Complies	Deficient	N/A	Item Location
Legible mapping				**D**
Printing and numbering can be easily read	☐	☐	☐	
Scale is large enough to clearly depict the topography	☐	☐	☐	
Clutter has been avoided	☐	☐	☐	
Match Lines provided for adjacent sheets	☐	☐	☐	
Existing contours				**D**
Dashed lines easily visible and labeled at 10' maximum intervals	☐	☐	☐	
Maximum contour interval is 2 feet	☐	☐	☐	
Type of Cover				**D**
Vegetative Cover shown on the plan map(s)	☐	☐	☐	
Existing improvements, i.e. roads, buildings, utilities, etc.				**D**
All public and private roadways on or adjacent to the site/labeled	☐	☐	☐	
All existing buildings, including those to be razed, on or adjacent	☐	☐	☐	
All existing waterlines, sewer lines, power lines, gas lines, etc.	☐	☐	☐	
Sufficient surrounding area				**D**
Drainage areas and receiving waters clearly shown	☐	☐	☐	
Complete mapping symbols legend and north arrow				**D**
All symbols used on the maps are clearly identified	☐	☐	☐	
North arrow provided on each map	☐	☐	☐	
Location map, i.e. USGS 7½ Min. Quad Map(s)				**D or N**
Site Outline on Legible photo copy of appropriate Quad Map(s)	☐	☐	☐	
Quad Name(s) provided	☐	☐	☐	
Existing Vegetation	☐	☐	☐	**D**

"The types, depth, slope, locations and limitations of the soils"

	Complies	Deficient	N/A	Item Location
Types, slopes, and locations of soil types				**D or N**
Soil boundaries clearly shown on plan maps	☐	☐	☐	
Legible photo copy of NRCS soil map with site outline provided	☐	☐	☐	
Soil symbols identified	☐	☐	☐	
Soil type use limitations and resolutions				**N**
Appropriate use limitations identified	☐	☐	☐	
Resolutions to use limitations adequately described	☐	☐	☐	
How resolutions are addressed in the E&S Plan described	☐	☐	☐	

	Complies	Deficient	N/A	
Hydric soils			☐	**N**
All Potentially hydric soils identified	☐	☐	☐	
Wetland Determination provided	☐	☐	☐	
Wetland Delineation provided	☐	☐	☐	

"The characteristics of the earth disturbance activity, including the past, present, and proposed land uses and the proposed alteration to the project site"

Proposed NPDES boundary and limits of construction			☐	**D**
Permit boundary is clearly shown on all plan maps	☐	☐	☐	
Limits of construction are clearly shown & within permit boundaries	☐	☐	☐	
Phase boundaries are clearly shown	☐	☐	☐	
Proposed contours/grades				**D**
All proposed grading is shown on Erosion Control Plan maps	☐	☐	☐	
Proposed contours are solid lines, darker than existing contours	☐	☐	☐	
Proposed contours tie into existing contours	☐	☐	☐	
Proposed waterways and stormwater management facilities				**D**
All proposed channels, swales, and pipes clearly shown & labeled	☐	☐	☐	
Transition points for all waterways clearly shown	☐	☐	☐	
All PCSM BMP locations clearly shown	☐	☐	☐	
All inlets identified/labeled	☐	☐	☐	
All proposed outfalls clearly shown and labeled	☐	☐	☐	
Proposed improvements, i.e., roads, buildings, utilities, etc.				**D**
All proposed roadways, including temporary access, clearly shown	☐	☐	☐	
Proposed building footprints, if known, are clearly shown	☐	☐	☐	
Lot boundaries and lot numbers are identified	☐	☐	☐	
Proposed utility mainlines, including sanitary, clearly shown	☐	☐	☐	
Station numbers provided	☐	☐	☐	
Proposed stockpile locations shown	☐	☐	☐	
Application has been made for required 105 permits	☐	☐	☐	
Past — at least 50 years, if known — present and proposed land uses				**N**
Brownfields identified, including reclaimed brownfields, abandoned landfills, old farm dumps, spill locations, underground fuel storage tanks and contaminated soil	☐	☐	☐	
Previously mined areas identified	☐	☐	☐	
Previous fruit orchards identified	☐	☐	☐	
Existing conditions adequately described	☐	☐	☐	
Proposed land use adequately described	☐	☐	☐	

"The volume and rate of runoff from the project area and its upstream watershed area"

Maximum drainage areas during construction				**D or N**
Drainage areas for all proposed basins, traps and channels shown correctly on plan maps	☐	☐	☐	
Photo copy of work map showing drainage areas provided	☐	☐	☐	
Drainage areas used are maximums during construction	☐	☐	☐	
Offsite drainage area(s) on USGS quadrangle map				**N**
Drainage areas too large for the plan maps are shown on the Location map or other photo copy of USGS Quad map	☐	☐	☐	
Discharge analysis provided (non-surface water discharges)	☐	☐	☐	N
Flowage easements addressed	☐	☐	☐	

“The location of all surface waters of this Commonwealth which may receive runoff within or from the project site and their classification under Chapter 93”

	Complies	Deficient	N/A	
Existing streams, wetlands, floodway, etc.			☐	**D**
All existing stream channels — defined bed and bank — within or adjacent to the site are shown on the plan map(s) & labeled	☐	☐	☐	
All existing wetlands and springs are shown on the plan map(s)	☐	☐	☐	
Wetlands shown are consistent with delineation report	☐	☐	☐	
For streams with FEMA study, 100-year floodways are shown	☐	☐	☐	
Receiving watercourses				**D**
All receiving storm sewer systems are clearly shown and labeled	☐	☐	☐	
Receiving waters beyond plan map coverage shown on USGS map	☐	☐	☐	
Downstream analysis provided for proposed discharges where needed	☐	☐	☐	N
Chapter 93 classification of streams or other water bodies				**N**
All special protection waters are clearly identified	☐	☐	☐	
All existing uses are clearly identified	☐	☐	☐	

“A narrative description of the location and type of perimeter and onsite BMPs used before, during and after the earth disturbance activity”

____________ Description provided in the narrative N

“A sequence of BMP installation and removal in relation to the scheduling of earth disturbance activities, prior to, during and after earth disturbance activities that ensure the proper functioning of all BMPs”

	Complies	Deficient	N/A	
Complete and site specific sequence of BMP installation				**D**
Access to site and perimeter BMPs is adequately addressed	☐	☐	☐	
Suitable BMPs are in place for clearing and grubbing and demolition operations	☐	☐	☐	
Sequence addresses installation of all proposed E&S BMPs	☐	☐	☐	
Proper handling of base flow during work within stream channels	☐	☐	☐	
Runoff from access roads and utility lines properly addressed	☐	☐	☐	
BMPs outletting to proposed structures are adequately addressed	☐	☐	☐	
Suitable BMPs are in place for all stages of construction	☐	☐	☐	
Suitable BMPs are in place for PCSM BMP installation	☐	☐	☐	
Appropriate instructions provided to avoid compaction of infiltration areas	☐	☐	☐	
Information is detailed and site specific	☐	☐	☐	
No maintenance items	☐	☐	☐	
Activities planned to limit exposed areas				**D**
Special value areas are kept outside the limits of construction	☐	☐	☐	
Initial clearing is limited to areas of perimeter BMPs	☐	☐	☐	
Sequence addresses field-marking the limits of disturbance	☐	☐	☐	
Cuts and fills are stabilized in regular vertical increments	☐	☐	☐	
Limits are placed on utility trenching	☐	☐	☐	
Disturbed subareas are stabilized upon reaching final grade	☐	☐	☐	
Blanketing is specified for disturbances in critical areas	☐	☐	☐	
Immediate stabilization provided in special protection watersheds	☐	☐	☐	

	Complies	Deficient	N/A	
Removal of temporary BMPs				**D**
Instructions provided for topsoil replacement, addition of soil amendments, seeding and mulching	☐	☐	☐	
Conditions of stabilization are adequately defined	☐	☐	☐	
Specific instructions given for removal/conversion of basins & traps	☐	☐	☐	
Removal of all temporary BMPs is addressed	☐	☐	☐	
Instructions provided for proper installation of PCSM BMPs	☐	☐	☐	
“Supporting calculations and measurements” and “Plan Drawings”				**D**
General				
Plan Drawings meet standards in Appendix D	☐	☐	☐	
Standard Notes added to plan drawings	☐	☐	☐	
Appropriate Optional Notes added to plan drawings	☐	☐	☐	
Grading Standards added to plan drawings	☐	☐	☐	
Site Access (Chapter 3)				**D**
Rock Construction Entrances provided where needed	☐	☐	☐	
Standard Construction Detail # 3-1 and/or 3-2 provided	☐	☐	☐	
Temporary and Permanent Access Roads shown	☐	☐	☐	
Standard Construction Detail # 3-3 and/or 3-4 provided	☐	☐	☐	
Broad-based Dips used on active haul roads	☐	☐	☐	
Standard Construction Detail # 3-6 and/or 3-7 provided	☐	☐	☐	
Spacing complies with Table 3.2	☐	☐	☐	
Open-top Culverts used on active haul roads	☐	☐	☐	
Standard Construction Detail #3-8 provided	☐	☐	☐	
Water Deflectors used on haul roads	☐	☐	☐	
Standard Construction Detail #3-9 provided	☐	☐	☐	
Ditch Relief Culverts used on haul roads	☐	☐	☐	
Standard Construction Detail #3-10 provided	☐	☐	☐	
Spacing Complies with Table 3.3	☐	☐	☐	
Turnouts provided where needed on haul roads	☐	☐	☐	
Compost Filter Sock Trap provided where needed	☐	☐	☐	
Temporary Stream Crossings provided where needed	☐	☐	☐	
Standard Construction Detail # 3-12-14 provided	☐	☐	☐	
Figure 3.4 provided for temporary bridges	☐	☐	☐	
Temporary Wetland Crossings provided where needed	☐	☐	☐	
Figure 3.5 3.6, or 3.7 provided	☐	☐	☐	
Figure 3.8 provided where Causeway is proposed	☐	☐	☐	
Temporary Bypass System provided for in-stream work	☐	☐	☐	
Figure 3.9, 3.10, 3.11, or 3.12 provided	☐	☐	☐	
Standard Construction Detail #3-15 or Figure 3.13 provided for Coffer Dams	☐	☐	☐	
Silt Curtain details comply with Figure 3.14, 3.15, 3.16, or 3.17	☐	☐	☐	
Pumped Water Filter Bags provided where needed	☐	☐	☐	
Standard Construction Detail # 3-16 provided	☐	☐	☐	
Standard Construction Detail #3-17 provided for sump pits	☐	☐	☐	
Sediment Barriers (Chapter 4)				
All sediment barriers are shown on existing level contour	☐	☐	☐	D
Barrier ends extended upslope or tied into constructed berms	☐	☐	☐	D
Sediment barriers avoid concentrated flows	☐	☐	☐	D
Slope lengths comply with Figure 4.2, Figure 4.3 or Table 4.4	☐	☐	☐	D
Typical details are provided for each type of barrier proposed	☐	☐	☐	D

	Complies	Deficient	N/A	
Details comply with standard details in Chapter 4, including notes	☐	☐	☐	D
Standard Construction Detail #4-3 and/or 4-4, or 4-5 provided for Weighted Sediment Filter Tubes	☐	☐	☐	D
Standard Construction Detail # 4-6 provided	☐	☐	☐	D
Standard Construction Det. #4-11 provided for Sediment Filter Log	☐	☐	☐	D
Standard Construction Det. # 4-12 provided for Wood Chip Berm	☐	☐	☐	D
Vegetative Filter Strip complies with Table 4.5	☐	☐	☐	D
Standard E&S Worksheet #1 completed for Compost Filter Socks	☐	☐	☐	N
Standard E&S Worksheet #2 completed for Compost Filter Berms	☐	☐	☐	N
Standard E&S Worksheet #3 completed for Standard Silt Fence	☐	☐	☐	N
Standard E&S Worksheet #4 completed for Reinforced Silt Fence	☐	☐	☐	N
Standard E&S Worksheet #5 completed for Alt. Reinforced SF	☐	☐	☐	N
Standard E&S Worksheet #6 completed for Super Silt Fence	☐	☐	☐	N
Standard E&S Worksheet #7 completed for Straw Bale Barriers	☐	☐	☐	N
Standard E&S Worksheet #8 completed for Rock Filters	☐	☐	☐	N

Note: Plan preparer may provide the information on the standard worksheets in another format as long as it is present in the narrative and identified as such.

Channels (Chapter 6)

	Complies	Deficient	N/A	
All proposed channels shown and labeled on plan map(s)	☐	☐	☐	D
Channel locations are accessible	☐	☐	☐	D
Conflicts with utility lines, roadways, buildings, cuts & fills avoided	☐	☐	☐	D
Sharp turns and flow obstructions avoided	☐	☐	☐	D
Steep slope problems avoided	☐	☐	☐	D
Temporary crossings provided where needed	☐	☐	☐	D
Diversions located upslope of disturbed areas	☐	☐	☐	D
Diversions and outlet channels discharge to waterways or adequately sized storm sewers	☐	☐	☐	D
Collectors located below disturbed areas	☐	☐	☐	D
Collectors discharge to upslope sides of basins or traps	☐	☐	☐	D
Outlet channels protected from adjacent disturbed areas	☐	☐	☐	D
Positive grade provided throughout length of channel	☐	☐	☐	D
Channel bed slopes consistent with those used in calculations	☐	☐	☐	D
Drainage areas are maximums for life of each channel	☐	☐	☐	D
Typical detail provided for each channel shape and lining	☐	☐	☐	D
Manufacturer’s installation & stapling details provided	☐	☐	☐	D
All critical dimensions specified	☐	☐	☐	D
Dimensions and linings consistent with those in calculations	☐	☐	☐	D
Temporary liners provided for vegetated channels	☐	☐	☐	D
Underlayment specified for riprap channels	☐	☐	☐	D
Transition zones identified (change in lining)	☐	☐	☐	D
No rock filters or check dams during earthmoving operations	☐	☐	☐	D
Peak flow calculations provided for all channels	☐	☐	☐	N
Standard E&S Worksheet #s 9 and 10 used for Rational Equation	☐	☐	☐	N
Runoff coefficients consistent with Table 5.2	☐	☐	☐	N
Weighted coefficients used for mixed cover drainage areas	☐	☐	☐	N
2-Yr/1-Hr storm used for temporary channels	☐	☐	☐	N
5-Yr/1-Hr storm used for temps in special protection	☐	☐	☐	N
10-Yr/1-Hr storm used for permanent channels	☐	☐	☐	N
Overland flow $\leq$ 150 feet	☐	☐	☐	N
Shallow concentrated flow consistent with Figure 5.1	☐	☐	☐	N

	Complies	Deficient	N/A	
Standard E&S Worksheet # 11 completed properly	☐	☐	☐	N
All channels addressed, including outlet channels for basins and traps	☐	☐	☐	N
Multipliers (1.6, 2.25, 2.75) used properly	☐	☐	☐	N
Significant changes in channel bed slope addressed	☐	☐	☐	N
Manning's "n" adjusted for flow conditions	☐	☐	☐	N
$Q \geq Q_r$	☐	☐	☐	N
$D \geq d$ + minimum required freeboard	☐	☐	☐	N
Flow width:flow depth ratios $\leq$ 12 w:1 d	☐	☐	☐	N
$V \leq V_a$	☐	☐	☐	N
$\tau_d \leq \tau_a$	☐	☐	☐	N
2 sets of calculations provided for vegetated channels, one for temporary liner and one for vegetated condition	☐	☐	☐	N

Note: Plan preparer may provide the information on the standard worksheets in another format as long as it is present in the narrative and identified as such.

Sediment Basins (Chapter 7)

	Complies	Deficient	N/A	
All proposed sediment basins shown and labeled on plan map(s)	☐	☐	☐	D
Basin locations are accessible	☐	☐	☐	D
Conflicts with utility lines, roadways, buildings, cuts & fills avoided	☐	☐	☐	D
Steep slope problems avoided	☐	☐	☐	D
Basins located below disturbed areas	☐	☐	☐	D
Stream channels and wetlands avoided	☐	☐	☐	D
Drainage areas are maximums for life of each basin	☐	☐	☐	D
Construction Detail provided for each basin	☐	☐	☐	D
Interior and exterior contours provided on each detail	☐	☐	☐	D
Principal and emergency spillway locations shown	☐	☐	☐	D
All proposed baffles, silt curtains, and forebays shown	☐	☐	☐	D
Sediment clean-out stake location shown	☐	☐	☐	D
Bottom elevation above seasonal high water table, adjacent wetlands, or perennial stream	☐	☐	☐	D
Required flow lengths, turbidity barrier or forebay provided	☐	☐	☐	D
Typical cross-section provided for each type of principal spillway	☐	☐	☐	D
All critical dimensions and elevations shown	☐	☐	☐	D
Sediment clean-out elevation $\geq$ 1 ft above basin bottom	☐	☐	☐	D
18" permanent pool provided where needed	☐	☐	☐	D
Dimensions and elevations consistent with those in calks	☐	☐	☐	D
$Z1 + Z2 \geq 5$	☐	☐	☐	D
Z1 and Z2 $\geq$ 3 for permanent basin	☐	☐	☐	D
Embankment top width $\geq$ 8 feet	☐	☐	☐	D
Key trench and anti-seep collars shown	☐	☐	☐	D
Impervious core shown	☐	☐	☐	D
Typical Detail provided for each type of principal spillway	☐	☐	☐	D
All critical dimensions and elevations shown	☐	☐	☐	D
Dimensions and elevations consistent with those in calcs	☐	☐	☐	D
Standard Construction Detail # 7-6 provided	☐	☐	☐	D
Typical provided for anti-seep collars	☐	☐	☐	D
Typical provided for outlet barrel in concrete bed	☐	☐	☐	D
Typical filter diaphragm detail provided where needed	☐	☐	☐	D
Standard Construction Detail #7-12 provided where needed	☐	☐	☐	D
Standard Construction Detail #7-13 provided where needed	☐	☐	☐	D

	Complies	Deficient	N/A	
Skimmer Details provided	☐	☐	☐	D
Standard Construction Detail #7-1 provided	☐	☐	☐	D
Standard Construction Detail #7-2, 7-3 and 7-4 provided	☐	☐	☐	D
Orifice diameter consistent with Figure 7.2	☐	☐	☐	D
Emergency spillway detail(s) provided	☐	☐	☐	D
Protective liner extends beyond toe of embankment	☐	☐	☐	D
Specs provided for embankment materials and compaction	☐	☐	☐	D
Baffle, silt curtain, forebay detail provided	☐	☐	☐	D
Cleanout stake detail provided	☐	☐	☐	D
Basin dewatering device detail provided	☐	☐	☐	D
Basins discharge to surface waters or approved alternative	☐	☐	☐	D
Standard E&S Worksheet #12 properly completed	☐	☐	☐	N
Total storage volume ≥ Total required storage volume	☐	☐	☐	N
Justification exists for all storage volume reductions	☐	☐	☐	N
Proper dewatering time provided	☐	☐	☐	N
Proper total basin discharge capacity provided	☐	☐	☐	N
Principal spillway discharge capacity ≥ 10 Yr./1 Hr storm	☐	☐	☐	N
If not discharging to a surface water, calcs provided to show accelerated erosion not a problem	☐	☐	☐	N
Standard E&S Worksheet #13 properly completed	☐	☐	☐	N
Elevation 4 is at least 0.5 ft above Elevation 3	☐	☐	☐	N
Elevation 6 is at least 2.0 ft above Elevation 5	☐	☐	☐	N
Elevation 6 is at least 1.0 ft above Elevation 5 with Discharge capacity for 100-year storm (on Worksheet #12)	☐	☐	☐	N
Required flow length:width ratio at Elevation 3 provided	☐	☐	☐	N
Emergency spillway provided	☐	☐	☐	N
Standard E&S Worksheet #14 properly completed	☐	☐	☐	N
Storage volume at water surface elevation equal to top of settling volume is ≥ "Total Storage Volume Provided" on E&S Worksheet #12	☐	☐	☐	N
Storage volume at water surface elevation equal to top of sediment storage volume ≥ "Required Sediment Storage Volume" on E&S Worksheet #12	☐	☐	☐	N
Standard E&S Worksheet #15 properly completed	☐	☐	☐	N
Top elevation = Top of dewatering zone	☐	☐	☐	N
Bottom elevation = Top of sediment storage zone	☐	☐	☐	N
Diagonal symmetry evident	☐	☐	☐	N
Standard E&S Worksheet #16 properly completed	☐	☐	☐	N
Figure 7.2 provided with dewatering volume and skimmer orifice size plotted	☐	☐	☐	N
Dewatering time measured from top of dewatering zone to top of sediment storage zone	☐	☐	☐	N
Standard E&S Worksheet #17 properly completed	☐	☐	☐	N
Orifice flow is calculated for flow into top of riser	☐	☐	☐	N
Principal spillway capacity is lesser of riser and barrel	☐	☐	☐	N
Total discharge capacity ≥ Required discharge capacity	☐	☐	☐	N
Standard E&S Worksheet #18 properly completed	☐	☐	☐	N
Lf is 1.1 X Ls for temp basin & 1.15 X Ls for perm. basin	☐	☐	☐	N
Downstream analysis OK	☐	☐	☐	N

Note: Plan preparer may provide the information on the standard worksheets in another format as long as it is present in the narrative and identified as such.

Sediment Traps (Chapter 8)

	Complies	Deficient	N/A	
All proposed traps shown on plan map(s)	☐	☐	☐	D
Spillway locations shown	☐	☐	☐	D
Trap locations are accessible	☐	☐	☐	D
Conflicts with utility lines, roadways, buildings, cuts & fills avoided	☐	☐	☐	D
Steep slope problems avoided	☐	☐	☐	D
Traps located below disturbed areas	☐	☐	☐	D
Stream channels and wetlands avoided	☐	☐	☐	D
Drainage areas are maximums for life of each trap	☐	☐	☐	D
Construction Detail provided for each irregular-shaped trap	☐	☐	☐	D
Interior and exterior contours provided for such traps	☐	☐	☐	D
Bottom elevation above seasonal high water table, adjacent wetlands, or perennial stream	☐	☐	☐	D
Required flow lengths, turbidity barrier or forebay provided	☐	☐	☐	D
Compost sock trap details provided and comply with SCD #3-11	☐	☐	☐	D
Typical cross-section provided for each type of trap	☐	☐	☐	D
All critical dimensions and elevations shown	☐	☐	☐	D
Dimensions and elevations consistent with those in calcs	☐	☐	☐	D
Sediment clean-out elevation $\geq$ 1 ft above trap bottom	☐	☐	☐	D
Typical Detail provided for each type of spillway	☐	☐	☐	D
All critical dimensions and elevations shown	☐	☐	☐	D
Dimensions and elevations consistent with those in calcs	☐	☐	☐	D
Skimmer details provided where needed	☐	☐	☐	D
Standard Construction Detail # 7-1 provided	☐	☐	☐	D
Standard Construction Details #7-2, 7-3 and 7-4 provided	☐	☐	☐	D
Orifice diameter consistent with Figure 7.2	☐	☐	☐	D
Specs provided for embankment materials and compaction	☐	☐	☐	D
Baffle, silt curtain, forebay detail provided	☐	☐	☐	D
Cleanout stake detail provided	☐	☐	☐	D
Trap Outlet Basin Detail provided	☐	☐	☐	D
Trap Dewatering Device Detail provided	☐	☐	☐	D
Traps Discharge to surface waters or approved alternative	☐	☐	☐	D
Standard E&S Worksheet #17 properly completed	☐	☐	☐	N
Tributary drainage areas do not exceed 5.0 acres	☐	☐	☐	N
Required storage capacity provided	☐	☐	☐	N
2:1 Flow length to width ratio provided at elevation h	☐	☐	☐	N
Embankment spillway width is 2 X # AC or 2 X h	☐	☐	☐	N
Barrel-riser spillway provides 1.5 CFS/AC discharge capacity	☐	☐	☐	N
Correct outlet basin dimensions specified	☐	☐	☐	N
Standard E&S Worksheet #13 provided for irregular shaped traps	☐	☐	☐	N
Downstream analysis OK	☐	☐	☐	N

Note: Plan preparer may provide the information on the standard worksheets in another format as long as it is present in the narrative and identified as such.

Outlet Protection (Chapter 9)

	Complies	Deficient	N/A	
All temporary and permanent outfalls are shown and labeled	☐	☐	☐	D
Locations are accessible to construction equipment	☐	☐	☐	D
Outlet protection provided for all temporary & permanent outfalls	☐	☐	☐	D
Sufficient space exists to construct outlet protection	☐	☐	☐	D
Discharges are properly oriented	☐	☐	☐	D
Outlet areas properly protected from adjacent disturbed areas	☐	☐	☐	D

	Complies	Deficient	N/A	
Typical Details are provided for all types of outlet protection	☐	☐	☐	D
All critical dimensions and elevations are provided	☐	☐	☐	D
Dimensions and elevations are consistent with calcs	☐	☐	☐	D
Standard E&S Worksheet #18 completed for all riprap aprons	☐	☐	☐	N
Calculations provided for adjusted discharge velocity	☐	☐	☐	N
Apron dimensions conform to Figure 9.3 or 9.4	☐	☐	☐	N
Flow transition mat lengths conform to Figure 9.6	☐	☐	☐	N
Stilling Basin Dimensions conform to Standard Construction Detail 9-4 and Figure 9.7	☐	☐	☐	N
Stilling Well Dimensions conform to Figures 9.8, 9.9, and 9.10	☐	☐	☐	N
Supporting calculations are provided for all other types of outlet protection	☐	☐	☐	N
Downstream stability analysis provided where needed	☐	☐	☐	N

Note: Plan preparer may provide the information on the standard worksheets in another format as long as it is present in the narrative and identified as such.

Other BMPs				
Waterbars specified on utility line ROWs and abandoned roads	☐	☐	☐	D
Standard Construction Detail # 3-5 provided	☐	☐	☐	D
Spacing complies with Table 3.1	☐	☐	☐	D
Storm sewer inlet protection provided where needed	☐	☐	☐	D
Standard Construction Detail # 4-15 and 4-16 provided for inlet filter bags	☐	☐	☐	D
Standard Construction Detail # 4-17 and 4-18 provided for stone and concrete block inlet protection	☐	☐	☐	D
Standard Construction Detail # 4-19 and 4-20 provided for stone inlet protection	☐	☐	☐	D
Standard Construction Detail # 4-21 provided for alternate type M stone inlet protection	☐	☐	☐	D
Standard Construction Detail # 4-22 provided for type C inlet not at grade	☐	☐	☐	D
Standard Construction Detail # 4-23provided for type M inlet not at grade	☐	☐	☐	D
Erosion Control Blanketing Locations shown on map(s)	☐	☐	☐	D
Complete installation detail(s) provided	☐	☐	☐	D
Typicals provided for on-lot BMPs	☐	☐	☐	D
Other BMPs (specify) ____________________				
Location(s) shown on plan map(s) & labeled	☐	☐	☐	D
Typical Detail provided with all pertinent dimensions and elevations	☐	☐	☐	D
Design calculations	☐	☐	☐	N

Temporary Stabilization				**D**
Seed type	☐	☐	☐	
Seed rate of application	☐	☐	☐	
Agricultural lime specified at 1 or 2 T/acre	☐	☐	☐	
Fertilizer type and application rate specified	☐	☐	☐	
Mulch type and application rate specified	☐	☐	☐	
Mulch anchoring type and application rate specified	☐	☐	☐	

	Complies	Deficient	N/A	
Permanent Stabilization				D
Topsoil replacement specs provided	☐	☐	☐	
Standard E&S Worksheet # 21 completed on plan drawings	☐	☐	☐	
Seed types suitable for soil and site conditions specified	☐	☐	☐	
Seed rate of application appropriate	☐	☐	☐	
Agricultural lime specified at 6 T/acre or as per soil test	☐	☐	☐	
10-20-20 fertilizer specified at ½ ton/acre or as per soil test	☐	☐	☐	
Mulch type and application rate specified	☐	☐	☐	
Mulch anchoring type and application rate specified	☐	☐	☐	
Blanketing shown in critical areas, steep slopes, & areas of concentrated flow	☐	☐	☐	
Stabilization of non-graded, but unstabilized, areas, including agricultural areas, within the project site boundaries addressed	☐	☐	☐	

"A maintenance program, which provides for the operation and maintenance of BMPs and the inspection of BMPs on a weekly basis and after each stormwater event, including the repair or replacement of BMPs to ensure effective and efficient operation. The program must provide for completion of a written report documenting each inspection and all BMP repair, or replacement and maintenance activities"

	Complies	Deficient	N/A	
Maintenance Information				D
All E&S BMPs inspected weekly and after each runoff event	☐	☐	☐	
Plan specifies maintenance of inspection & maintenance logs	☐	☐	☐	
Maximum sediment storage elevation/level in BMPs specified	☐	☐	☐	
Time frames for completing specific maintenance and repairs for each type of BMP proposed.	☐	☐	☐	
Site stabilization repair parameters and directions	☐	☐	☐	
Disposal directions for sediment removed from BMPs	☐	☐	☐	

"Procedures that ensure that the proper measures for the recycling or disposal of materials associated with or from the project site will be undertaken in accordance with this title"

	Complies	Deficient	N/A	
Offsite Waste and Borrow Areas (see Standard notes 10 & 11 in Appendix C)				D
Project construction wastes are identified	☐	☐	☐	
Directions for recycling/disposal of construction wastes	☐	☐	☐	
Soil/rock disposal and borrow areas provided with BMPs	☐	☐	☐	
Note on plans regarding clean fill requirements	☐	☐	☐	

"Identification of naturally occurring geologic formations or soil conditions that may have the potential to cause pollution during earth disturbance activities and include BMPs to avoid or minimize potential pollution and its impacts from the formations"

	Complies	Deficient	N/A	
Potential for geologic or soil conditions to cause pollution during construction is addressed	☐	☐	☐	N
Soil sample locations shown on plan maps	☐	☐	☐	D
Instructions for proper handling and/or disposal of all materials that could cause pollution are provided	☐	☐	☐	D
Typical details are provided for proper handling and/or disposal of all such materials	☐	☐	☐	D
The locations of all such materials are clearly shown on the plan maps	☐	☐	☐	D

“Identification of the potential thermal impacts to surface waters of this Commonwealth from the earth disturbance activity including BMPs to avoid, minimize or mitigate potential pollution from thermal impacts”

	Complies	Deficient	N/A	
An analysis of how thermal impacts associated with the project will be avoided is provided	☐	☐	☐	N
If thermal impacts cannot be avoided, impacts are minimized	☐	☐	☐	D&N
BMPs provided to mitigate thermal impacts	☐	☐	☐	D&N

“The E&S Plan shall be planned, designed, and implemented to be consistent with the PCSM Plan under § 102.8 (relating to PCSM requirements). Unless otherwise approved by the Department, the E&S Plan must be separate from the PCSM Plan and labeled “E&S” or “Erosion and Sediment Control Plan” and be the final plan for construction”

Overall design of project supports managing of stormwater for erosion control during earth disturbance activities	☐	☐	☐	D&N
Erosion control BMPs can be integrated into structural and Non-structural PCSM practices and approaches	☐	☐	☐	D&N

“Identification of existing and proposed riparian forest buffers”

Existing and proposed riparian forest buffers are shown on the plan drawings	☐	☐	☐	D

Figure 1-29. Illustrative Checklist for a Pennsylvania Erosion and Sediment Control Plan.

Example Construction Site Erosion Control and Stormwater Management Requirements [1]

Rationale and Purpose

The objective of an effective construction site erosion control and stormwater management ordinance is to protect the local water resources from water quality degradation from many potential sources and activities. Specific provisions of an ordinance may:

- Control development and related activities that may increase pollution from these sources,
- Provide for treatment practices that promote the public health, safety, and general welfare, and
- Restrict or prohibit discharges that are dangerous to, or potentially may increase pollution of, the watershed and public water supply.

[1] This discussion (and much of the preceding material) is based on material and experiences from a number of individuals and agencies besides the authors. Earl Shaver, formerly of the Auckland Regional Council, New Zealand, was helpful in the preparation of some of the material reflecting his many years of experience in Maryland and Delaware. While working at the Wisconsin Department of Natural Resources, Bob Pitt was greatly influenced by his colleagues while preparing early versions of the WI model ordinance and later by environmental attorneys and other reviewers when he prepared an early version of the watershed protection ordinance for the Cahaba River watershed in Jefferson County, AL. These discussions therefore reflect a compilation of ideas that are presented to aid local agencies in meeting NPDES erosion control requirements.

Standards and Specifications for Construction Site Erosion Control

Construction site monitoring (especially research on the yields and delivery of construction site erosion material) has shown that the type of development (i.e., final land use) has very little effect on erosion rates. Instead, construction site erosion losses vary with the amount of land disturbed, the duration of that disturbance, and the presence of effective erosion controls. A watershed protection ordinance, therefore, should require erosion control permits for all types of development and exclude only small construction projects (such as those disturbing less than 2,000 square feet, or involving excavation and/or filling of less than 500 cubic yards of material). Thus, projects such as home additions or household gardening activities will generally be too small to require permits, while construction of most individual homes and all larger types of development would require permits. Even small land disturbing activities should have erosion controls, though formal permits may not be required. In most cases, these small projects would only require simple good housekeeping provisions, good drainage, simple mulching, and a quick project period. When these small developments are in high-value watersheds, more extensive erosion control practices may be needed.

Construction site monitoring has also revealed that sediment delivery (the amount of sediment leaving its source compared to the amount entering the receiving water) is very close to 100 percent for typical urban construction sites in developing areas. These very large delivery ratios probably result from the normal practice of installing the storm drainage system during the initial construction phase. The early installation of storm drainage systems also apparently makes sediment yield and delivery insensitive to site slope. An erosion control ordinance, therefore, should not exempt construction projects on the basis of percentage disturbance of a watershed, or construction site slope.

Vague regulations and general criteria regarding erosion control sometimes found in many erosion control ordinances should be replaced by criteria that specify when and where specific control practices are to be used. Such guidance should help site engineers as well as site plan reviewers and inspectors. In addition, specific criteria should promote more uniform construction site erosion control throughout the watershed.

The main purpose of construction site erosion control requirements is to prevent sediment and other pollutants from leaving construction sites. The secondary purpose is to significantly reduce the quantity of any “escaped” material that reaches receiving waters. Past research projects that have characterized construction erosion discharges and transport processes have concluded that very large amounts of sediment, phosphorus, and other pollutants erode from most construction sites. Sediment yields from uncontrolled construction sites may, for example, be several hundred to several thousand times the annual sediment yields from most developed urban areas. Small areas of active construction may therefore contribute much more pollution to receiving waters than entire cities or surrounding agricultural lands. By requiring reasonable and effective construction site erosion controls for most developing areas, discharges of many pollutants to receiving waters can be greatly reduced.

Site Erosion Control Requirements

Site erosion control requires three main elements to protect downslope property, the storm drainage system, and receiving waters. The first main element involves diverting water from upslope, undisturbed areas so that it does not flow across disturbed land, e.g., preventing run-on. This preventive measure can reduce the volume of water and energy available to transport soil exposed by construction activity.

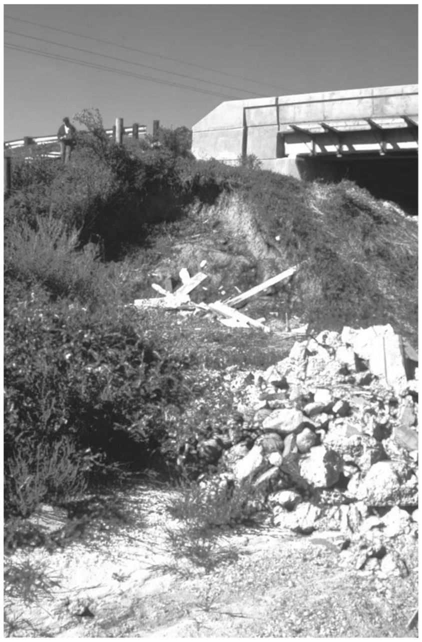


Figure 1-30. The lack of an appropriate diversion structure to safely drain water down sensitive slopes can cause much damage and sediment loss.

The second element requires stabilizing disturbed ground at time intervals that permit necessary grading but that also reduces erosion losses during intense rains. With the new federal regulations, careful phasing to decrease the amount of land disturbed at one time and to speed the entire construction process is encouraged. Site erosion control, on-site mulch, or temporary vegetation is needed to control erosion from disturbed sites during periods of site inactivity or when the erosion potential is very high. In some areas of the country, storms having high erosion potential can occur at any time, so immediate on-site mulching is a very important aspect of effective construction site erosion control programs. A risk assessment of the erosion potential of Jefferson County, AL, rainfall showed that rains occur about every three days. Although about three rains could occur during any seven-day period, the probability of a rain with high erosion potential during any seven-day period is relatively low. The probability increases with longer periods of time, however. A time limit of 14 days of no activity before mulching is required on portions of the construction site is a compromise between potential erosion damage and construction scheduling problems. Unfortunately, many disturbed sites are commonly left inactive for periods much longer than 14 days, resulting in very high probabilities of severely erosive rains occurring when sites are left disturbed and inactive. Stabilization of these inactive but disturbed areas is needed, therefore, to prevent site erosion, to eliminate the cost of regrading severely eroded areas, and to protect off-site areas from erosion products. In many cases, better timing of grading operations could also reduce the time an area is left disturbed.

Figure 1-31. Unattended severely eroded land causes great amounts of sediment loss and requires site regrading.

The third site erosion control element requires downslope controls to minimize the quantity of erosion products and of pollutants leached from the control practices that leave the site. This element is necessary because significant exposed land will always occur at construction sites and because many control practices contain leachable amounts of pollutants, especially during the early rain events at a site. Moreover, plantings can require several weeks to become established and capable of reducing erosion. For small sites (less than 10 acres) with no channelized flow, silt fences or other perimeter controls may be adequate. These controls are not very robust, however, and suitable only for sheetflows at low velocities. When larger flows can be expected, sedimentation basins are needed because high flow rates can quickly destroy silt fences. Further continued maintenance is critical to maintain the performance of any installed erosion control device.

Figure 1-32. Silt fencing for small drainage areas

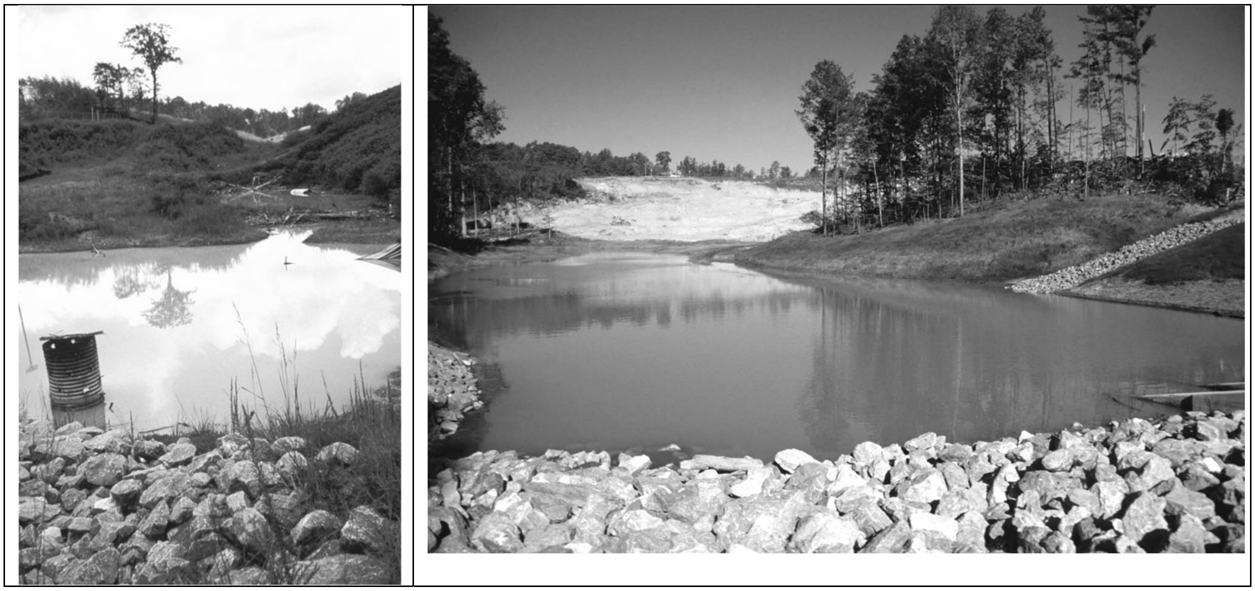


Figure 1-33. Sediment ponds for larger construction areas

Downslope controls alone cannot offer adequate protection from severely erosive rains that may occur at any time during the construction season. Because such rains could completely and quickly wash out a silt fence or silt-in a sedimentation basin if a site had no other protection, downslope controls should be installed in conjunction with above-site flow diversions and site mulching or plantings. Together, these three erosion control elements can significantly reduce potential erosion damage, which can be very expensive, if not impossible, to remedy once it has occurred. Nevertheless, occasional severe rains occurring at the “wrong time” in relation to site protection requirements may still cause downstream damage. The intent of an erosion control ordinance is to give site planners and engineers as much flexibility as possible in applying required specifications and standards to proposed projects. Although construction site regulations may appear restrictive, they should allow many choices about matters such as location of storage piles, mulch types, timing of grading, etc.

Summary of Erosion Control Requirements

As included in many regulations, including the current EPA regulations, all erosion control efforts should consist of four basic elements:

1. Divert upslope water around the disturbed site, or pass it through the site along a protected channel,

2. Expose disturbed areas for the shortest possible time (allowing a maximum time limit of about 14 days for inactive disturbed land before required protection), either through improved construction phase scheduling, or through temporary or permanent mulching, and

3. Treat any runoff water before it leaves the site (by perimeter silt fencing, or if a “large” site, with a sediment pond).

4. Continued maintenance of established controls.

This approach is needed because of the potential failure of any one system due to random rains that may cause severe site and erosion damage. As an example, if a temporary seeding is not fully established, a moderate rain of greater than 0.5 inch (which may occur about every 10 days in the Birmingham, AL, area) can easily wash it away. In addition, special considerations are also necessary, such as the following examples:

- Construction wastes (do not allow their burial on the site),
- Tracking restrictions (all main site roads, which have greater than about 25 vehicles per day traffic, and all site entranceways have to be graveled, and travel is restricted off these graveled areas),
- Treat dewatering wastes before discharge,
- Protect storm drain inlets (such as with straw bale or silt fence barriers),
- Locate material storage piles away from storm drain inlets (by at least 50 feet), and if left for a long time (greater than 14 days), then they must be covered, mulched and temporarily-seeded, or surrounded with a perimeter silt fence or straw bale barrier,
- Direct all on-site concentrated runoff (especially down steep slopes) along protected channels, or in flexible down drains,
- Require contractor to inspect all erosion controls on the site and make necessary repairs at least weekly and after large rains (greater than about 0.5 inch),
- Perform construction vehicle maintenance in special protected areas.
- Monitor turbidity from discharges, if required.

Barrier fencing setting outer limits of disturbance at construction site.

Truck being cleaned as it leaves construction site for public right-of-way.

Vehicle being cleaned as it leaves a construction site to prevent debris from affecting pubic roads.

Figure 1-34. Preventative measures and “good housekeeping” controls should also be used at construction sites.

Incorporating Adequate Design and Inspection Specifications

Adequate design specifications, especially those based on local experience, can minimize potential construction site erosion problems. Construction site erosion controls may fail for several reasons. Unusual rains that exceed the design capacities of even correctly constructed and maintained control facilities may cause their failure. However, a wet detention basin installed early during the construction period will act as a good sediment trap during a wide range of rains. In-stream detention facilities that receive large amounts of runoff from above a construction project can be easily damaged during large rains. The basin must be cleaned (dredged) often during construction and after final landscaping, for the construction period can produce as much sediment as many years of “normal” urban runoff. Large rains can also damage silt fences and other barriers and can severely erode culverts and waterway diversions. Failed controls are not only unable to reduce expected large amounts of erosion materials during severe rains but also may discharge previously retained sediment.

Downslope controls (silt fences and sediment ponds) must be installed first, followed by upslope diversions and then any on-site channel protection measures. Construction limit barriers may also need to be installed. Only when these controls are correctly installed should actual construction begin.

Improperly located, designed, constructed, or maintained control devices produce little to no benefit. A common example of a poor location for a control device is the placement of silt fences in established waterways that drain large areas. Silt fences behave as miniature detention basins and do not filter small sediment particles from water. They are supposed to be used to control shallow sheetflows. When placed in channels draining areas that are too large, backed up water may topple the silt fence, or the stream may increase in elevation and collapse the fencing, or the water may flow around the silt fence edges. Similar problems exist when straw bales are placed in large waterways. If large drainage channels cannot be diverted and must pass through a project, silt fencing must be placed appropriately to control sheetflows entering the channel. Well-designed wet detention (sediment) basins may also be needed below the site.

Probably the most common reason for failure of construction site erosion control devices is inadequate maintenance. If control devices are properly constructed, but not properly or frequently maintained, very little benefit may be expected. Newly installed devices will perform as initially expected until their "capacity" is exceeded. Silt fences, for example, should be maintained before the material that accumulates behind them becomes excessive. More importantly, the integrity of the fence also needs to be checked frequently. Many silt fences at construction sites are undermined or bypassed because of large flows or large sediment accumulations. Sedimentation basins, silt traps, catchbasins, etc., also need to be cleaned frequently. Rill or gully erosion must be corrected immediately when first observed. Similarly, mulched or planted areas need frequent inspections and repairs before large amounts of material are lost. Proper plan reviews and adequate inspections by administrative officials can prevent many of the problems caused by improper location, construction, and maintenance of construction erosion and stormwater control devices.

Inspection during Construction[2]

During construction, inspections need to be made of both erosion and sediment controls and stormwater management facilities. Erosion and sediment controls must be inspected periodically throughout the construction process, especially after storms. Stormwater management systems need to be inspected at critical times during construction of the individual practices.

Inspection frequency needs to be flexible, corresponding to shifts in the intensity of activity occurring at the site. When active construction is occurring, erosion and sediment control inspections should be conducted on a specified, appropriate frequency. When work on the site stops temporarily, inspections should be done periodically to assure that erosion and sediment controls are being maintained and still working, and to ensure that work has not resumed. Ideally, inspections should be done at a specified regular time interval and after significant storm events. This allows any changes in site conditions to be observed and ensures that erosion and sediment controls are still functioning as designed and approved. It is recommended that inspections be conducted by a public agency representative at least once every two weeks.

Inspection staff resources typically are insufficient to visit all active construction sites as frequently as needed. An implementation strategy decision must be made whether to visit fewer sites and completely follow the inspection procedures, or to conduct less comprehensive inspections at more sites. It is recommended that the inspection procedures be followed completely at sites that are inspected. Inspections need to be prioritized based on potential impacts, helping to assure compliance on tougher sites. Following the prescribed procedures also is important should legal enforcement action become necessary.

Inspectors should always attempt to contact an on-site individual who is responsible for the site grading activities. The contractor should be aware that the inspector is visiting the site even if the contractor does not accompany the inspector. This improves the dialogue that is important between the inspector

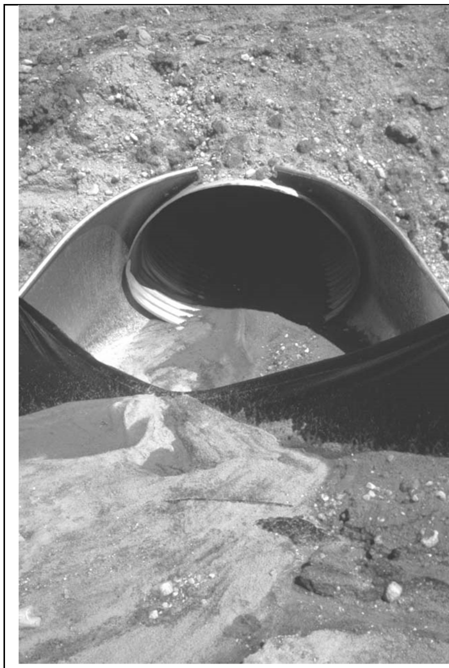
[2] Earl Shaver, formerly of the Auckland Regional Council, New Zealand, prepared the following comments on construction site inspections based on his many years of developing and managing erosion and sediment control programs in Maryland and Delaware.

and contractor. Highly visible inspections reinforce the commitment and importance a jurisdiction places on effective implementation of site controls. By knowing that the site will be inspected periodically, contractors are more likely to be aware of, and meet, site control responsibilities.

After completing the inspection, the inspector should leave an inspection report with the contractor and should send a copy to the developer and possibly the property owner. The report should serve as a site report card, clearly documenting proper installation and maintenance of site controls as well as any deficiencies in site control implementation. If there is a violation, the inspection report initiates a "paper trail" which is integral to successful enforcement actions.

It is unlikely that public agencies will ever have enough inspectors simply due to the large number of active construction projects at any time and to the resource limitations of stormwater management programs. A creative innovation to solve this problem is a partnership between the stormwater management program agency and the development community. This concept is being used in Delaware where the contractor or developer supplies their own inspectors. This person must attend and pass a State sponsored training course for inspectors. They are then responsible for inspecting the site at least once a week, completing an inspection form, and providing a copy of the form to the contractor, developer, and appropriate inspection agency. Having a "certified" private inspector on the site weekly can reduce the inspection frequency by the appropriate agency.

To improve the effectiveness of inspections, it is important to establish standard, well-documented inspection procedures. These procedures should specify in detail the actions an inspector conducts at a site, set out options and list steps to be taken when site compliance is inadequate, and establish an appeals process, should the inspector and developer disagree on matters. The procedures need to be developed in conjunction with available legal authorities and penalty provisions. Inspection of the stormwater management system during construction typically is not done on a regular schedule, but at certain stages of practice construction. For each type of construction site control, there are certain stages of construction where inspection is essential to assure proper construction and performance.

 Improper use of erosion controls must be corrected before excessive damage occurs (J. Voorhees photo)	 Inspections should require replacement of damaged mulch, or preferably the use of appropriate materials that are suitable for the site conditions.
 Inspections must require replacement of damaged erosion controls (J. Voorhees photo)	 Inspections must enforce needed maintenance before failure. This silt fence is retaining massive amounts of sediment and is near its limit and needs to be maintained soon.


Inspections need to monitor sediment accumulations. This dry sediment pond is almost full of accumulated material.


Lack of supplemental irrigation jeopardizes sodded areas.


Poorly covered mulched areas need to be remulched.


Damaged erosion controls need to be repaired or replaced as soon as possible.


Excessive tracking due to insufficient or non-maintained graveled access needs to be corrected.

Figure 1-35. Maintenance problems at construction sites.

Needed enforcement actions need to be obvious (WI DNR photo)


Education of erosion control contractors is mandatory (Maryland DNR, Earl Shaver, photo)

Figure 1-36. Necessary Enforcement and Education

Useful Internet Links

The following are the main Internet links referenced in this chapter and provide much additional information, especially concerning the federal programs and resources. These URLs frequently change so it is recommended that the current linkage addresses be found by using an Internet search tool.

EPA. Office of Wastewater Management (OWM) information:
http://www.epa.gov/owm/

Final Federal Register notice and supporting materials for Effluent Limits Guidelines for Erosion and Sediment control:
http://www.epa.gov/guide/construction

EPA links to on-line manuals and guidance documents:
http://www.epa.gov/waterscience/guide/construction/.

National Management Measures to Control Nonpoint Source Pollution from Urban Areas
http://www.epa.gov/owow/nps/urbanmm/

Smart Growth Program
http://www.epa.gov/livability/

Section 319 Nonpoint Source Management Program
http://www.epa.gov/owow/nps/cwact.html

The Construction Industry Compliance Assistance Center (http://cicacenter.org/) contains information and links to a wide variety of information, including state regulatory programs and manuals for sediment and erosion controls.

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Problems

1. Conduct a search in a newspaper database of articles related to sediment and erosion problems in your area (limit this search to the last three years). If no local articles are found, broaden your search to the state or national region. What percentage of these articles focused on agricultural erosion and what percentage were focused on erosion during land development for urban uses?
2. Determine which state agency is responsible for sediment and erosion control in your area. Review that agency's website relating to sediment and erosion control. Is the authority for plan review and enforcement retained at the state level? County level? Local level?
3. Determine which public agency is responsible for plan review. Find out how to obtain a copy of an approved erosion and sediment control plan (do not ask for one unless requested by the instructor). Find out if the plans are available for review in the office of the review agency. Who is responsible for writing project-specific erosion and sediment control plans?
4. Determine if the state and local authority's sediment erosion control regulations are available on the Internet. If not, find out where you can locate them.
5. Find three construction sites near your home, school or office. Answer the following questions regarding each site:
    a. Are there noticeable erosion problem on the site?
    b. Are these resulting in off-site problems?
    c. Do the perimeter erosion-control measures look well maintained? (NOTE: Do not enter any part of an active job site without the owner's permission, preferably in writing).
    d. If they are in the early stages of construction, were the minimum controls followed in setting up the work area for construction?

Appendix 1A: Example Components of Local and State Construction Site Regulations

Table 1A-1. Example Erosion and Sediment Control Exemptions and Waivers

Jurisdiction	Exemptions and Waivers
City of Alexandria, VA	<2,500 ft^2
City of Austin, TX	Agriculture; state facilities, projects disturbing < 1,000 ft^2
City of Bellevue, WA	None
City of Fort Collins, CO	Single family homes
City of Olympia, WA	Agriculture; forestry; public & private projects in right-of-way that add no impervious surface, grading projects that don't require grading permit
City of Orlando, FL	Single family homes not part of subdivision
City of Seattle, WA	Agriculture, forestry, WA DOT projects that comply with Puget Sound Highway Runoff Program, projects discharged directly to receiving water or piped storm drain (under certain conditions), < 750 ft^2 new impervious surface or < 2,000 ft^2 total impervious surface
District of Columbia	Agriculture, forestry, projects that disturb < 500 ft^2 or total cost < $2,500.
City of Winter Park, FL	None
Baltimore County, MD	Agriculture, activities disturbing < 5,000 ft^2
Clark County, WA	Agriculture, forestry, projects disturbing < 2,000 ft^2
King County, WA	Agriculture; single family homes exempt from detailed ES control plan
Kitsap County, WA	Agriculture (Kitsap SWCD stormwater related activities funded by county stormwater program
Maricopa County, AZ	N/A because state NPDES program exempts projects disturbing < 5 acres
Montgomery County, MD	Agriculture, projects disturbing < 5,000 ft^2
Prince George's County, MD	Agriculture
Snohomish County, WA	Agriculture
Somerset County, NJ	See New Jersey State Soil Conservation Committee Program Summary.
Washington County, OR	None
Urban Drainage and Flood Control District (Denver)	State NPDES permit exempts activities disturbing < 5 acres; other requirements depend on regulations of 10 local government programs
Northeastern Illinois Planning Commission	Agriculture, forestry, activities disturbing < 5,000 ft^2, activities disturbing < 500 ft^2 if next to water
South Florida Water Management District	Agriculture using closed water management systems
Southwest Florida Water Management District	Agriculture (with site specific Conservation Plan with appropriate BMPs); forestry (complying with "Florida Silviculture BMP Manual"); single family homes not in subdivision
Suwannee River Water Management District	Agriculture (with site specific Conservation Plan with appropriate BMPs); forestry (complying with "Florida Silviculture BMP Manual"); single family homes not in subdivision
State of Delaware	Agriculture
Florida Department of Environmental Protection	Agriculture (if using approved Conservation Plan with appropriate BMPs); forestry (complying with "Florida Silviculture BMP Manual"); single family homes not in subdivision
Maryland Department of the Environment	Agriculture; activities disturbing < 5,000 ft^2 or 100 cu. yds.
State of New Jersey	Agriculture, forestry, single family homes not part of larger development, activities disturbing < 5,000 ft^2
State of North Carolina	Construction sties < 5 acres and not located; within ½ mile of a water classified as a High Quality Water, in a coastal county and draining to a saltwater or other classified water, and located in a non-coastal county and draining to or within one mile of a water classified as a High Quality Water or an Outstanding Resource Water.
State of Pennsylvania	Timber harvesting disturbing < 25 acres; agricultural plowing & tilling pursuant to conservation plan; activities disturbing < 5 acres
State of South Carolina	Agriculture, forestry, single family homes not part of large development, utility operations with certificate of environmental compatibility
State of Virginia	Agriculture; forestry; activities disturbing < 10,000 ft^2; mining & gas exploration activities
Washington State Department of Ecology	Agriculture, forestry operation (except for forest conversions); activities disturbing < 1 acre; single family homes

Table 1A-2. Example Erosion and Sediment Control Preferred Practices

Jurisdiction	Preferred Practices
City of Alexandria, VA	Sediment basins & traps designed to capture 15 cu. yds/acre drainage area.
City of Austin, TX	Sediment basins & traps designed to capture 1,800 cu. yds/acre drainage area.
City of Bellevue, WA	Sediment basins & traps to contain runoff volume from: 10 yr storm for sites < 5 ac., or > 0.25 mi from waters; 20 yr storm for sites > 5 ac. or < 0.25 mi from waters
City of Fort Collins, CO	Sediment basins & traps designed for 100 cu. yds/acre
City of Olympia, WA	Sediment basins & traps to hold 2-yr (24 hr) storm volume.
City of Orlando, FL	Sediment basins & traps to capture 2.33 yr (6 hr) storm.
City of Seattle, WA	Sediment traps to retain runoff volume from 2 yr (24 hr) storm. Basins sized to settle medium silt soil particles (0.02 mm) during peak discharge from 10 yr (24 hr) storm.
District of Columbia	Sediment basins & traps to capture 1,800 cu. ft./acre drainage area.
City of Winter Park, FL	Sediment basins & traps to capture 67 cu. yds./acre drainage area.
Baltimore County, MD	Sediment basins & traps to contain 1,800 cu. yds runoff from drainage area.
Clark County, WA	Sediment traps to hold 2 yr (24 hr) storm runoff; basins to treat 10 yr (24 hr) storm.
King County, WA	Sediment traps to treat 2 yr (24 hr) storm runoff; basins sized for 10 yr (24 hr) storm.
Kitsap County, WA	Sediment traps & basins to treat runoff from 2 yr (24 hr) storm.
Maricopa County, AZ	None
Montgomery County, MD	Sediment basins & traps to capture 1,800 cu. ft/acre drainage area (to be changed to 3,600 cu. ft./ac.)
Prince George's County, MD	Sediment basins & traps to capture 1,800 cu. ft/acre drainage area (to be changed to 3,600 cu. ft./ac.)
Snohomish County, WA	Sediment basins & traps to capture runoff from 10 yr (24 hr) storm
Somerset County, NJ	See New Jersey State Soil Conservation Committee Program Summary.
Washington County, OR	Sediment basins & traps to capture runoff from 10 yr (24 hr) storm (RARELY USED)
Urban Drainage and Flood Control District (Denver)	Sediment basins & traps to retain 0.25 in of runoff from site.
Northeastern Illinois Planning Commission	Sediment basins & traps to capture runoff from 10 yr storm
South Florida Water Management District	None
Southwest Florida Water Management District	Sediment basins & traps to capture 67 cu. yds./acre drainage area
Suwannee River Water Management District	Sediment basins & traps to capture 67 cu. yds./acre
State of Delaware	Sediment traps & basins to retain 3,600 cu. ft./acre of contributing drainage area.
Florida Department of Environmental Protection	Sediment basins & traps to capture 67 cu. yds./acre
Maryland Department of the Environment	Sediment basins & traps to treat 1 in of runoff from disturbed area
State of New Jersey	Sediment basins & traps to retain 1 inch of runoff from disturbed area
State of North Carolina	Preventive Measures (nonstructural controls)
State of Pennsylvania	Sediment basins to treat 7,000 cfs/acre; sediment traps to treat 2,000 cfs/acre (max. 5 acres)
State of South Carolina	Sediment basins & traps to achieve 80% removal of average annual total suspended solids loading
State of Virginia	Sediment basins to capture 134 cu. yds/acre
Washington State Department of Ecology	Sediment basins & traps to detain 10 yr (24 hr) developed condition design storm

Table 1A-3. Example Erosion and Sediment Control Allowed Practices

Jurisdiction	Allowed Practices
City of Alexandria, VA	Silt fences, gravel const. entrance, slope protection, temp. & perm. veg. stabilization
City of Austin, TX	Construction sequencing, rock berms, filter dikes, diversion swales, temporary & permanent vegetation stabilization
City of Bellevue, WA	Seasonal limits on disturbed area, silt fence, gravel construction entrance, wheel washes; slope protection; temporary & permanent vegetation stabilization
City of Fort Collins, CO	Straw bales, surface roughening, diversions, gravel filters, silt fence, inlet barriers, terraces, temporary & permanent vegetation stabilization
City of Olympia, WA	Seasonal limits on disturbed area, silt fence, straw bales, gravel construction entrance, slope protection, inlet prot., temp. & permanent vegetation stabilization
City of Orlando, FL	Silt fences, gravel construction entrance, inlet protection, temporary & permanent vegetation stabilization, limited exposed areas
City of Seattle, WA	Silt fences, gravel construction entrance, wheel wash, slope protection, inlet protection, temporary & permanent vegetation stabilization
District of Columbia	Silt fences, vehicle wash area, straw bales, stabilized construction entrance, inlet protection, temporary & permanent vegetation stabilization
City of Winter Park, FL	Silt fences, straw bales, inlet & slope protection, temp. & perm. veg. stabilization.
Baltimore County, MD	Silt fences, straw bales, inlet & slope protection, temp. & perm. veg. stabilization.
Clark County, WA	Seasonal limits on disturbed area, stabilized construction entrance, wheel wash, slope drain, straw bales, silt fence, mulching, temp. & perm. vegetation stabilization.
King County, WA	Seasonal limits on disturbed area, mulching, silt fences, gravel construction entrance, slope drains, temporary & permanent vegetation cover.
Kitsap County, WA	Seasonal limits on land disturbance, gravel construction entrance, wheel wash, silt fences, straw bales, slope drains, mulching, temp. & perm. vegetative stabilization
Maricopa County, AZ	None
Montgomery County, MD	Mulching, sodding, staged clearing, silt fences, gravel construction entrances, temporary & permanent vegetation
Prince George's County, MD	Mulching, sodding, staged clearing, silt fences, gravel construction entrances, temporary & permanent vegetation
Snohomish County, WA	Mulching, seasonal limitation on disturbed area, silt fences, gravel construction entrance, slope drains, temporary & permanent vegetative stabilization
Somerset County, NJ	See New Jersey State Soil Conservation Committee Program Summary.
Washington County, OR	Silt fences, gravel construction entrances, diversions, bio-bags, straw, compost, temporary & permanent vegetation cover
Urban Drainage and Flood Control District (Denver)	Mulching, silt fences, temporary & permanent vegetation cover
Northeastern Illinois Planning Commission	Temporary & permanent vegetative cover; mulching; seeding; sodding; erosion blankets; silt fences; gravel construction entrances; outlet stabilization
South Florida Water Management District	None listed.
Southwest Florida Water Management District	Mulching; sodding, staged clearing, silt fences, gravel construction entrance, temporary & permanent vegetative cover
Suwannee River Water Management District	Mulching, sodding, staged clearing, silt fences, gravel construction entrances, temporary & permanent vegetation
State of Delaware	Silt fences, straw bales, gravel construction entrances, diversions, slope drains, temporary & permanent vegetation stabilization
Florida Department of Environmental Protection	Mulching, sodding, staged clearing, silt fences, gravel construction entrances, temporary & permanent vegetation
Maryland Department of the Environment	Mulching, sodding, staged clearing, silt fences, gravel construction entrances, temporary & permanent vegetation
State of New Jersey	Mulching, sodding, staged clearing, silt fences, gravel construction entrances, temporary & permanent vegetation
State of North Carolina	Preventative measures, detention and retention ponds and infiltration devices such as infiltration basins, trenches or underground trenches and dry wells
State of Pennsylvania	Silt fences, temp. & perm. vegetation, diversions, rock filters, riprap, inlet protection
State of South Carolina	Mulching, sodding, staged clearing, silt fences, gravel construction entrances, temporary & permanent vegetation
State of Virginia	Sediment traps, silt fences, temp. & perm. veg., diversions, daily street cleaning
Washington State Department of Ecology	Seasonal disturbed area limits, staged clearing, silt fences, gravel construction entrance, mulching, sodding, temporary & permanent vegetative cover, slope drains

Table 1A-4: State Regulations on the Control of Construction Phase Stormwater (USEPA 2002)

Geographic Area Name	Disturbed Area Limit for Permet Coverage (feet^2)	Numeric Standard or Pollutant Reduction Requirement	Minimum Depth of Runoff or Storm Return Frequency to Treat for Water Quality Management (per acre)	Maximum Allowed Denuded Acreage or Soil Stabilization Requirement	Visual Inspection Frequency	Notes
Clean Water Act NPDES Storm Water program for Phase I and Phase II MS4s	43,560				After 0.5 inch rainfall and every 14 days	Phase II compliance date is March 10, 2003.
CZARA	5,000					Must prepare and implement an approved erosion and sediment control plan or similar document that contains erosion and sediment control provisions.
Alabama	217,800	Turbidity < 50 NTU				
Alaska (AK)	217,800	TSS > 20 microns	2 year / 6 hour		After 0.5 inch rainfall and every 7 days	Inspector must be qualified personnel provided by the discharger.
Arizona	217,800					
Arkansas	217,800		10year / 24hour		Every 7 days	Developers must submit erosion and sediment control plan and storm water pollution prevention plan before filing a notice of intent. Sites 10 acres or more need temporary or permanent sediment basin. Sites less than 10 acres need sediment traps and silt fences.
California (CA)	217,800		2 year / 24 hour		After 0.5 inch rainfall	Inspections will be performed before anticipated storm events, during extended storm events, and after storm events, and once each 24-hour period during extended storm events to identify BMP effectiveness and implement repairs or design changes as soon as feasible depending on field conditions. Discharger is also responsible for inspecting and cleaning all public and private roads for sediment. Construction activities that fall under the jurisdiction of the California Department of Transportation (CALTRANS) have separate permit and regulations.
Colorado (CO)	217,800				Any precipitation or snowmelt event that causes erosion and every 14 days	Storm water management plan must be submitted to state for a 10 day review, as well as be retained on site.
Connecticut	217,800	80% TSS reduction				
Delaware	5,000	80% TSS reduction	0.5 inch			
Florida , DEP, Northern District (only applies in NW Florida)	217,800	80% TSS reduction	0.5 inch*			*>100 acres, 1 inch rainfall, <100 acres, 0.5 inch rainfall.
Florida, South Florida Water Management District (General, Standard General, Noticed General and Individual Permits)	435,600		1 inch			
Florida, Southwest Florida Water Management District	217,800		0.5 inch			
Florida, St. Johns River Water Management District	217,800	Turbidity <29 NTU				
Florida, Suwannee River Water Management District	43,560	80% TSS reduction	1 inch			
Georgia	47,916	Turbidity < 10-25 NTU*	25 year / 24 hour			*<25 nephelometric turbidity units for waters supporting warm water fisheries, or <10 nephelometric turbidity units for waters classified as trout waters.

Geographic Area Name	Disturbed Area Limit for Permet Coverage (feet^2)	Numeric Standard or Pollutant Reduction Requirement	Minimum Depth of Runoff or Storm Return Frequency to Treat for Water Quality Management (per acre)	Maximum Allowed Denuded Acreage or Soil Stabilization Requirement	Visual Inspection Frequency	Notes
Hawaii (HI)	217,800				After 0.5 inch rainfall and every 7 days during dry season, every day during rainy season	Construction shall be phased for large projects; one phase must be stabilized before another can begin. 50 days maximum from destruction of pre-construction conditions to temporary stabilization.
Idaho (ID)	217,800				After 0.5 inch rainfall and every 14 days	
Illinois	217,800		3,600 cubic feet per acre		Every 7 days	
Indiana	217,800				Every 7 calendar days and within 24 hours of 0.5 inch of precipitation	
Iowa	217,800	80% TSS reduction			Every 7 days	
Kansas	217,800				At least once per week	
Kentucky	217,800	Goal of 80 % TSS reduction (compared to pre-construction conditions)				
Louisiana	217,800					
Maine	217,800	40-80% TSS reduction	2 year			
Maryland	5,000	80% TSS reduction*	2 year / 24 hour			*Based on the average annual TSS loading from all storms less than or equal to the 2 year/24 hour storm.
Massachusetts	217,800	80% TSS reduction	2 year / 24 hour			
Michigan	43,560		3,600 cubic feet per acre		Encourage weekly inspections	Sites >10 acres require onsite temporary basin.
Minnesota	217,800		0.5 inch		1 time every 7 days or within 24 hours after a significant rain event which results in runoff leaving a construction site.	
Mississippi	217,800					
Missouri	217,800	Settleable Solids < 0.5 -2.5 mL/L/hour*			Periodic	*2.5 mL/L/hour for normal land disturbance, 0.5 mL/L/hour for land disturbance within sensitive areas.

Geographic Area Name	Disturbed Area Limit for Permet Coverage (feet^2)	Numeric Standard or Pollutant Reduction Requirement	Minimum Depth of Runoff or Storm Return Frequency to Treat for Water Quality Management (per acre)	Maximum Allowed Denuded Acreage or Soil Stabilization Requirement	Visual Inspection Frequency	Notes
Montana (MT)	217,800		2 year / 24 hour		After 0.5 inch rainfall and every 7 days	Dischargers must submit with the state application form a stormwater erosion control plan (SWECP) that resembles EPA's construction site SWPPP. Permit coverage begins only when Montana DEQ reviews and approves SWECP. Must also inspect everyday during prolonged precipitation or snowmelt periods. A registered PE must prepare the ESC plan if site is greater than 20 acres. Also regulate down to 1 acre if construction site within 100 feet of a surface water body. Montana has a sediment and erosion control guidance manual that lists standard use BMPs. If other BMPs are used, they need to be submitted with ESC plan to the state for approval. For slopes steeper than 3:1 and greater than 5 vertical feet, surface roughening is required. Filter fences should be used on drainage areas >1acre; sediment traps should only be used on drainage areas > 3 acres; and temporary sediment ponds should only be used on drainage areas > 10 acres.
NC	43,560	Y		20 acres total disturbance at any given time for areas discharging to high quality waters	Every 7 days	
Nebraska	217,800				Once a month.	
Nevada	217,800					
New Hampshire	100,000					
New Jersey	5,000					
New Mexico	217,800				Y	
New York	217,800		0.5 inch			
North Dakota	217,800				Y	
Ohio	217,800					
Oklahoma	217,800		3,600 cubic feet per acre		Y	A vegetated buffer zone of at least 100 ft must be retained or successfully established between the area disturbed during construction and all perennial or intermittent streams on or adjacent to the construction site. A vegetated buffer zone at least 50 ft wide must be retained or established between the area disturbed during construction and all ephemeral streams or drainages. Treatment volume is the lesser of 3,600 or the runoff volume of a 2 year 24 hour storm.
Oregon (OR)	217,800				Every 7 days, and daily during periods of stormwater runoff and snowmelt runoff; only every 14 days during periods of 7 days or more of non-construction activity.	If site is >20 acres, erosion and sediment control plan must be prepared by a Professional Engineer, or Registered Landscape Architect, or Certified Professional in Erosion and Sediment Control, and plan must be submitted 90 days before construction begins. All permittees must submit an Oregon Land Use Compatibility Statement if they do not already have one on file with Oregon DEQ.
Pennsylvania	217,800		5 year		Y	Basins should drain no quicker than 4 days and no longer than 7 days.

Geographic Area Name	Disturbed Area Limit for Permet Coverage (feet^2)	Numeric Standard or Pollutant Reduction Requirement	Minimum Depth of Runoff or Storm Return Frequency to Treat for Water Quality Management (per acre)	Maximum Allowed Denuded Acreage or Soil Stabilization Requirement	Visual Inspection Frequency	Notes
Rhode Island	217,800	80-90% TSS reduction	10 year			
South Carolina	>87,120	80% TSS reduction	3,600 cu ft / ac		Y	Trapping efficiency is a performance based requirement for any BMPs. The major requirements for storm water control plans are: application, location map, type and location of BMP's, construction sequencing, location of disturbed areas, property line & waters of the state, standard notes, grassing specifications. The minimum required volume for water quality management is 3600 cubic feet for a disturbed area of more than 10 acres. If there is not a sediment basin of 3600 cubic feet and the drainage area is less than 10 acres, then sediment traps, silt fences, or equivalent measures are needed for sideslope and downslope boundaries for the construction area. However, the first 0.5 inch rainfall runoff in a 24-hr period is applicable to the coastal counties only.
South Dakota	217,800		5 year			
Tennessee	217,800				Y	The permittee shall maintain records of checks and repairs.
Texas	217,800		3,600 cubic feet per acre			
Utah (UT)	217,800		24 hour OR 1 inch storm event		Once every 14 days, before anticipated storm events expected to cause significant runoff, and within 24 hours of the end of a storm that is 0.5 inch or greater.	Where sites have been finally or temporarily stabilized, or when runoff is unlikely due to winter conditions, or during seasonal arid periods in arid areas and semi-arid areas inspections shall be conducted at least once every 30 days. 10yr, 24hr storm event for water quality is for 10 acres or greater. For areas less than 10 acres, or where calculations for volume of runoff for disturbed acres is not performed, a sediment basin providing 3600 cubic feet of storage per acre drained or equivalent control measures shall be provided. 1) Where the initiation of stabilization measures by the 14th day after construction activity temporary or permanently cease is preclude by snow cover or frozen ground conditions, stabilization measures shall be initiated as soon as possible. 2) In arid areas , semi-arid areas, and areas experiencing droughts where the initiation stabilization measures by the 14th day after construction activity has temporarily or permanently ceased is precluded by seasonal arid conditions, stabilization measures shall be initiated as soon as practicable.
Vermont	217,800					
Virginia	217,800		3,600 cubic feet per acre		Y	Sediment basins required for sites of 10 acres or more (except those with final stabilization); for sites <10 acres, same units required but only for sideslope and downslope boundaries of construction sites.
Washington (WA), Large Parcel	>43,560		24 hour / 6 month	2 days between October 1 and April 30 (i.e., the wet season); 7 days between May 1 to September 30 (dry season)		

Geographic Area Name	Disturbed Area Limit for Permet Coverage (feet^2)	Numeric Standard or Pollutant Reduction Requirement	Minimum Depth of Runoff or Storm Return Frequency to Treat for Water Quality Management (per acre)	Maximum Allowed Denuded Acreage or Soil Stabilization Requirement	Visual Inspection Frequency	Notes
Washington (WA), Small Parcel	<43,560		24 hour / 6 month	2 days between October 1 and April 30 (i.e., the wet season); 7 days between May 1 to September 30 (dry season)		
West Virginia	130,680		2 year		Y	
Wisconsin	"217800				Y	
Wyoming (WY)	217,800	Turbidity <10-15 NTU			Inspect every 7 days, except during seasonal shutdowns and during the period following completion of construction but prior to return of the site to "finally stabilized" conditions and termination of coverage, then the site must be inspected every quarter.	

Chapter 2: Selection of Controls and Site Planning

Contents

Introduction

This chapter presents examples of available guidance for selecting erosion controls for construction sites. There are many manuals available for throughout the US; some have been in use for more than 25 years. The 2018 update of the Alabama Handbook is periodically used in this chapter as sidebars to illustrate example guidance for the different stormwater practices (ASWCCC 2014). The 2018 version of the Alabama handbook is available at: https://alconservationdistricts.gov/resources/erosion-and-sediment-control/.

This chapter describes and details the major construction site erosion and sediment control categories. In addition, steps are provided to guide a user in preparing an erosion control plan for local construction sites. Later chapters discuss how local rains, soils, and objectives need to be considered when designing the selected controls for site specific conditions.

Table 2-1 lists the erosion and sediment control tools contained in 95 recent US and international construction site erosion and sediment control manuals, as shown in Appendix B, listed in order of occurrence, illustrating the wide range of erosion and sediment controls being used.

Table 2-1. Most Common Erosion and Sediment Controls in Guidance Manuals

Erosion and Sediment Control Tool	**included in % of 95 reviewed US and international manuals**
Erosion Control Blanket/Geotextiles	97
Silt Fence	96
Temporary seeding	92
Mulching	91
Sediment Basin/Trap	91
Diversion/Berm	83
Check Dam	83
Permanent Seeding	81
Construction Entrance/Exit	77
Temporary Slope Drain	75
Block and Gravel Inlet Protection	73
Grass Swale	71
Riprap-lined Swale	68
Rock Outlet Protection	67
Surface Roughening	64
Sediment Barrier	64
Fabric Drop Inlet Protection	63
Lined Swale	54
Sodding	52
Temporary Stream Crossing	52
Preserving Natural Vegetation	51
Topsoiling	49
Straw Wattles	45
Excavated Drop Inlet Protection	41
Groundcover Planting	39
Brush/Fabric Barrier	39
Vegetated Buffer Strips	39
Rock Filter Dam	37
Land Grading	33

Floating Turbidity Barrier	31
Level Spreader	31
Compost Socks and Berms	29
Gravel and Mesh Wire Inlet Protection	28
Subsurface Drain	27
Filter Strip	25
Soil Binders	23
Sod Drop Inlet Protection	21
Tree Planting	20
Chemical Stabilization (PAM) land application	19
Chemical Stabilization (PAM) water application	19
Drop Structure	9
Straw Bale Sediment Trap (at one time these were very common, but most areas no longer allow straw bale use)	7
Rock Flume	3
Treatment/Coagulation Unit	1

Construction Activities

As noted in Chapter 1, there are many different types of construction activities and each of these require different approaches for site development. These different site characteristics and types of activities, such as rainfall patterns and amounts, winter working conditions, local topography, soil type (and cutting and filling operations and importing non-native soils), varying land cover, shallow and seasonal groundwater conditions, run-on drainage and access points from off-site areas, result in a complex matrix of challenges for the design of the project and associated sediment and erosion controls.

Steep Slopes on a project site must be stable for erosion and sediment control practices to function properly. The slopes should be investigated for their soil properties including geotechnical stability, and associated factors such as gradation and plasticity as well as their overall stratigraphy and the identification of seepage planes. The angle of the slope can play a major role in freeze/thaw relationships and moisture retention that is critical for successful establishment of vegetative cover. The length and steepness of the slope and potential surface water run-on must be considered and managed to prevent surface rill erosion and slope slump failures.

Surface run-on from off-site areas can be channelized using diversions located above the top of the slope cut, intercepting the flow and directing it to stable outlets. Longer slopes can be benched in a manner to collect sheetflows from the slope itself and carry it off the slope. Persistent internal seepage may require subsurface drains to capture the water in the slope and provide appropriate safe outlets. In some cases, blanket drains, designed on the slope's surface, may be required for larger seepage areas.

Steep slopes adjacent to water environments usually require toe revetment to prevent erosion, scour, and undermining that leads to bank failures. This is often provided in the form of rock riprap, sometimes supplemented with biotechnical plant materials. In other situations, toe revetments can be in the form of structural components such as bin walls, cribs, gabions and cast in place retaining walls. These methods are more appropriate for stabilization on sites that are constrained and to reduce slope steepness above the structure. These structures can also be supplemented with plant materials.

Linear Projects, such as pipelines or freeways, are challenging because they intersect multiple drainage ways and natural resource areas along their course. In order to complete the construction at optimum cost, excavation and fill materials must be moved along the corridor to minimize waste or offsite borrow. Often, the rights-of-way established for these projects are narrow, limiting the staging and work area and equipment options and methods. Dewatering the work areas require more discharge locations due to the topographic changes and creative approaches are needed for providing stable outlets within the construction limits.

In so far as practicable, the phasing of linear construction projects should be done to balance cut and fill areas over the shortest distances possible to minimize exposed soil areas and their erosion risk. Temporary soil stabilization should be applied as the work progresses. Surface water management for highway work often includes lined swales, diversions, stone check dams, pipe slope drains, and rock outlet protection for culverts. Practices on pipeline projects often incorporate water bars closely spaced with stone weeper outlets on steep, narrow rights-of-way. Trench dewatering is accomplished by sandbag dams in the trench at intervals dependent on the slope of the trench, from which the turbid water is pumped into temporary sediment traps or filter bags. In order to prevent the dewatering of wetlands that pipelines cross, impermeable trench plugs are used on the low side of the wetland areas.

Streambank Stabilization and Stream Restoration projects are directly connected to the natural resources that are to be protected. Projects along the stream systems generally dewater each phase of the work by diverting the existing stream flow away from the construction area into an old channel (if one exists) or a constructed by-pass channel. If the site is constrained, berms are often constructed to flume the stream flow through one side of the work area. Turbid water from work areas is often pumped to sediment traps or dewatering bags located away from the stream. These devices generally outlet to vegetated buffers. The size of the stream's drainage area and the floodway width at the worksite are critical considerations to the dewatering scheme.

Shoreline Stabilization projects generally rely on turbidity curtains placed offshore close to the work area to contain turbid water created by construction disturbance. Other barriers that have been used for the same purpose are manufactured water structures and structural barriers with geotextiles attached. These elements are moved linearly along the shoreline from one phase to the next as stabilization is completed above the high-water elevation in each phase. It is important to remove or armor any sediment trapped between the shoreline and the curtain: failure to do so will often allow the trapped sediment to move downstream after the curtain is removed.

Dam Embankment construction to create ponds, lakes, water supply reservoirs, wet and dry stormwater basins and flood control projects, all begin below the original ground line at the low point of the drainage area. It is necessary to construct a cutoff trench along the centerline of the structure to prevent water from moving through the foundation or abutments. Such flow could create a breach failure of the dam. The depth and width of the cutoff trench depends on the geology of the foundation area of the dam. To begin construction of the cutoff trench, the stream flow is diverted to one side of the floodplain, so it by-passes the entire foundation footprint of the dam. Then the cutoff trench is excavated and backfilled on one side of the floodplain for enough length so that the service spillway system (the conduit, riser, and reservoir drain,) can be built in one operation. After that is completed, the stream flow is then re-directed through the service spillway system of the dam and the cutoff trench is completed in the remaining section of the flood plain.

Surface water management during dam construction usually includes diversions and swales around disturbed areas to keep the clean water from becoming turbid and out of the work area. Interior swales direct turbid water to sediment traps and ponds, while silt fences, placed on the contour, impound turbid runoff from earth fill slopes. Soil stabilization with seeding and mulch should be accomplished as soon as surfaces are graded. Temporary surface protection may be necessary if soils will be left exposed for periods of a week or more. Site management considerations include waste disposal from clearing and grubbing operations, adequate staging areas for equipment and material stockpiles, stabilized access points, and offsite drainage discharges.

Commercial Development is generally more localized and located in urban and semi-urban areas. Staging areas, access points, and stormwater runoff are major considerations in preparing a SWPPP for these enterprises. Often, these sites are totally disturbed and the sequencing of operations for the construction activities and overall site management become the keys for a successful project. Construction runoff techniques employed on these sites are similar to other types of construction but are likely to be confined to pipe segments and the drainage infrastructure. Portable sediment traps are often used for dewatering discharges from pumps, and concrete truck washout facilities are utilized to contain this hazardous material for proper disposal. Frequent inspections with responsive, timely maintenance help ensure SWPPP compliance for these sites.

Residential Development can disturb tracts of land that vary from single lot to large sub-divisions of many hundreds of acres. The rate at which larger projects develop is a function of the economic growth of a region. However, even in the best of times, these projects are usually completed in multiple phases extending over many years. Often a developer will complete construction of the basic infrastructure in one phase of the development. This is usually the main entrance and the first loop roads, utilities, and the storm drainage system including a stormwater detention basin. This may also include overall grading of the complete area to achieve the design configuration. Building lots can then be sold in this phase to speculation builders or prospective homeowners. Piecemeal home building on individual lots can create water quality problems due to lack of attention by those working on a lot site to maintain a resource protection system. This is why, generally, the overall developer must prepare and maintain the SWPPP for the entire development project. This SWPPP usually contains the post-construction stormwater controls for water quality and quantity, as well as the overall project’s erosion and sediment control plan for construction activities, including the erosion and sediment control details for the individual lots.

Stormwater ponds are usually constructed early in the project and used as sediment ponds during construction. Grass buffer strips are usually employed along the newly constructed roads to reduce sediment discharging to the road drain inlets. All graded areas and stockpiles of topsoil are usually stabilized with a perennial rye grass. It is common to see silt fence, stone construction entrances, drainage swales with stone check dams, topsoil stockpiles, and sediment traps for this type of construction. Concrete truck washout facilities are more prevalent in residential construction SWPPPs to prevent haphazard washout in road ditches or catchbasins. It is again, very important that frequent inspections be conducted to ensure on-lot activities are being installed in accordance with the overall project SWPPP.

Example Construction Site Control Requirements

Construction site control requirements can be divided into two major categories as described in Chapter 1: primary controls and supporting controls. It is also possible to categorize the controls into preventative measures (much preferred), usually termed erosion control practices, and treatment measures (typically not as effective), usually termed sediment controls. The requirement categories are summarized in the following sections, along with a list of example controls that can be used to help meet each requirement. This list indicates the range of available tools to address these issues, but emerging controls are continuously being developed and marketed.

Primary Construction Site Control Requirements

The following discussion lists available construction site controls that can be applied to different categories of site issues. These practices are organized by the different site issues that should be addressed for all construction sites. Each category should be addressed for all construction sites, but the specific controls to be selected must be based on site-specific conditions. Chapters 3 through 6 address techniques and tools that can be used to select and design these controls for specific site conditions.

Minimize Upslope Water Contributions.

Upslope water must be diverted around disturbed areas, and existing large channels passing through the site must be protected from erosion runoff. These controls must be installed before any other site disturbance in order to minimize the amount of water flowing across disturbed areas, contributing to site erosion and placing a greater burden on sediment control practices. These controls are all preventative erosion control practices.

Large diversion berm and swale to divert water from downslope area at an abandoned mine site (SCS photo).

Temporary slope diversion at highway construction site.

Highway slope diversion during initial construction.

This photo of U.S. Route 1 being relocated around Dover, Delaware shows pipe slope drains that carry sediment laden runoff downslope to a collector swale. Note that the side slopes are graded and seeded as the work progresses to keep soil from washing down.

Large slope diversions carrying water from upslope benches (IECA photo).

Figure 2-1. Slope Diversions

Flow diversion practices include:

General Diversion Structures:

- Diversions
- Level spreaders

Temporary Diversion Structures:

- Temporary diversion
- Temporary diversion dike
- Temporary fill diversion
- Temporary right-of-way diversion

Permanent Diversion Structures:
- Permanent diversion

General Channel Stabilization:
- Permanent channel stabilization
- Structural streambank stabilization
- Rock and concrete lined waterways
- Channel stabilization
- Lined waterway
- Channel stabilization
- Gabion

Check Dams:
- Check dams
- Temporary sediment trap
- Sediment traps

Riprap:
- Riprap

Waterway Drops:
- Grade stabilization structure
- Waterway drop structure
- Drop structure
- Gabion

Stream Crossing:
- Temporary stream crossing
- Stream crossing

Grassed Waterways:
- Vegetative streambank stabilization
- Grassed waterways
- Sodding
- Geotextile reinforced grassed waterway
- Waterway or stormwater channels

Slope Protection:
- Slope protection strictures
- Temporary slope drain
- Paved flume
- Retaining wall
- Down drain structure
- Gabion

Provide Downslope Controls

In general, wet detention (sediment) ponds are required to treat all runoff leaving construction sites for drainage areas greater than about 10 acres. If the drainage area is less than 10 acres, then silt fences, smaller sediment traps, or equivalent perimeter sediment controls, may need to be used at all side slope and downslope edges of the construction site, depending on the site hydraulics. These controls must also be installed before any other site disturbance. These controls are all treatment, or sediment control, practices, as they are intended to remove sediment from the flowing water before it leaves the construction site. Erosion control (prevention) practices must always be emphasized, but sediment controls will always be needed as it will not be possible to prevent all erosion from occurring.

Figure 2-2. Downslope side of perimeter wire-backed silt fence intercepting sheetflows.

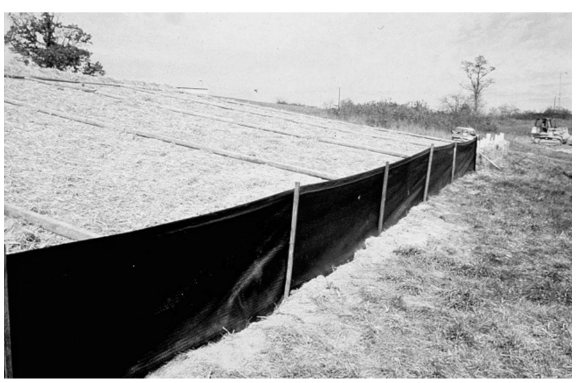


Figure 2-3. Silt fence on mulched slope (SCS photo).


Figure 2-4. Sediment pond at landfill

Sediment control practices include:

General Sediment Fence:

- Sediment barrier
- Retrofitting

Silt Fences:

- Silt fence
- Filter fabric fences
- Filter fabric barriers
- Temporary right-of-way diversion
- Sediment barrier/fence

Sediment Basins:

- Temporary sediment basin
- Sediment basins
- Sediment traps
- Storm water retention structure

Outlet Protection:

- Outlet protection
- Riprap discharge aprons
- Small silting basins

Inlet Protection:

- Silt fence covers over inlet grates
- Wood framed silt fabric barriers around intake structures
- Filter bags placed inside inlets

Protect Disturbed Areas

Disturbed areas exposed for extended periods (14 days is a typical limit, see Chapter 3 for discussion of risks associated with different rains) without any activity must be stabilized with mulches, temporary vegetation, permanent vegetation, turf reinforcing mats, or by other equivalent control measures. These controls would all be considered preventative, or erosion control, practices, and are usually considered the most effective, especially when used in conjunction with a good phasing plan to minimize the amount of land being disturbed at any one time.

Figure 2-5. Large expanses of unprotected soils left exposed for long periods cause most of the sediment losses from construction sites.

Figure 2-6. Various slope protection treatments and tree conservation

Erosion control practices include:

Mulching:

- Mulching
- Stabilization with mulch only
- Guide to mulching materials
- Turf reinforcing mats
- Chemical spray-on stabilization

Local Vegetation Information:

- Vegetative controls to protect exposed surfaces
- Lime and fertilizer requirements for plant growth
- Planting guide

- Selection of vegetation
- Native vegetation for deep-rooted stabilization
- Information on installing vegetative measures

General Seeding:
- Surface roughening
- Surface treatment for an even and loose seed bed
- Topsoiling
- Seeding

Temporary Seeding:
- Temporary seeding
- Temporary vegetative cover for soil stabilization
- Temporary vegetation-seeding

Permanent Seeding:
- Permanent seeding
- Permanent vegetative cover for soil stabilization

Sodding:
- Sodding
- Permanent stabilization with sod

Trees and Shrubs:
- Trees, shrubs, vines, and ground covers

Maintenance of Vegetation:
- Maintaining vegetation
- Tree preservation and protection
- Tree protection during construction
- Irrigation

Supporting Construction Site Control Requirements
A number of construction site controls are also typically specified in local ordinances. The following are examples of some of these controls, some of which are preventative (represented by the "good-housekeeping" controls) while others are treatment (such as inlet filters) practices. Erosion control manuals contain descriptions of many "structural" practices that can be used on construction sites to prevent erosion, or to capture sediment that has already eroded. The most basic controls that should be considered include: short durations for open and disturbed areas, temporary and permanent seed and mulch, construction site exits, stormdrain inlet protection, use of riprap, check dams in channels, and protection of pond outlets. Jurisdictions have commonly developed local lists of mandatory and recommended controls. These handbooks are periodically revised, and local regulatory agencies and/or the local USDA extension offices should be consulted for updated recommendations. The erosion and sediment control benefits of most of these controls have not been measured in the field, but these controls are generally acknowledged as essential elements of construction site erosion control programs.

Control Wastewater from Dewatering Operations
Wastewater from site dewatering operations should be controlled to limit the discharge of sediment. Typical criterion restricts particles greater than 50 μm, or turbidity levels greater than 100 NTU, from being discharged during dewatering operations. This level of control can be obtained by using simple sedimentation devices sized according to the maximum dewatering pumping rates. Chemical-enhanced settling can provide even greater control for small structures.

- Dewatering settling basin
- Dewatering sediment basin

Properly Dispose of Construction Debris
All building material and other wastes need to be removed from the site and disposed of in licensed disposal facilities. No wastes or unused building materials may be buried, dumped, or discharged at construction sites.

Figure 2-7. Unsafe storage disposal of empty oil containers at construction site.

Control Tracking of Sediment Off-Site
Each site needs to have rocked tracking pads for site access and graveled parking areas to reduce the tracking of sediment onto public or private roads. An example regulation would require that all unpaved roads on the site carrying more than 25 vehicles per day also be graveled. Any sediment or debris tracked onto public or private roads needs to be removed daily by street cleaners (and not by washing it down the storm drain system!).

WI DNR photo

Figure 2-8. Proper construction site entrance or graveled driveway can eliminate much tracking of sediment onto public roads.

Figure 2-9. Dust control with water truck (D. Lake photo)

Off-site tracking prevention controls include:

Entrance Controls:
- Temporary rock construction entrance
- Stabilized construction entrance
- Construction exit

Site Road Controls:
- Construction road stabilization
- Temporary graveled access roads and parking areas
- Traffic control
- Construction exit

Dust Control:
- Dust control with water
- Dust control with chemicals

Protect Construction Site Entrances and Exits
The following sidebar discussion is from the most recent *Alabama Handbook* (ASWCC 2018) as an example of the guidance provided by a state agency for the controlling tracking from construction exits.

===

Sidebar: "Construction Exit Pad-CEP
Practice Description
A construction pad is a stone base pad or manufactured product designed to provide a buffer area where mud and caked soil can be removed from the tires of construction vehicles to avoid transporting it onto public roads. This practice applies anywhere traffic will be leaving a construction site and moving directly onto a public road or street.

Planning Considerations
Roads and streets adjacent to construction sites should be kept clean for the general safety and welfare of the public. A construction exit pad (Figure 2-10) should be provided where mud can be removed from construction vehicle tires before they enter a public road.

Where possible the construction exit pad should be located and constructed at a site where surface runoff from the pad will not transport sediment from the pad off the site. If the pad slope toward the road exceeds 2%, a diversion ridge 6" to 8" high with 3:1 side slopes should be constructed across the foundation approximately 15 feet from the entrance. This diversion ridge should divert surface runoff from the pad away from the road and into a sediment trap or basin.

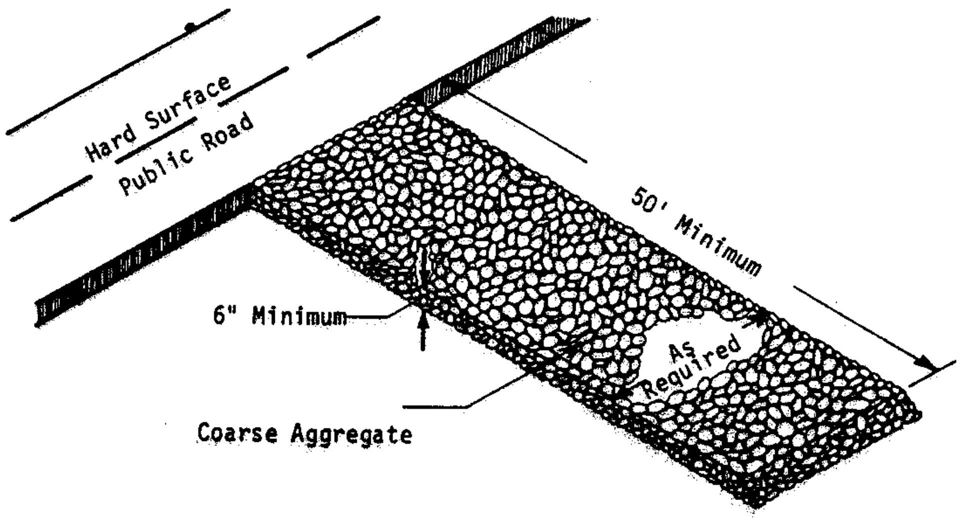


Figure 2-10. Gravel Construction Exit

If the action of the vehicle traveling over the gravel pad does not sufficiently remove the mud or if the site is in a particularly sensitive area, a washing facility should be included with the pad (Figure 2-11). When a washing facility is required all wash water shall be diverted to a sediment trap or basin.
If the construction exit pad is located in an area with soils that will not support traffic when wet, an underliner of geotextile will be required to provide stability to the pad.

Construction of stabilized roads throughout the development site should be considered to lessen the amount of mud transported by vehicular traffic. The construction exit pad should be located to provide for maximum use by construction vehicles.

Consideration should be given to limiting construction vehicles to only one ingress and egress point. Measures may be necessary to make existing traffic use the construction exit pad.

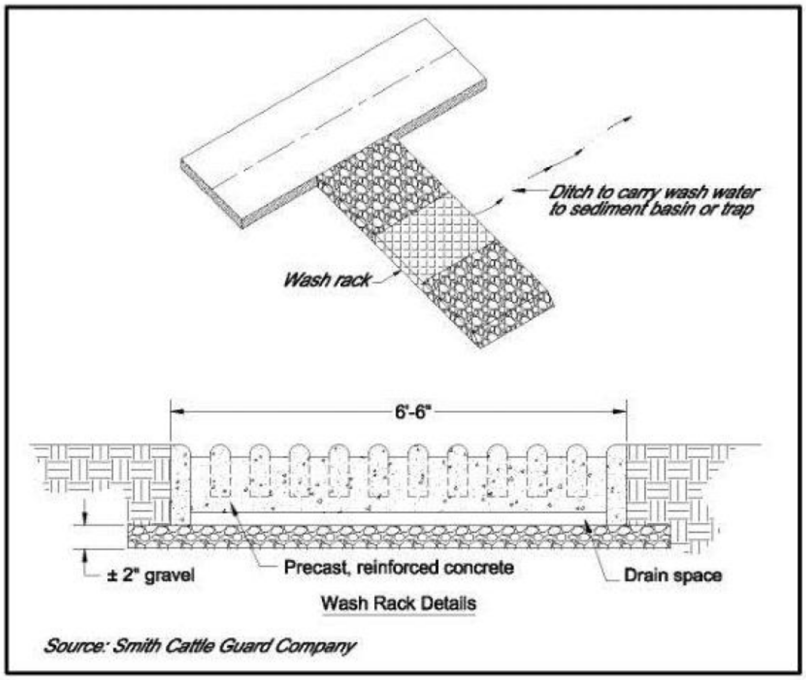


Figure 2-11. Construction Exit with Wash Rack

Design Criteria

Aggregate size

Aggregate should be Alabama Highway Department coarse aggregate gradation No.1.

Pad Thickness

The exit pad shall have a minimum aggregate thickness of 6".

Geotextiles

A non-woven geotextile shall be placed underneath the aggregate. The geotextile shall be of the strength and durability required for the project to ensure the aggregate and soil base are stable. Generally, the non-woven geotextile should meet the requirements for a Class 2 geotextile used for separation that is found in the current version of AASHTO M288.

Pad Length

The exit pad should provide for entering and parking the longest anticipated construction vehicles. A pad is typically 50 feet long but the required length may be longer or shorter.

Pad Width

The exit pad width is typically 20 feet but may be narrower or wider to equal the full width of the vehicular egress.

Washing

A washing facility shall be provided if necessary to prevent mud and caked soil from being transported to public streets and highways. It shall be constructed of concrete, stone, and/or other durable materials. Provisions shall be provided for the mud and other material to be carried away from the

washing facility to a sediment trap or basin to allow for settlement of the sediment from the runoff before it is released from the site."
===

Concrete truck washout basin (E. Hahn photo)

Truck washing system (D. Lake photo)

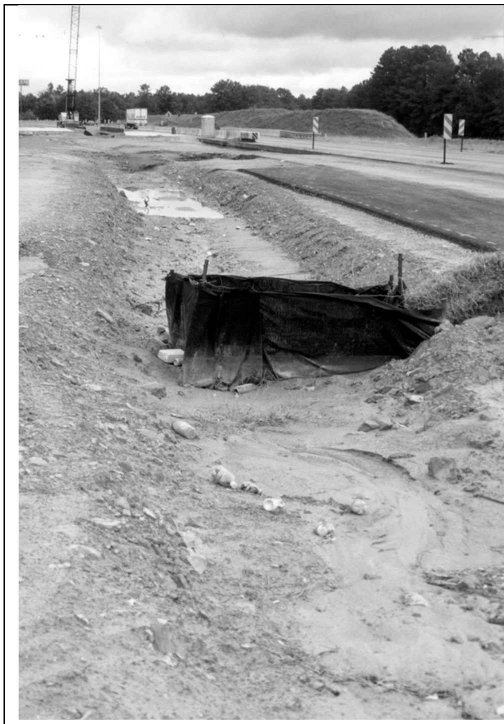
Figure 2-12. Truck washing facilities.

Protect Storm Drain Inlets
All storm drain inlets need to be protected from erosion materials.

Figure 2-13. Inlet barriers (E. Hahn photos)

Figure 2-14. Cinder block and gravel barrier to protect inlet (SCS photo)

Figure 2-15. Proprietary filter fabric storm drain inlet covers



Typical filter fabric enclosure surrounding inlet (J. Voorhees photo).

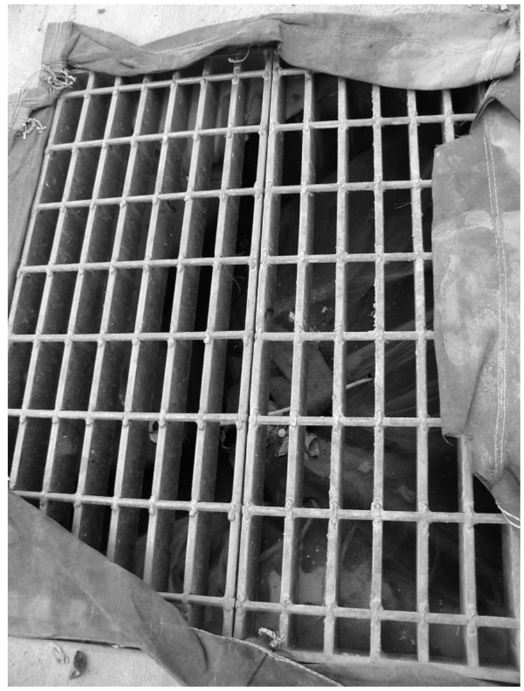
Inlet protected by filter fabric, thick matting to protect new grass, and chemically stabilized soil (Illinois).

Large accumulation of debris surrounding filter fabric inlet barrier, requiring maintenance.

Typical reinforced filter fabric barrier surrounding elevated inlet.

 Older concrete block, lumber, and stone inlet barrier (historical SCS photo).	 Older concrete block, lumber, and stone inlet barrier (historical SCS photo).
 Older concrete block and stone inlet barrier (historical SCS photo).	 Netted stone barrier to attempt to divert bypassing gutter flows into inlet.
 Typical straw bale barrier surrounding inlet (notice tight bales and large amount of sediment collected around outside of bales, needing removal). Most agencies no longer allow the use of straw bale barriers.	 Straw bale barrier showing large gaps between bales and decomposing bales, needing replacement (SCS photo). Most agencies no longer allow the use of straw bale barriers.

Temporary inlet filter fabric bag placed under inlet at redevelopment construction site.



Temporary inlet filter fabric bag placed under inlet at redevelopment construction site.

Figure 2-16. Inlet protection devices.

Inlet protection controls include:

- Storm drain inlet protection
- Inlet protection barriers
- Storm sewer inlet protection
- Inlet insert baskets
- Inlet protection

There have been many types of inlet barriers used over the years, with poor to moderate success. Most have suffered from lack of proper maintenance or poor construction.

Perez, *et al.* (2015) developed protocols and examined inlet protection practices under controlled large-scale tests at the Auburn University Erosion and Sediment Control Testing Facility in Alabama. This 0.9 ha facility was developed for testing, evaluating, and improving erosion and sediment control practices and products typically used on highway construction projects. A wattle barrier inlet protection practice was installed according to ALDOT standards. During the tests, measured parameters indicating performance included erosion losses around the barrier, deposition outside and inside the barrier ring, ponding depth and duration, flows, turbidity, and TSS levels. The erosion and deposition volumes were measured using a Trimble S6 Robotic Total Station. The ALDOT standard installation resulted in about a

70% capture of total solids behind the barrier, while an enhanced barrier retained about 85% of the total solids.

The following sidebar discussion is from the current *Alabama Handbook* (ASWCC 2018) and is an example of the guidance provided by a state agency for the protection of stormdrain inlets. The main change in recent manual revisions removes the use of straw bales as a recommended erosion control.

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Sidebar: "Inlet Protection (IP)

Practice Description

Inlet protection is a structurally supported barrier placed around a stormwater drop inlet to create ponding which allows coarse sediment to be deposited in the pooled area. The practice does not decrease turbidity. This practice applies where early use of the storm drain system is necessary prior to stabilization of the disturbed drainage area. This practice is suitable for inlets with a drainage area of less than 1 acre. Gentler approach slopes provide for more storage. If used at a storm drain for a road, the practice could cause hazardous conditions to motorists due to ponding and should only be used when there is no public transportation allowed or when the height of ponded water is not a hazard.

Planning Considerations

Storm sewers which are made operational before their drainage area is stabilized can convey large amounts of sediment to natural drainage ways. In case of extreme sediment loading, the storm sewer itself may clog and lose a major portion of its capacity. To avoid these problems, it is necessary to prevent sediment from entering the system at the inlets which may discharge directly to waters of the State.

The best way to prevent sediment from entering the storm sewer system is to stabilize the site as quickly as possible, preventing erosion and stopping sediment at its source. Sediment is best treated by preventing erosion. Leave as much of the site undisturbed as possible in the total site plan by phasing construction. Clear and disturb the site in small increments, if possible.

Numerous products have been developed to facilitate the capture of suspended soil particles at inlets. The Design Criteria for performance should be considered when evaluating alternative products. Products that will likely not meet performance goals or that usually fail under storm conditions should not be selected.

Recommended installation procedures of the Auburn University Erosion and Sediment Control Test Facility (AU-ESCTF) should be followed to insure the inlet protection practice is to be most successful. The Alabama Department of Transportation has developed drawings and specifications for many of these type installations.

Silt Fence Inlet Protection

As a minimum, incorporate the following into a silt fence inlet protection practice at a stormwater drop inlet:

• Use geotextile (8 oz. non-woven) as an underlayment on the compacted earth surface from the inlet to at least 1 ft. beyond the silt fence. The geotextile must be securely pinned at 5-inch centers at the inlet and around the outside edge of the geotextile.

• Use steel T-posts on maximum 3 ft. centers around the inlet.

• Do not trench the silt fence. Install the wire backing tightly from the compacted earth surface to the top of the posts, and secure to the posts.

• Add 2 x 4 bracing at the top of the posts and diagonally across the corners. Drill holes to fit over T-posts once T-posts are installed to ensure a proper fit.

• Install a dewatering device to remove water from the impoundment within 48 hours. A 2 x 4 vertical board with graduated holes (smallest a bottom and largest at top) has been found to work well. The fabric should be secured to the board with staples and the geotextile punctured at each hole.

• Install the geotextile (4 oz. non-woven) Type A silt fence. The top of the geotextile shall be folded over the 2 x 4 bracing and stapled. The bottom of the geotextile shall extend about 8 inches horizontally from the bottom of the fence and secured with pins every 5 inches. The bottom of the fabric at the corners shall be cut and pinned securely to prevent water undermining. Attach the geotextile to the wire as normally done for a silt fence.

Block and Gravel Inlet Protection

As a minimum, incorporate the following into a block and gravel inlet protection practice at a stormwater drop inlet:

• Use geotextile (8 oz. non-woven) as an underlayment on the compacted earth surface that extends from the inlet, under the blocks and at least 1 ft. beyond the blocks, and securely pinned at 5 inches centers at the inlet and around the outside edge of the geotextile. A second underlay that extends from the inlet, under the blocks, and to the top of the blocks between the blocks and gravel. Note: place geotextile vertically on the blocks surface after blocks and hardware cloth are installed.

• Use 8-inch cinder blocks no more than two blocks high. Stacked the second layer of blocks in a staggered fashion. All blocks are placed in a normal orientation with at least one block turned sideways for dewatering.

• The dewatering block(s) shall be at the lowest elevation, faced with hardware cloth, and the geotextile cut out in a three-inch-tall rectangular section for dewatering.

• Place aggregate (ALDOT no. 4 stone) in a triangular cross-section to the top of the blocks with the aggregate extending out 1 ft. at the top from the blocks before sloping down at a 1:1 ft./ft. slope.

Sand Bag Inlet Protection

As a minimum, incorporate the following into a sand bag inlet protection practice at a stormwater drop inlet:

• Use geotextile (8 oz. non-woven) as an underlayment on the compacted earth surface that extends from the inlet to at least 1 ft. beyond the sand bags. Pin the geotextile securely at the inlet and around the edges on 5-inch centers.

• Place sand bags tight against each other around an inlet in a circular fashion with at least a 1 ft. space between the bags and the inlet.

• Orient the three layers of bags into a triangular cross-section with the first layer consisting of two bags oriented tangent to the circle, the second layer consisting of one bag perpendicular to the circle, and the third layer consisting of one bag tangent to the circle.

Wattle Inlet Protection
As a minimum, incorporate the following into a wattle inlet protection practice at a stormwater drop inlet:

• Use geotextile (8 oz. non-woven) as an underlayment on the compacted earth surface that extends from the inlet to at least 1 ft. beyond the wattles. Pin the geotextile securely at the inlet and around the edges on 5-inch centers.

• Use a wattle that is denser and less porous to ensure ponding occurs.

• Place the wattle in a circular fashion at least 1 ft. from the inlet. Wattle ends should be overlapped at least 18 inches and secured with grade stakes or hardwood stakes a T-Pee or A-Frame type installation method.

• Stake the wattles with T-Pee stakes at least 2 ft. on centers.

• Prevent the wattles from floating by securing with sod staples on each side of the wattle on 10-inch centers.

Manufactured Inlet Protection
As a minimum, insure that the manufactured inlet protection device accomplishes the following:

• Is structurally supported to withstand sediment and hydrostatic loads.

• Ponds water to allow for coarse sediment to settle out of suspension.

• Does not float or undermine.

• Does not cause erosion of the soil surface between the device and the inlet.

• Has a dewatering mechanism to prevent prolonged flooding.

Design Criteria

Drainage Area
Drainage area should be less than 1 acre per inlet.

Height
The height of the inlet protection device should be at least 1 foot but no more than 2.5 foot. Ensure the height of the structure when fully ponded does not cause unintentional damage or hazards to adjacent areas.

Approach
A gentle approach to the inlet protection provides more storage.

Sediment Storage

Maximizing storage increases ponding and sediment deposition. Whenever possible, either through structure height and/or excavated storage, provide 67 cubic yards per disturbed acre for sediment storage. This will provide sediment storage for ½ inch runoff from the disturbed area. For example, if the disturbed area is 0.3 acre, provide 20 cubic yards of storage (0.3 X 67 = 20).

Structural Frame
The inlet protection device should be designed to withstand sediment and hydrostatic loads without failure due to buckling, fabric sagging, or undermining.

Performance
The inlet protection device should be designed to trap most of the coarse sediment. Turbidity is not controlled by the inlet protection practice. The system of protection for the project must be designed to meet the NTU requirements for discharge.

Maintenance
When sediment has accumulated to ½ the height of the structure, it should be removed and disposed of properly.

Safety
Protection should be provided to prevent children from entering open-top structures. Do not use the practice if it ponds water on roads used by motorist."
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Minimize Area Disturbed
One of the most effective erosion controls would require that all construction activities be conducted in a logical sequence that minimizes the area of bare soil disturbed at any one time, and their exposures be for short durations.

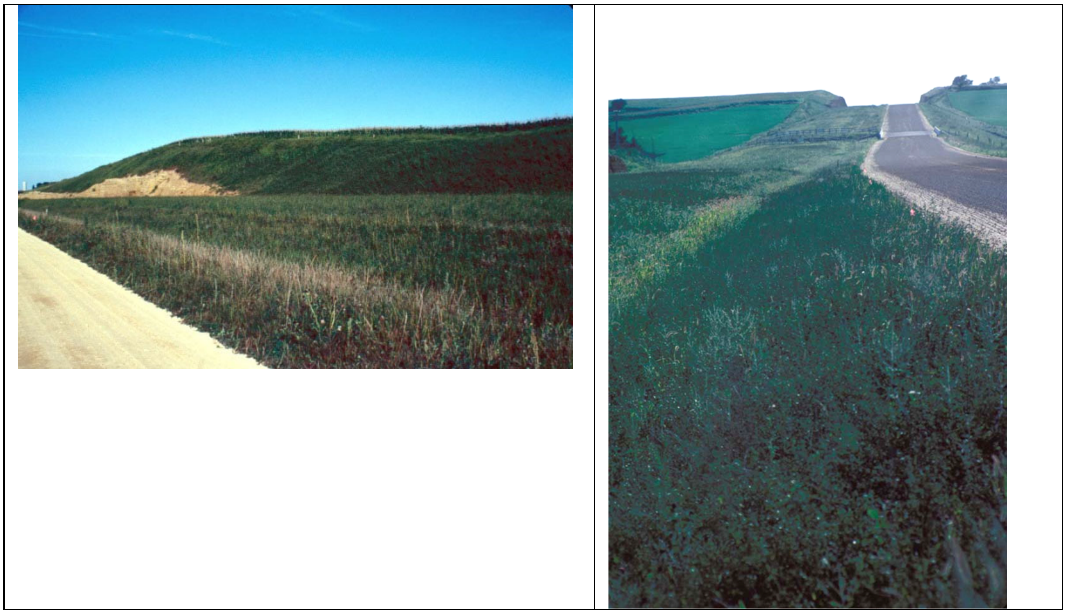


Figure 2-17. Highway construction being conducted in phases with permanent vegetative cover to protect future work area.

Control Erosion Scour from Roof Runoff
Roof runoff must be directed to stabilized surfaces.

Figure 2-18. Small-scale slope diversion to safely carry roof runoff away from building and down sensitive adjacent slope.

Control Erosion from Storage Piles
All uncovered soil or dirt storage piles also need to be controlled to prevent erosion. An example regulation may contain the following restrictions.

> An uncovered storage pile, containing more than 10 cubic yards of material, should be located more than 25 feet from a roadway or drainage channel. If these piles remain for 14 or more days, then their surfaces must be stabilized. If the piles will be in place for less than 14 days, then their perimeters must be surrounded by filter fencing or other appropriate barriers. Dirt or soil storage piles located less than 25 feet from the road, containing more than 10 cubic yards of material, and in place for 14 or more days must be covered with tarps or other control. If the piles will be in place for less than 14 days, then their perimeters must be surrounded by filter fencing or other appropriate barriers. Storm drain inlets must be protected from potential erosion from near-street storage piles by filter fencing or other appropriate barriers.

Many of the above practices may be applicable for erosion control of storage piles, such as filter fabric fences for perimeter protection, plus temporary mulching and seeding practices to reduce direct erosion of material from the storage piles.

Figure 2-19. Soil stockpile next to road needing protection

Planning Steps and Components for Construction Site Erosion and Sediment Control

Construction sites are estimated to comprise about 84,500 acres of the Chesapeake Bay watershed and deliver about 16% of the total annual sediment load to the Bay. An expert panel was convened by the Chesapeake Research Consortium and Chesapeake Stormwater Network to review the regional erosion and sediment control programs (Clark, *et al.* 2014). They organized these programs into four levels, as shown in Table 2-2.

Table 2-2. Four Levels of Erosion and Sediment Control by Chesapeake Research Consortium and Chesapeake Stormwater Network (Clark, *et al.* 2014)

Practices	Level 1 ESC	Level 2 ESC	Level 3 ESC
Protect Natural Resources	Locate natural areas and mark LOD (up to edge of natural area)	Do #1 and add buffers to LOD to prevent discharge to natural area	Do # 2, and provide enhanced perimeter controls at LOD boundary for sensitive areas
Minimize Disturbance	No numeric construction phasing requirement	Construction phasing required for largest projects (e.g., 25 + acres)	Construction phasing required for smaller projects
Stabilize Soils	Stabilize w/in 14 to 21 days	Stabilize w/in 7 -14 days	Stabilize w/in a week
Internal Drainage	Temporary swales	Swales/diversions with check-dams and erosion control blankets	Do #2, but enhance with passive use of polymer (e.g., floc logs or wattles)
Perimeter Controls	Standard Controls (e.g., hay bales, entrance stabilization)	Reinforced silt fence and berms/diversions	Enhanced perimeter controls (i.e., super silt fence, compost logs, and filtering practices).
Sediment Traps and Basins	Sediment traps, filters, and basins that meet the 0.5" (1,800 cu.ft/acre) standard	Sediment basins that meet the 1.0" (3,600 cu.ft/ac) standard, with permanent pools and/or dewatering control devices (e.g., skimmers)	Do # 2, but enhance performance with passive use of chemical additives to improve settling, filtration and surface outlets
Inspections	Monthly	Every 1 to 3 weeks	Inspections once every seven days and after each precipitation event > 1.0"
Level 4 ESC	Do Level 3 and employ active chemical treatment system (ATS) with fully automated pumps, controls, settling tanks, and sand filters that are specifically designed to achieve low numeric turbidity effluent concentrations for construction site discharge		

These ESC program levels are described below (Clark, *et al.* 2014):

"Level 1 ESC: Includes practices implemented under historical performance standards from approximately 2000, or before. The sediment trapping requirements were typically based on storage volumes of 1,800 cubic feet/acre, stabilization requirement were less rapid, and inspections occurred less frequently, among other factors. At one point, all of the Bay states operated at this performance level; none of them are doing so now.

Level 2 ESC: This level of performance reflects the more stringent ESC requirements that have been adopted by local and state governments in the Chesapeake Bay watershed over the last several years, and generally conform to the standard requirements in EPA's 2012 Construction General Permit. These include a greater sediment treatment capacity (typically 3,600 cf/ac), surface outlets, more rapid vegetative cover for temporary and permanent stabilization, and improved design specifications for individual ESC practices to enhance sediment trapping or removal. In addition, many states now have construction phasing requirements for larger sites and all require more frequent self-inspections and regulatory inspections. As of the 2014 report, all Chesapeake Bay states are operating at this level of performance.

Level 3 ESC: This level of performance reflects the gradual shift in several Chesapeake Bay states to improve performance by expanded use of passive chemical treatment within Level 2 ESC practices. Chemical treatment involves the passive use of polyacrylamide (PAM) and other flocculants. The treatment relies solely on gravity to dose the sediments in construction site runoff (e.g., adding PAM granules to a check dam, erosion control fabric, or running basin flows across a block or sock containing flocculants). This approach also integrates other design features to enhance the performance of individual practices, such as skimmers, baffles, surface outlets, compost, and stronger geotextiles. Level 3 also involves more frequent inspection and maintenance, and more stringent requirements for phasing and resource protection. While several Chesapeake Bay states are experimenting with some of these techniques, none of them are currently requiring them on a widespread basis. Therefore, no Chesapeake Bay state yet qualifies for Level 3 practice at this time. The Panel outlined quantitative benchmarks for states and localities to achieve a Level 3 of ESC practice as they continue to improve their programs in future years.

Level 4 ESC: The highest level of performance is associated with active treatment systems (ATS) that are employed for turbidity and suspended solids control. The ATS captures and pumps turbid water to a location where PAM or other flocculants can be injected or introduced. ATS are specifically designed to achieve low numeric turbidity effluent concentrations for construction site discharge. A typical ATS is fully automated and includes pumps, controls, settling tanks, and sand filters. Consequently, ATS is very expensive and requires extensive manpower for operation. While some ATS have been tested and refined in California and the Pacific Northwest, they have been rarely applied and never required at construction sites in the Chesapeake Bay watershed. Indeed, several Chesapeake Bay states have been concerned about the possible environmental impacts associated with flocculants on downstream ecosystems, and have been cautious about expanding their use."

Site Preparation and Management

Construction procedures and techniques vary with different types of projects. They are not all built the same way. Projects may be linear in nature such as road and highway construction, utility construction such as power lines and pipelines for sewer, water, gas and oil; or more concentrated such as residential development, commercial and light industrial projects, dam construction for ponds and reservoirs, shoreline protection; and even more varied with streambank protection and stream restoration construction. In addition to the varied types of construction, there are attributes that add difficulty and risk to the projects and can lead to environmental damage to water resources. These can include steep slopes, groundwater seepage flows, unstable soils, constrained construction limits, winter conditions of freezing and thawing and snow management, and surface water running onto work areas, to name a few.

Prior to beginning construction activities on a project, the Contractor should participate in a pre-construction meeting with the design professional and owner to review the erosion and sediment control and water management requirements for the project. The Contractor should understand the timing of the phases for the project and the sequence of operations necessary for each phase.

The Contractor will need to plan and schedule activities to install, inspect, maintain, and remove erosion and sediment control practices as the project landscape changes during construction. Management activities include, but are not limited to, developing a solid waste disposal plan; creating a staging area and site support infrastructure with access, storage and parking; creating a safety program that incorporates spill prevention and response, as well as coordinating maintenance activities to reduce dust and offsite tracking of sediment.

Typical State Guidance for Planning

Most state guidance provides for the incorporation of newly-developed control practices for erosion and sediment control, provided that the new control's performance is known. For example, Pennsylvania provides detailed guidance for the specification and use of controls that are not contained in the Erosion & Sediment Pollution Control Manual. This section of the state manual is quoted below. The interesting point of interest for persons planning to use a novel control practice is the requirement that a conventional control practice of known performance must be specified to be installed if the novel control practice fails (PA DEP 2000).

> **"NEW PRODUCTS AND PROCEDURES**
> The BMPs set forth in this manual shall be appropriately incorporated into all erosion and sedimentation control plans unless the designer shows that alteration of these BMPs or inclusion of other BMPs shall effectively minimize accelerated erosion and sedimentation. Since the burden of proof for whether a proposed new product or procedure will be effective lies with the designer, all necessary information required to approve the use of the new product or procedure must be submitted as part of the application. At a minimum, this should include:
>
> 1. The name of the product (and type of control if a brand name is used)
>
> 2. Proposed use (e.g. storm sewer inlet protection). If this product or procedure has the potential to minimize accelerated erosion and sedimentation more effectively or efficiently than current methods, this should be stated and the reason given (e.g. same protection for less cost, less maintenance required, etc.). It should be demonstrated that the proposed use meets with any manufacturer's recommendations (e.g. manufacturer's recommendations showing such use, test data, limitations, etc.).
>
> 3. Where the proposed use is in a protected watershed (HQ* or EV*) or a critical area (e.g. adjacent to a stream channel or wetland), an alternative conventional BMP should be

specified for installation should the innovative product or procedure fail. The definition of a product failure must be clearly stated.

4. Sufficient installation information must be provided to ensure its proper use. This should include a clear, concise sequence as well as a typical detail showing all critical dimensions and/or elevations.

5. The plan maps must show all locations where the proposed new product or procedure will be used. All receiving waters must be identified. Any downstream public water supplies, fish hatcheries, or other environmentally sensitive facilities must be noted.

6. A suitable maintenance program must be provided. Specific instructions, which identify potential problems and recommended remedies must be included.

New products and procedures which meet the above criteria will be reviewed on a case-by-case basis until their effectiveness has been sufficiently demonstrated by successful use in the field."

*Note: HQ: high quality and EV: exceptional value.

Planning Steps and Components for Construction Site Control

Most construction site control handbooks and design manuals include some information pertaining to the selection of controls needed for construction sites, and guidance on submitting acceptable control plans. As an example, the following discussion lists the minimum standards applicable for all construction sites in Virginia. Also included is planning guidance from the 2018 *Alabama Handbook* for erosion control.

Virginia Erosion and Sediment Control Regulations, Minimum Standards

The following is the list of the 19 "minimum standards" for erosion and sediment control as required in Section 4VAC50-30-40 of the Virginia Erosion and Sediment Control Regulations. This is a typical listing representative of most erosion and sediment control regulations and indicates which controls need to be considered for construction-site activities.

"(1) Soil Stabilization.
Permanent or temporary soil stabilization shall be applied to denuded areas within seven days after final grade is reached on any portion of the site. Temporary soil stabilization shall be applied within seven days to denuded areas that may not be at final grade but will remain dormant for longer than 30 days, but less than one year. Permanent stabilization shall be applied to areas that are to be left dormant for more than one year

(2) Soil Stockpile Stabilization.
During construction, soil stockpiles and borrow areas shall be stabilized or protected with sediment trapping measures. Temporary protection and permanent stabilization shall be applied to all soil stockpiles on site and borrow areas or soil intentionally transferred off site.

(3) Permanent Stabilization.

Permanent vegetative cover shall be established on denuded areas not otherwise permanently stabilized. Permanent vegetation shall not be considered established until a ground cover is achieved that is: uniform, mature enough to survive, and will inhibit erosion.

Thick netting and fiber mulch protection for new grass.

Netting and mulch along with cemented soil for roadside stabilization

Figure 2-20. Permanent stabilization solutions (Illinois roadside).

(4) Sediment Basins & Traps.
Sediment basins, sediment traps, perimeter dikes, sediment barriers, and other measures intended to trap sediment shall be constructed as a first step in any land-disturbing activity and shall be made functional before upslope land disturbance takes place.

(5) Stabilization of Earthen Structures.
Stabilization measures shall be applied to earthen structures such as dams, dikes, and diversions immediately after installation.

(6) Sediment Traps and Sediment Basins.
Sediment traps and basins shall be designed and constructed based upon the total drainage area to be served by the trap or basin as follows:

Sediment Traps: Only control drainage areas less than three acres. Minimum storage capacity of 134 cubic yards per acre of drainage area.

Sediment Basins: Control drainage areas greater than or equal to three acres. Minimum storage capacity of 134 cubic yards per acre of drainage area. The outfall system shall, at a minimum, maintain the structural integrity of the basin during a 25 year storm of 24-hour duration

(7) Cut and Fill Slopes Design and Construction.
Cut and fill slopes shall be designed and constructed in a manner that will minimize erosion. Slopes found to be eroding excessively within one year of permanent stabilization shall be provided with additional slope stabilizing measures until the problem is corrected.

(8) Concentrated Runoff Down Slopes.
Concentrated runoff shall not flow down cut or fill slopes unless contained within an adequate temporary or permanent channel, flume, or slope drain structure.

(9) Slope Maintenance.
Whenever water seeps from a slope face, adequate drainage or other protection shall be provided.

(10) Storm Sewer Inlet Protection.
All storm sewer inlets made operable during construction shall be protected so that sediment-laden water cannot enter the stormwater conveyance system without first being filtered/treated to remove sediment.

(11) Stormwater Conveyance Protection.
Before newly constructed stormwater conveyance channels or pipes are made operational, adequate outlet protection and any required temporary or permanent channel lining shall be installed in both the conveyance channel and the receiving channel.

(12) Work in Live Watercourse.
When work in a live watercourse is performed, precautions shall be taken to minimize encroachment, control sediment transport, and stabilize the work area to the greatest extent possible during construction; non-erodible material shall be used for the construction of causeways and cofferdams; and earthen fill may be used for these structures if armored by non-erodible cover materials.

(13) Crossing Live Watercourse.
When a live watercourse must be crossed by construction vehicles more than twice in any six-month period, a temporary vehicular stream crossing constructed of non-erodible material shall be provided.

(14) Regulation of Watercourse Crossing.
All applicable federal, state and local regulations pertaining to working in or crossing live watercourses shall be met.

(15) Stabilization of Watercourse.
The bed and banks of a watercourse shall be stabilized immediately after work in the watercourse is completed.

(16) Underground Utility Line Installation.
Underground utility lines shall be installed in accordance with the following standards in addition to other applicable criteria: no more than 500 linear feet of trench may be opened at one time; excavated material shall be placed on the uphill side of trenches; effluent from

dewatering operations shall be filtered or passed through an approved sediment trapping device, or both, and discharged in a manner that does not adversely affect flowing streams or off-site property; material used for backfilling trenches shall be properly compacted in order to minimize erosion and promote stabilization; re-stabilization shall be accomplished in accordance with these regulations; and all work shall comply with applicable safety regulations.

(17) Vehicular Sediment Tracking.
Where construction vehicle access routes intersect paved or public roads: provisions shall be made to minimize the transport of sediment by vehicular tracking onto the paved surface; where sediment is transported onto a paved or public road surface, the road surface shall be cleaned thoroughly at the end of each day; and sediment shall be removed from the roads by shoveling or sweeping and transported to a sediment control disposal area. Street washing shall be allowed only after sediment is removed in this manner.

(18) Removal of Temporary Measures.
All temporary erosion and sediment control measures shall be removed within 30 days after final site stabilization, or after the temporary measures are no longer needed, unless otherwise authorized by the program authority. Trapped sediment and the disturbed soil areas resulting from the disposition of temporary measures shall be permanently stabilized to prevent further erosion and sedimentation.

(19) Stormwater Management.
Properties and waterways downstream from development sites shall be protected from sediment deposition, erosion, and damage due to increases in volume, velocity, and peak flow rate of stormwater runoff for the stated frequency storm of 24-hour duration in accordance with the following standards and criteria:

- Concentrated stormwater runoff leaving a development site shall be discharged directly into an adequate natural or man-made receiving channel, pipe, or storm sewer system. For those sites where runoff is discharged into a pipe or pipe system, downstream stability analyses at the outfall of the pipe or pipe system shall be performed.

- Adequacy of all channels and pipes shall be verified:

    - Natural Channels- use 2-year storm event
    - Manmade Channels- use 2- and 10-year storm events
    - Pipe and Pipe Systems- use 10-year storm event

- If existing natural receiving channels or previously constructed man-made channels or pipes are not adequate, the applicant shall provide channel, pipe, or pipe system improvement or provide a combination of channel improvement, site design, stormwater detention, or other measures that is satisfactory to the program authority to prevent downstream erosion.

- Provide evidence of permission to make the improvements.

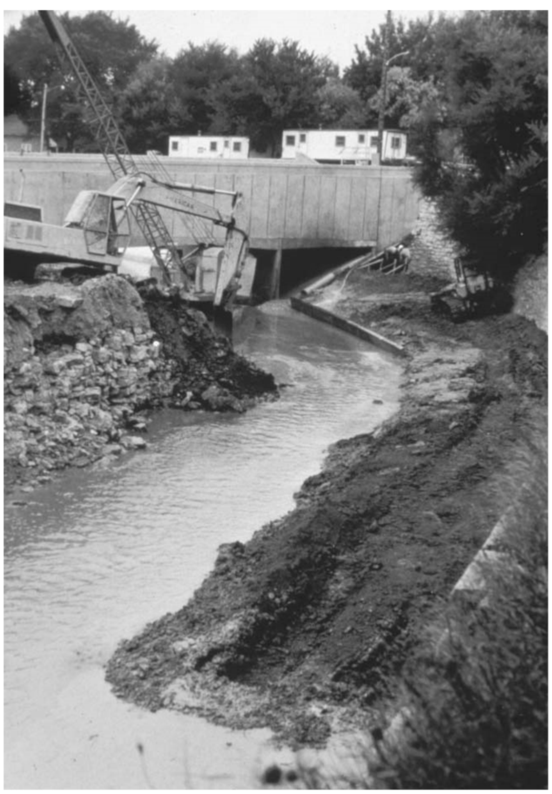
- If the applicant chooses an option that includes stormwater detention, he shall obtain approval from the locality of a plan for maintenance of the detention facilities. The plan shall set forth the maintenance requirements of the facility and the person responsible for performing the maintenance.

- Outfall from a detention facility shall be discharged to a receiving channel, and energy dissipators shall be placed at the outfall of all detention facilities as necessary to provide a stabilized transition from the facility to the receiving channel.

- Increased volumes of sheetflows that may cause erosion or sedimentation on adjacent property shall be diverted to a stable outlet, adequate channel, pipe or pipe system, or to a detention facility.

- In applying these stormwater runoff criteria, individual lots or parcels in a residential, commercial or industrial development shall not be considered to be separate development projects. Instead, the development as a whole shall be considered to be a single development project.

- • All measures used to protect properties and waterways shall be employed in a manner that minimizes impacts on the physical, chemical and biological integrity of rivers, streams and other waters of the state."



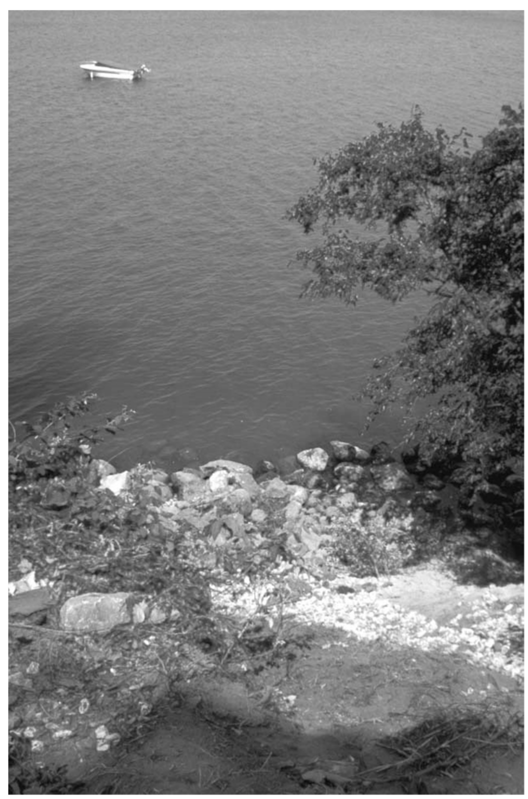


Figure 2-21. Working in rivers, streams, or lake shorelines requires special consideration (none of the above examples have any erosion controls).

Sidebar: Use of Cofferdams to Protect Waterbodies to Support Near-Shore Construction
The New York state power authority built a hydraulic turbine generating plant on the eastern shore of a pristine lake in 1918. After almost 80 years of operation, a crack was noticed in the supporting structural carriage for one of the turbines at the plant's outlet on the lake. In order to gain access to the turbine area, the authority needed to construct a coffer dam out into the lake, and then dewater the area, construct access and complete repairs.

The neighborhood along the shore and inhabitants of the area had changed dramatically in the decades since the plant was first built. There were many concerns about construction impacts such as noise, access and disruption of traffic as well as environmental impacts to the lake, even with the construction of a coffer dam to isolate the work area. The project engineer for the authority investigated constructing an earthen coffer dam with a rock riprapped face for wave protection. The length would be only 150 feet and the height needed about 4 feet. He found that this would take a week to construct at a cost of about $27,000 and then another week to remove after the turbine repairs were made. However, this activity would also cause disturbance to the lake bed.

After consulting with an erosion control expert, he decided to use a coffer dam of two polyethylene tubes filled with water and wrapped with a durable geotextile. The system cost $2,100 and was installed in just four hours, including dewatering. At the completion of the work, the system was drained and removed in an hour and a half. This system was floated into position then filled with water and had essentially no disturbance to the lake bed. Its height extended well above lake level to allow protection from wave action by wind or watercraft. Although this structure is not bullet proof and can freeze solid if used in cold climate applications, it is an excellent system for isolating work areas that require small depth control with low environmental impact.

These two photos at the New York State Electric & Gas Corporation hydroelectric plant on Keuka Lake demonstrate the use of water structures as cofferdams. Two tubes of polyethylene wrapped with a geotextile are filled with water to act as a low ground pressure, environmentally friendly cofferdam. They can be installed and removed quickly.

This is another example of how utility line crossings can be accomplished without routing construction equipment through the stream. This Aqua-Barrier allows one side to be completed then the set up can be moved to the opposite bank for completion of the crossing.

Figure 2-22. Water-Filled Coffer Dams Allowing Near-Shore Work

Sidebar: Use of Cofferdams to Support In-Lake Dam Rehabilitation

Not 60 miles from a major U.S. city, a nuclear fuel processing facility operated on this 54-acre lake from 1946-1972. Dam safety inspections statewide found a number of dams that did not meet safety standards. This particular project required the installation of a reservoir-drain system in the high-hazard dam in order to assist in meeting current safety standards. Since the existing 100 foot long dam had a competent concrete core in the center of the dam beginning about four feet below the top of dam and extending down to the rock foundation, breaching the dam to install a conventional pipe/gate system was not feasible.

It was decided to install a siphon system for reservoir drawdown. To do this and maintain the integrity of the ecosystem of the lake, a coffer dam system was constructed of structural steel A-frames with a geo-membrane that was placed on the frame and extended out into the pool area. The entire system was put in place by divers. This coffer dam was about 125 feet long and about 8 feet high. Once the dam was in place, the work site was dewatered by pumps whose intakes were located well away from the base of the structural frame.

Once the construction was complete, the area was cleaned up of excess materials and some fish habitat structures placed in the area. The water was then pumped back into the work area and the divers removed the coffer dam with minimal disturbance to the lake bottom.

These photos show the use of a Port-A-Dam system in use at Nuclear Lake in Dutchess County, New York. This 54 acre lake is about 12 feet deep and would have had to be pumped dry to fix the dam. This system was installed by divers, then the interior pumped dry for working, protecting lake ecosystem.

Figure 2-23. Near-Shore Barrier Dams

Alabama Procedures for Developing Plans for Erosion and Sediment Control

The following sidebar discussion is excerpted from the *Alabama Handbook for Erosion Control, Sediment Control, and Stormwater Management on Construction Sites and Urban Areas*, produced by the Alabama Soil and Water Conservation Committee Montgomery, AL, July 2018 (https://alconservationdistricts.gov/resources/erosion-and-sediment-control/).

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Sidebar: "An adequate plan contains sufficient information to describe the system intended to control erosion on the construction site, minimize related off-site sediment delivery and turbidity and address potential problems associated with hydrologic changes off-site. If regulations exist, more details may be required to satisfy the approving authority that the potential problems of erosion and sediment will be adequately addressed.

The length and complexity of the plan should be commensurate with the size and importance of the project, severity of site conditions, and the potential for off-site damage. Obviously, a plan for constructing a house on a single subdivision lot will not need to be as complex as a plan for a shopping center development. Plans for projects undertaken on relatively flat terrain will generally be less complicated than plans for projects constructed with steep slopes with higher erosion and sediment delivery potential. The greatest level of planning and detail should be evident on plans for projects which are adjacent to flowing streams, wetlands, dense population centers, high value properties, coastal resources and other critical habitats where damage may be particularly costly or detrimental to the environment.

A plan should contain enough information to ensure that the party responsible for development of a site can install the measures in the correct sequence at the appropriate season of the year. Sufficient information should be included to provide for maintaining the practices and measures during construction and after installation has been completed. A schedule of regular inspections and repair of erosion and sediment control BMP's should be set forth to ensure that maintenance receives appropriate attention and is accomplished."

Components of the Plan

"There are typically two components of a plan: a Site Plan Map showing locations of the planned practices and a Written Narrative. Supporting materials are essential to develop the plan and they should be a part of the associated file material available with the plan. In addition, additional components such as a site location map are needed or required to satisfy regulatory requirements.

Site Plan Map (Sometimes Referred to as Treatment Map)

This map may include a site development drawing and a site erosion and sediment control drawing depicting types and, to the extent possible, locations of planned practices. Map scales and drawings should be appropriate for clear interpretation. Site planners are urged to use the standard coding system for practices contained at the end of this chapter. Use of the coding system will result in increased uniformity of plans and better readability for plan reviewers, job superintendents, and inspectors statewide.

Written Narrative

Where needed, addition information that is not included on the site plan map should be included in a plan narrative that is written in a clear, concise manner. Typical items to include are the planned measures. Other items that may be needed include (a) a construction schedule that provides information both on sequence and time of year for installing the various practices and measures. (b) information on maintaining the practices and measures during construction and after installation have been completed and (c) a schedule for regular inspections and repair of erosion and sediment control and stormwater measures during construction. In some instances, existing conditions at the site and adjacent areas and rationale for those decisions involved in choosing erosion and sediment control measures may be included to help clarify the plan."

Supporting Materials (Referred to later in Chapter as Supporting Data)
These items include inventory information collected and used during the planning process (contour maps, soils maps, charts, or other materials as applicable used in evaluating the site and formulating the plan). Supporting materials are important to all those involved in plan formulation and plan reviews and should be available to those with a specific need for them."

Step-By-Step Procedures for Plan Development
Step 1 -Data Collection

"Data collection includes inventorying the existing site conditions to gather information which will help in developing the most effective erosion and sediment control plan. The information should be shown to the extent practical on a map and explained in well-organized notes. This information eventually becomes a part of Supporting Data and is used to analyze and evaluate the site and practice options.

A. Topography - A large-scale topographic map of the site should be prepared. The suggested contour interval is usually 1 to 2 feet depending upon the slope of the terrain. However, the interval may be increased on steep slopes.

B. Drainage Patterns - All existing drainage swales and patterns on the site should be located and clearly marked on the topographic map.

C. Soils - Major soil type(s) on the site should be noted and shown on the topographic map if the information is available. Soils information for previously undisturbed sites can be obtained from soil survey information for the county of the site location. Soil information can be found on the Web Soil Survey (http://websoilsurvey.nrcs.usda.gov) or obtained from the local Natural Resources Conservation Service (NRCS) office. On-site soils evaluations and borings can be provided by soil consultants. For ease of interpretation, soils information should be plotted directly onto the map or an overlay of the same scale.

D. Ground Cover - The existing vegetation on the site should be determined. Such features as trees and other woody vegetation, grassy areas, and unique vegetation should be shown on the map or described in the notes describing the site. In addition, existing bare or exposed soil areas should be indicated. This information may be important in determining clearing limits and establishing stages of construction.

E. Adjacent Areas - Areas adjacent to the site should be inventoried and important features that may be impacted by the proposed plan should be marked on the topographic map or identified in the notes. Applicable features include streams, springs, sinkholes, roads, wells, houses, other buildings, utilities and other land areas.

F. Floodplain Boundaries - Floodplains should be determined. Sources of information include soil surveys available from the Natural Resources Conservation Service, topographic maps, flood insurance maps, and flood plain maps that are available from many municipalities.

G. Receiving Waters - The use classification and special designation of streams and lakes that receive stormwater from the proposed site should be determined. This information is available from the Alabama Department of Environmental Management.

H. Wetlands - Wetlands and other areas that are possibly wetlands should be identified. Wetlands may be quite apparent or there may be areas that are questionable. Maps developed as part of the National Wetlands Inventory, USGS topographic maps and soil surveys should be collected to evaluate an area for wetlands. Boundaries of wetlands must be delineated if wetlands exist on areas to be disturbed by construction.

I. Contaminated Sites - Trash, abandoned appliances, potential contaminated soil and hazardous waste or any other material that should not be on the site should be identified. Brownfields fit into this category.

J. Cultural Resources - If federal funds (grants or other directed federal funds) or federal property is involved, a cultural resources review or survey is required before any ground–disturbing activities may begin (Section 106, National Historic Preservation Act). On public and private lands, the Alabama Historical Commission is the primary state agency responsible for archaeological resources protection and maintains the State Archaeological Site Files. According to the Code of Alabama (Alabama Code), the State reserves the right to explore, excavate and survey prehistoric and historic sites. In addition to cultural resource regulations, there are laws protecting cemeteries and human remains (marked and un-marked); permits are required to excavate graves.

K. Threatened and Endangered Species - Threatened and endangered species that may exist in the area and their associated habitat should be considered. Lists containing both the species and their habitat characteristics are available from the local office of the Natural Resources Conservation Service."

The following information is expanded to supplement the sidebar discussion on plan development:
Step 2 - Data Analysis
When all of the data in Step 1 are considered together, a picture of the site potentials and limitations should begin to emerge. The site planner should be able to determine those areas which have potentially critical erosion hazards. The following are some important points to consider in site analysis:

Topography – Topographic considerations are slope steepness and slope length and the longer and steeper the slope, the greater the erosion potential from surface runoff. Slope modifications with large cuts and fills may exacerbate the potential for erosion."

The primary topographic considerations are slope steepness and slope length. The longer and steeper the slope, the greater the erosion potential from surface runoff. When the percent of slope has been determined, areas of similar steepness should be outlined. Slope gradients can be grouped into three general ranges of soil erodibility:

0-2% - Low erosion hazard potential
2-5% - Moderate erosion hazard potential
over 5% - High erosion hazard potential

Within these slope gradient ranges, longer slope lengths further increase the erosion hazard. Therefore, in determining potential critical areas, the site planner should be aware of excessively long slopes. As a general rule, the erosion hazard will become critical if slope lengths exceed these combined values:

0-2% - 300 feet
2-5% - 150 feet
over 5% - 75 feet

Figures 2-24 and 2-25 are examples of pre-development and final grading site topography evaluations for these slope erosion hazards. The pre-development topography shows much of the site having steep slopes and critical erosion hazards because many of the steep slopes were greater than 75 feet long. The site was originally heavily wooded, with little observed erosion problems. However, the site clearing operations left these soils exposed at these slopes while the site was slowly graded to the final site contours, as shown in Figure 2-25. Because the site was located at the top of the local drainage area and was surrounded by major roads on the upslope sides, little off-site drainage flowed across the site as it was being developed. Diversion structures were therefore not needed, and downslope controls were critical during the grading operation to minimize sediment transport off the site. Because the site was relatively small (between 5 and 10 acres), with concurrently small subdrainage areas, only filter fabric fences were used, and not a sediment pond. However, a pond would have been more suitable due to the most of the site draining towards one area. The final grading contours shown on Figure 2-25 show that most of the site was graded flat for building pads and therefore had low erosion hazards. The slopes on the bottom edges of the terraces, however, are quite steep and have high erosion hazard potential. The final slope lengths are all relatively short, so the only critical erosion hazard is near the bottom outlet area. These steep slopes require protection, as described in Chapter 5.

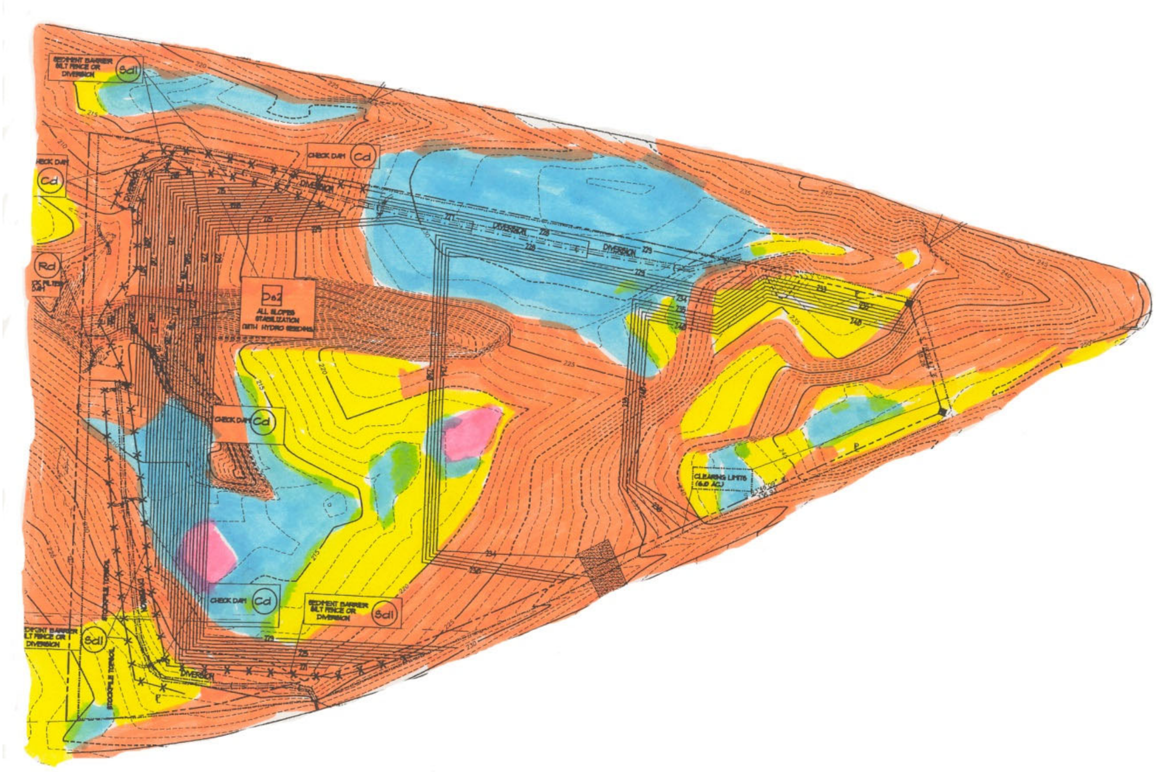

Figure 2-24. Evaluation of pre-development topography (dashed contour lines) for erosion hazards (orange: >10% slopes and high hazard; yellow: 5 to 10% slopes and high hazard; blue: 2 to 5% slopes and moderate hazard; pink: <2% slopes and low hazard).

Figure 2-25. Evaluation of final grading plan topography (solid contour lines) for erosion hazards (orange: >10% slopes and high hazard; yellow: 5 to 10% slopes and high hazard; blue: 2 to 5% slopes and moderate hazard; pink: <2% slopes and low hazard).

“B. Drainage Patterns - Swales, depressions, and natural watercourses, should be evaluated in order to plan where water will concentrate and the measures that will be needed to maintain a stable condition for concentrated flow. Where it is possible, natural drainageways should be used to convey runoff over and off the site to avoid the expense and problems of constructing an artificial drainage system. Man-made ditches and waterways become part of the erosion and turbidity problem if they are not properly stabilized. Potential for flooding and possible sites for stormwater detention ponds, sediment basins and low impact features such as rain gardens should be determined.

C. Soils - Soil properties such as depth to bedrock, depth to seasonal high water table, permeability, shrink-swell potential and texture should exert a strong influence on development decisions. Also, the flood hazard related to the soils can be determined based on the relationship between soils and flooding.

D. Ground Cover - Groundcover is the most important factor in preventing erosion. Any existing vegetation which can be saved will help prevent erosion. Trees and other vegetation protect the soil as well as beautify the site after construction. Therefore, it is important to recognize vegetation that can be retained during, and possibly after construction, to assist in stabilizing the site.

E. Adjacent Areas - The analysis of adjacent properties should focus on areas downslope, upslope and downstream from the construction project. The potential for sediment deposition on adjacent properties because of construction-related erosion should be analyzed so that appropriate erosion and sediment control measures can be planned. Obviously, the potential for impacting streams with turbidity must be considered. In some instances, water that enters the site from upslope should be diverted to minimize the potential for erosion, sediment and turbidity.

Step 3 - Facility Plan Development
This step applies to sites that are in the planning stage where planning of the facilities have not been firmly determined. After analyzing the data about the site and determining any site limitations, the erosion and sediment control professional can assist the professional developing the overall site plan formulate a site plan that is in harmony with the conditions unique to the site. An attempt should be made to locate the buildings, roads, and parking lots and develop landscaping plans to utilize the strengths and overcome the limitations of the site. *Ideally, there can be flexibility in the location of facilities and low-impact development concepts will be strongly considered*. The following are some points to consider in making these decisions:

• Fit development to terrain. The development of an area should be tailored, as much as possible, to existing site conditions. For example, confine construction activities to the least critical areas. This will avoid unnecessary land disturbance while minimizing the erosion hazards and development costs, including cost of erosion and sediment control.

• Cluster buildings together. This minimizes the amount of disturbed area, concentrates utility lines and connections while leaving more open natural space. The cluster concept not only lessens the erodible area, but it generally reduces runoff and development costs.

• Minimize impervious areas. Keep paved areas such as parking lots and roads to a minimum. This goes hand in hand with cluster developments in eliminating the need for duplicating parking areas, access roads, etc. The more land that is kept in vegetative cover, the more water will infiltrate thus minimizing runoff and erosion. Consider the use of special paving products which will allow water to infiltrate or cellular blocks which have soil and vegetation components.

• Utilize the natural drainage system. If the natural drainage system of a site can be preserved instead of being replaced with storm sewers or concrete channels, the potential for downstream damages due to increased runoff can be reduced.

• Determine if there are any "environmentally sensitive" areas (areas of special concern), to be protected during and after project implementation. In general, most erosion and control projects will have an overall beneficial effect to cultural resources since they would be protected from further environmental degradation.

Step 4 – Planning for Erosion and Sediment Control
When the site facility plan layout has been developed, a plan is developed to minimize erosion on-site and delivery of sediment and turbid water off-site. Additional objectives may include those related to increased peaks and runoff associated with a development, flood control and off-site erosion control. The following procedure is recommended for formulating the system of practices and measures for erosion and sediment control and stormwater management.

• Divide the site into drainage areas. Determine how runoff will travel over the site.

• Determine limits of clearing and grading. Decide exactly which areas must be disturbed in order to accommodate the proposed construction. Pay special attention to critical areas which can be avoided (areas with high potential for erosion and needing special treatment if disturbed). The important point in this activity is to minimize the areas to be disturbed.

• Select erosion and sediment control and stormwater management practices and measures using a systems concept. Practices and measures should be selected that are compatible and, as a system, can be expected to meet objectives for the development or activity."

1. Vegetative Controls - Vegetative controls should generally be considered first, because of economics. Usually, vegetation should be established on a temporary basis to minimize offsite impacts at the beginning of land disturbances. Vegetation protects the soil surface from raindrop impact and overland flow of runoff water. Vegetative measures should be maximized to provide as much erosion and sediment control as possible, with a minimum of structural measures. One of the simplest ways to protect the soil surface is by preserving existing ground cover where protective cover already exists. Where existing ground cover must be removed and land disturbance is necessary, temporary seeding or mulching can be used on areas that are to be exposed for long periods. Erosion and sediment control plans must contain provisions for permanent stabilization of disturbed areas. Selection of permanent vegetation should include the following considerations:

    a. adaptability to site conditions
    b. establishment requirements
    c. aesthetics

d. maintenance requirements

2. Structural Controls - Structural measures are generally more costly than vegetative controls. However, they are necessary on areas where vegetation alone will not control erosion. In addition, structural measures are often needed in combination with vegetative measures as a second or third line of defense to capture sediment before it leaves the site. It is very important that structural measures be selected, designed, constructed, and maintained according to the standards and specifications in the *Alabama Handbook*. Poorly planned or constructed structural measures can increase development costs and create maintenance problems. Structural measures that fail may increase erosion and sedimentation. Therefore, it is very important that structural measures be designed and installed properly.

3. Management Measures - Good construction management is as important as physical measures for erosion and sediment control and there is generally little or no cost involved. Following are some management considerations which should be included in the erosion and sediment control plan:

   a. Sequence construction so that no area remains exposed for unnecessarily long periods of time.

   b. When possible, avoid grading activities during months such as July and November through February, because these months are unsuitable for seeding and the potential for erosion and sedimentation is high.

   c. Temporary seedings should be done immediately after grading.

   d. On large projects, stage the construction if possible, so that one area can be stabilized before another is disturbed.

   e. Develop and carry out a regular maintenance schedule for erosion and sediment control measures.

   f. Physically mark off limits of land disturbance on the site with tape, signs or other methods, so the workers can see areas to be protected.

   g. Make sure that all workers understand the major provisions of the erosion and sediment control plan.

   h. Responsibility for implementing the erosion and sediment control plan should be designated to one individual (preferably the job superintendent or foreman).

Step 5 - Plan Assembly

"The final step of plan development consists of compiling and consolidating the pertinent information into a site-specific plan for erosion control, sediment control and stormwater management. The major plan components are a <u>narrative</u> and a <u>site plan map</u>. <u>Supporting data</u> is assembled to substantiate planning options considered and developed and to aid in review of a plan. For a plan to be effective the works that are planned must reflect what is needed for the

site, the planned works must be understood and accepted by the developer, and the document must be presented so clearly that the contents be contracted and constructed to meet developer and environmental objectives.
The following checklist may be used in assembling the narrative and site plan map to be sure all major items are included."

Checklist for Erosion and Sediment Control Plans

Narrative

"Explain the solutions for existing and predicted problems in the narrative (tables and charts may be used to display information in a format that is easier to understand).

Project Description

Briefly describe the nature and purpose of the land disturbing activity and the amount of disturbance involved.

Practices and Measures

Identify the practices and methods which will be used to control erosion on the site, prevent or minimize sediment from leaving the site, and address turbidity and hydrologic changes associated with the proposed project. Sequence and staging of construction activities to minimize disturbance and erosion should be addressed.

Inspections

Prescribe a schedule for inspections and repair of practices.

Maintenance

Include statement(s) explaining how the project will be maintained during construction until final stabilization. In some instances, maintenance that will be needed after construction should be included.

Site Plan

The site plan map is one or a series of maps or drawings pictorially explaining information contained in the narrative.

Site Plan Label

The label should include the name of owner, name of site or facility, county name, location (township, range and section) name of qualified design professional, and date plan made, and if applicable, date of latest revision.

Existing Contours

The existing contours of the site should be shown on a map (the scale used for this map should be of sufficient scale for meaningful evaluations). The scale of the site plan may range from 1" = 100 feet to 1" = 20 feet.

Existing Vegetation

The existing tree lines, grassy areas, or unique vegetation should be shown on a map.

North Arrow

The direction of north in relation to the site should be shown. The top of all maps should be north, if practical.

Existing Drainage Patterns
The dividing lines and the direction of flow for the different drainage areas should be shown on a map.

Final Contours
Planned contours should be shown on a map.

Development Features
The outline of buildings, roads, drainage appurtenances, utilities, landscaping features, parking areas, improvements, impervious areas, topographic features, and similar man-made installations should be shown to scale and relative location.

Limits of Clearing and Grading
Areas which are to be cleared and graded should be outlined on a map.

Wetlands
The location of wetlands is important and should be shown accurately and preferably on the site map

Cultural Resources
The locations of cultural resources should be shown accurately on the plan map and construction plans. Their location is essential if these areas are to be avoided or protected during project construction.

Location of Practices and Legend
The locations of the erosion and sediment control and stormwater management practices planned for the site should be shown on a map. A combination of symbols and acronyms are used to identify the practices."

Chapter 2 Summary

This chapter presented examples of available guidance for selecting erosion controls for construction sites, drawing on many example manuals. Major construction site erosion and sediment control categories are described, along with typical steps guide a user in preparing an erosion control plan for local construction sites. Later chapters discuss how local rains, soils, and objectives need to be considered when designing the selected controls for site specific conditions.

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Problems

1. After locating a site for project study, obtain a copy of the erosion and sediment control regulations that govern the on-site practices. Who has the authority to approve the plans? Who has the authority to enforce the plans? Are they the same entity? What is the scheduled inspection frequency for the site?
2. Find out from the regulatory agency that approved the plan who is the responsible party. Contact the responsible party and obtain agreement to use the site for a class project. If agreement cannot be obtained, repeat problems 1 and 2, or obtain permission from instructor to still use the site, but without the specific information. The site will need to be highly visible from public access areas. It may be possible to obtain copies of the erosion control plan and site maps from the regulatory agency.
3. Using Google Earth (preferably with 2-foot contour lines imported into Google Earth) or a topographic map, for the site, identify any areas of the site that would be considered high risk due to steep slopes or nearby waterways. Using your local erosion control manual, what practices would you expect to see installed at the site and especially in the high-risk areas?
4. On your site, perform a preliminary inventory of the erosion-control measures that have been installed. Are the erosion and sediment control categories discussed in this chapter considered?
5. Compare the approved erosion and sediment control plan with actual site conditions (try to find a site that will release a copy of the erosion-control measures map/plan, or where a plan is available from the review agency). Are the measures located where the plan writer described for each measure? If not, speculate why not. For example, did site conditions require revision of the plan and the “final” location of these structures/measures?
6. Given your site plan, estimate the cost of the erosion control measures listed/described on the plan. If the data is available, compare the cost of erosion and sediment control to the overall cost of the project. What percentage of the project is represented by the erosion control costs?

Useful Internet Links

The following Internet Links should be visited to obtain additional information. Some of the locator addresses will likely change, so it is recommended that the material be located using a search tool.

Natural Resources Conservation Service, USDA
http://www.nrcs.usda.gov/

EPA "Surf you Watershed" (compiled water and watershed information for your watershed)
http://www.epa.gov/surf/

USGS "Science in your Watershed" (additional water and watershed information)
http://water.usgs.gov/wsc/index.html

Chapter 3: Regional Rainfall Conditions and Site Hydrology for Construction Site Erosion Evaluations

Contents

Introduction: Hydrology for the Design of Construction Site Erosion and Sediment Controls

This chapter provides an overview of hydrology analysis techniques appropriate for the design of construction site erosion and sediment controls. The NRCS's TR-55 procedure will be used in this chapter, as it provides most of the needed information and is generally applicable to conditions found on most construction sites.

The reference list contains the URL for an on-line copy of TR-55, *Urban Hydrology for Small Watersheds* by the US Dept. of Agriculture/Soil Conservation Service (now NRCS) (1986). A Windows version of TR-55 (WinTR55, 2015 most recent version) can be used to greatly simplify these calculations, and that URL is also given. TR-55 provides a good set of tools to determine many of the hydrologic parameters needed for effective design of construction site erosion and sediment controls. However, major changes to the curve number rainfall-runoff hydrology methods are currently being reviewed and not yet available (as of late 2018). While some of the underlying equations and table values are likely to change, the basic procedures described in this chapter for calculating expected flow rates for the analysis of construction site sediment losses and the design of controls should still be useful. Regardless of those changes, the local review agency will need to approve any calculation methods used and appropriate calculation methods may be specified in their manual.

The following list shows typical controls and the types of hydrologic information needed for their complete evaluations and design (later chapters will review and present examples of how this information is used in these designs):

- Mulches – water velocities and water depth
- Ditch liners – water velocities and water depth
- Slope down chutes – peak flow rates
- Diversion dikes and swales – peak flow rates
- Silt fences – water velocities and hydrographs
- Sediment ponds – water volume and hydrographs

Factors Affecting Runoff

Rainfall

The temporal extent of the storm and the distribution of rainfall during the storm are two major factors which affect the peak rate of runoff. The storm distribution can be thought of as a measure of how the rate of rainfall (intensity) varies within a given time interval. If a certain amount of precipitation was measured in a given 24-hour period, this precipitation may have occurred over the entire 24-hour period or in just one hour. The duration of the rain and the peak intensity directly affect the runoff rates. The peak intensity is directly related to the energy of the rain, which affects erosion rates.

The size of the storm is often described by the length of time over which precipitation occurs, the total amount of precipitation occurring and how often this same storm might be expected to occur or be exceeded (frequency). Thus, a 10-year, 24-hour storm can be thought of as a storm producing the amount of rain in 24 hours with a 10% chance of occurrence in any given year. Storms with the same rainfall depth but a longer duration have a greater chance of occurrence while storms with the same depth and shorter duration have a smaller chance of occurrence because shorter durations increase the intensity of the rain. Higher intensity rains are rarer than extended lower intensity rains.

Antecedent Moisture Content

The runoff from a given storm is affected by the existing soil moisture content resulting from the precipitation preceding the event of interest, defined as a five-day period by the NRCS. This has a much smaller effect in areas having mostly paved surfaces. On construction sites, this factor can be important, at least in areas where substantial soil compaction has not occurred.

Surface Cover

The type of cover and its condition affects the runoff volume through its influence on the infiltration rate of soil. Bare soil at a construction site generates more runoff than forested or grass land for a given soil type. As a site develops, compaction of soil during construction and then creation of paved areas reduces the surface storage and infiltration capacity of the area and thus increases the amount of runoff.

The reason why forested or grass land has a higher infiltration than uncompacted bare soil is because foliage and leaf litter maintain the soils infiltration potential by preventing the sealing of the soil surface from the impact of the raindrops, root systems aerate the soils, and these areas have less use preventing compaction. Some of the raindrops are retained on the surface of the foliage, increasing their chance of being evaporated back to the atmosphere (interception losses). Some of the intercepted moisture can take a long time draining from the plant down to the soil (trunk flow) that it is withheld from the initial period of runoff. Foliage also transpires moisture into the atmosphere, thereby creating a moisture deficiency in the soil which must be replaced by rainfall before runoff occurs. Vegetation, including its ground litter, forms numerous barriers along the path of the water flowing over the land surface, which slows the water down and reduces its peak rate of runoff.

Soils

In general, the higher the rate of infiltration, the lower the quantity of stormwater runoff. Fine textured soils, such as clay, produce a higher rate of runoff than do coarse textured soils, such as sand. In addition, compacted soils also produce much more runoff than natural soils (Pitt, *et al.* 1999). Sites having clay soils are much more susceptible to compaction problems than most other soils.

Time of Concentration (T_c or t_c)

The time of concentration (T_c) is the minimum time needed for runoff originating from the complete project site to arrive at the outlet. By definition, T_c is the time required for water to flow from the hydraulically most-distant point in the watershed to the outlet. When rain events last at least as long as the T_c, the outlet is receiving runoff from the entire watershed. The time of concentration affects the peak and shape of the hydrograph. With land clearing and subsequent development, the drainage efficiency usually dramatically increases, with shorter T_c values, resulting in much greater peak runoff values that occur earlier in the storm. In addition, land development (and soil compaction) decease the infiltration capacity of the site, further increasing the runoff volume and the peak runoff rate.

Important aspects of T_c to remember include the following:

- The design storm duration must be equal to the time of concentration for the drainage area.
- The time of concentration (T_c) is equal to the longest flow path (by time).
- The longer the T_c, the lower the peak rain intensity. If the T_c is 5 min for a storm having a return period of 25 years, the associated peak intensity (which has a duration of 5 min) would be about 9.72 in/hr for Birmingham, AL (6.70 in/hr in Harrisburg, PA; 5.93 in/hr in Phoenix, AZ) (Source: NOAA Atlas 14, https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html). If the T_c for this same return period was 30 min, the peak rain intensity would be "only" 4.29 in/hr.

Figure 3-1 illustrates the relationships between watershed topography, slopes, and drainage times (McCuen 1989). The "iso-time" plot indicates the times for water to travel to the watershed outlet from all locations in the watershed. This is a complete, but tedious, method to determine T_c. The T_c for this watershed is seen to be 13 minutes.

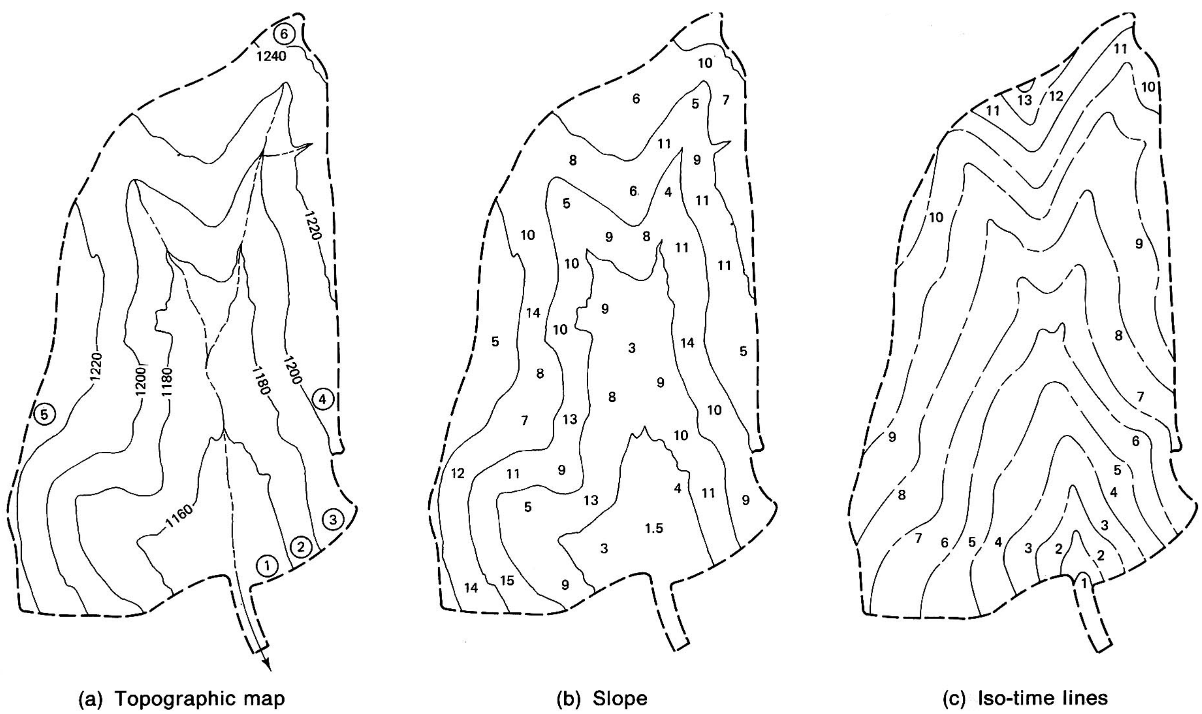


Figure 3-1. Relationships between water topography, slope, and drainage times (McCuen 1989).

An area-time plot for this watershed example is shown in Figure 3-2 (McCuen 1989). In this example, 13 minutes is the watershed time of concentration, but almost all of the watershed area is contributing runoff at 9 or 10 minutes. The very small additional area contributed by the increased travel time would normally not compensate for the increased T_c used in calculating the peak flow rate for this watershed.

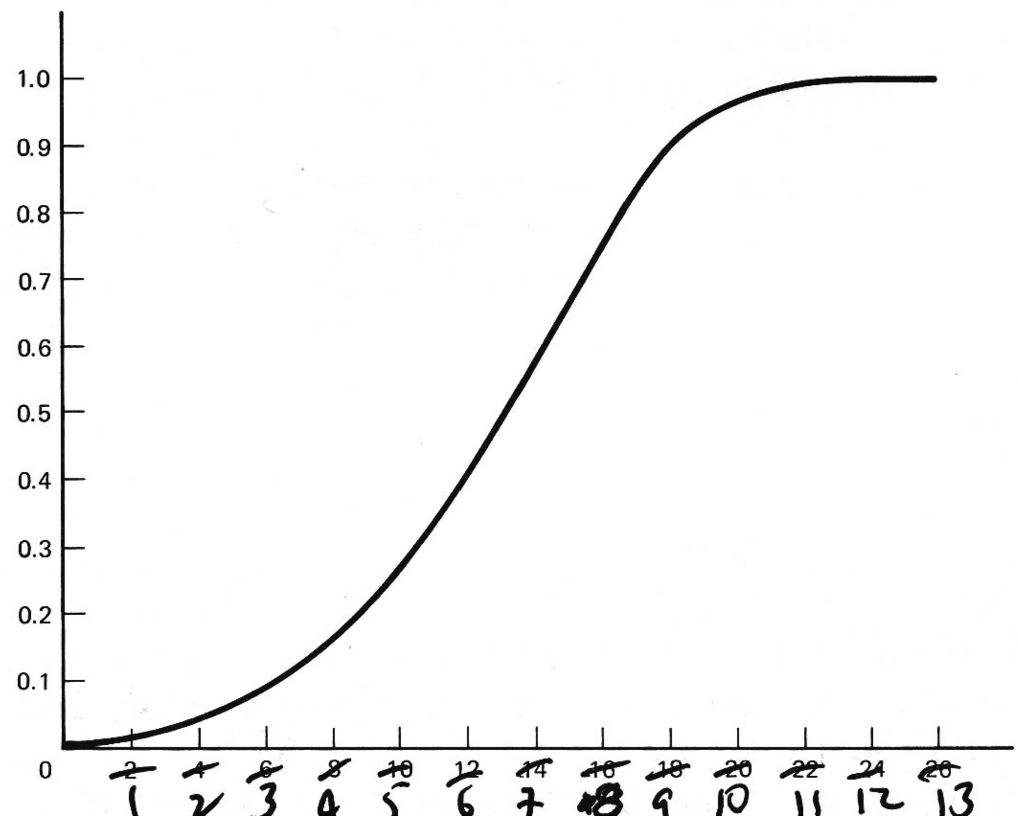


Figure 3-2. Area of watershed contributing runoff as a function of flow travel time (T_t) (McCuen 1989)

Generally, only a rain duration equal to the T_c produces the maximum peak runoff rate at the critical rain intensity. Shorter duration rains do not produce runoff from the complete area, while longer duration rains do not have any additional contributing areas, as shown on Figure 3-3.

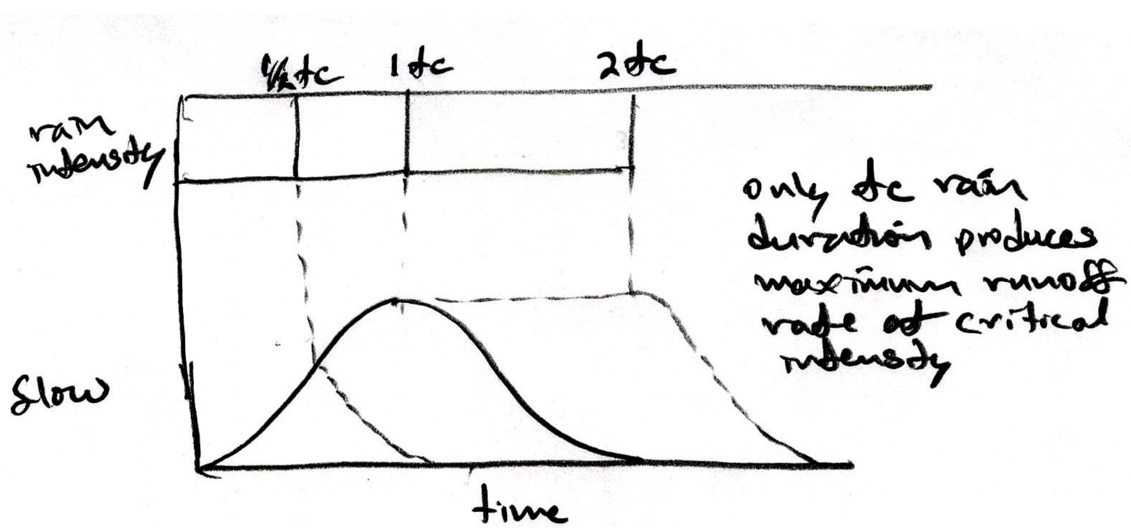


Figure 3-3. Hydrographs associated with different rain durations related to watershed T_c.

Rains having durations equal to the T_c must be used in drainage designs as they produce the critical intensity for the area and the level of service (likelihood of failure in any one year, usually indicated by the regulatory authority as an XX-year storm), as indicated on Figure 3-4. Longer duration rains have lower intensities for the same level of service, while shorter duration rains do not have the complete drainage area contributing flows during that time period. It is important that the same rain frequency (level of service associated with the acceptable failure rate) be used when examining alternative durations and rain intensities.

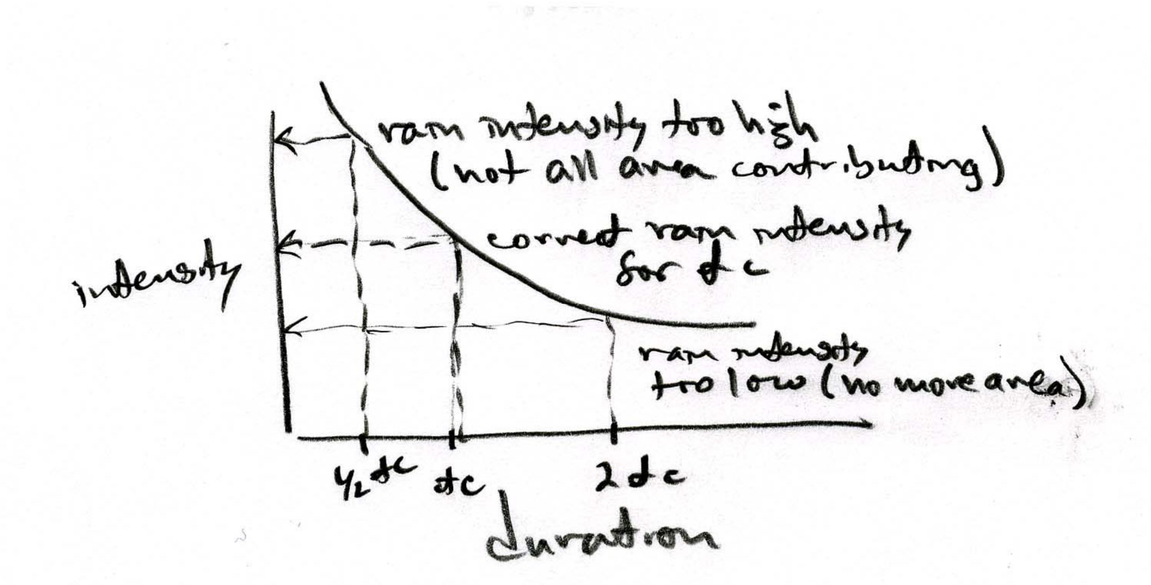


Figure 3-4. The critical rain intensity is only associated with the duration equal to the watershed time of concentration.

Local Rainfall Conditions Relevant to Construction Site Erosion and Sediment Control Design

The following discussion is an example assessment of typical Alabama rain conditions to determine the frequency of highly erosive rains and the relative importance of various rains in generating construction site erosion yields.

Typical Birmingham Rain Conditions

Monthly rain depths from 1955 to 1986 were examined to identify a single rain year that had total depths and rain distributions similar to the long-term average conditions. The years 1975 and 1976 both were found to have similar rain conditions that were close to these average conditions during this period. Individual events in these years were identified using hourly rain records. A rain event was defined as a series of hourly observations containing no more than six adjacent hours having no rain. Rain events may last from one day to the next and for multiple days. This definition has been commonly used in many urban runoff studies as it produces discrete runoff hydrographs. The six-hour period of no rain also almost always allows urban streams to return to near baseflow conditions.

Table 3-1 lists the expected rainfall distribution for typical Birmingham conditions. There are about 100 individual rains per year in Birmingham, ranging from 0.01 to about 4 inches in depth. Most of the rains are less than 0.5 inches in depth, but more than one-half of the total annual rain depth is associated with rains greater than one inch. Rain interevent periods are important when determining the periods of time that bare ground may remain unprotected at construction sites. The interevent periods shown on this table are for all rains greater than the minimum rain in the range. As an example, rains greater than 2 inches occur about every 56 days, while rains greater than 0.5 inch occur about every 10 days.

Table 3-1. Birmingham Rain Depth Distributions (average for 1975 and 1976)

Rain depth range (inches)	Interevent period (days)	Annual number of rains in range (out of 100 rains per year)	Total annual rain in range (inches)	% of annual rain in range	Accumulative % of rain in range
0 to 0.5	4	62	15.5	25	25
0.5 to 1.0	10	19	14.3	23	48
1.0 to 1.5	21	9	11.3	17	65
1.5 to 2.0	41	3	5.3	8	73
2.0 to 2.5	56	3	6.8	10	83
2.5 to 3.0	122	2	5.5	8	91
3.0 to 3.5	183	1	3.5	3	94
3.5 to 4.0	365	1	3.8	6	100

Table 3-2 summarizes the runoff quantities that may be expected for each rain depth class, for a typical construction site area, without significant soil compaction. More than half of the runoff from this area is associated with rains less than 1.5 inches in depth. Less than 20 percent of the runoff is associated with rains greater than 2.5 inches in depth. Only rains greater than about 1.25 inches will contribute runoff quantities greater than 0.5 inches, a commonly used detention criterion contained in runoff control ordinances. The first 0.5 inch of runoff from all rains therefore includes all rains smaller than about 1.25 inches, plus portions of larger rains. The remaining runoff, after the first 0.5 inch, totals about 5.5 inches for typical construction areas using the 1975 and 1976 Birmingham rains.

Table 3-2. Birmingham Runoff Volume Distributions for Typical Construction Site

Rain depth range (inches)	Example volumetric runoff coefficients for construction sites (Rv)	Annual runoff in range (inches)	% of annual runoff in range	Accumulative % of annual runoff in rain depth range
0 to 0.5	0.27	4.2	19	19
0.5 to 1.0	0.34	4.9	22	41
1.0 to 1.5	0.36	4.1	17	58
1.5 to 2.0	0.39	2.0	9	67
2.0 to 2.5	0.41	2.8	11	78
2.5 to 3.0	0.44	2.4	10	88
3.0 to 3.5	0.45	1.5	4	92
3.5 to 4.0	0.48	1.8	8	100
Total, or weighted average:	0.36	23.7	100	

Rainfall Energy for Different Alabama Rain Categories

It is possible to estimate the relative rainfall energy contributions of different rains, as shown in Table 3-3. Thronson (1973) presented the following equation to estimate the erosion potential for individual rains, as measured by the rainfall energy factor R, when complete kinetic energy or intensity information is not available:

$$R = \frac{19.25(P)^{2.2}}{(dur)^{0.4672}}$$

where R = rainfall energy factor (lb_f in/ac-h-y)
P = rain depth (inches)
dur = rain duration (hours)

This equation was proposed for the original SCS type II rain category which was applicable for most of the US. Long-term rain series data for Huntsville, Birmingham, Tuscaloosa, Montgomery, and Mobile were extracted from EarthInfo CD-ROMS (Golden, CO) and processed in WinSLAMM (www.winslamm.com) to combine the hourly data into individual rain records. Each rain was defined as having at least a 6-hour-dry interevent period. About 50 years of data were available for each city, although some of the records were incomplete. The number of events evaluated for each city ranged from about 2,500 to 5,200 separate rains. The calculations were made for each of 12 rain categories and the total annual R was estimated by multiplying the partial R for each category by the number of events in each category. The calculated annual R values for these 5 cities were similar to the published annual R values (differences of 6 to 34%). The calculated R values for each category were therefore used to indicate the approximate portion of the total annual R associated with the different rain categories. Table 3-3 summarizes these data for Birmingham.

Table 3-3. Erosion Potential Analysis for Birmingham Rains Occurring from 1948 through 1999

Rain range (inches)	Mid Point Rain (inches)	Duration (hours)	Average Intensity (in/hr)	#/year in range category	% of rains in category	Thronson R	% of annual R in category	Accumulative % of total R
0.01 to 0.05	0.03	3	0.01	22.9	20.7	0.1	0.0	0.0
0.06 to 0.10	0.08	7	0.01	17.4	15.8	0.4	0.1	0.1
0.11 to 0.25	0.18	8	0.02	17.3	15.6	2.4	0.7	0.8
0.26 to 0.50	0.38	10	0.04	19.5	17.6	12.4	3.5	4.4
0.51 to 0.75	0.63	12	0.05	9.4	8.5	16.6	4.8	9.1
0.76 to 1.00	0.88	14	0.06	8.3	7.5	28.6	8.2	17.3
1.01 to 1.50	1.26	16	0.08	7.9	7.2	56.4	16.1	33.4
1.51 to 2.00	1.76	18	0.10	3.8	3.5	53.9	15.4	48.8
2.01 to 2.50	2.26	20	0.11	1.6	1.5	38.0	10.9	59.7
2.51 to 3.00	2.76	24	0.12	0.8	0.7	26.3	7.5	67.2
3.01 to 4.00	3.5	30	0.12	1.1	1.0	57.0	16.3	83.5
over 4.01	5.67	36	0.16	0.4	0.4	57.9	16.5	100.0
4583 events	41.5 years	13.58 in. max rain	Totals:	110.5	100.0	350.0	100.0	

Figure 3-5 is a plot of the accumulative total R associated with the different rain depths. The larger rains contribute most of the erosion potential for these Alabama rain conditions. For all of these cities, except Mobile, the rain depth associated with the median of the annual R is about 2.25 inches, while it is about 2.75 inches for Mobile. Therefore, only 3.6% of the total number of rainfall events (those greater than 2 inches) are responsible for about half of the annual erosion potential. Rains less than about 0.75 to 1 inches in depth are responsible for only about 10% of the total annual erosion potential. About 20 to 30% of the rains (generally between 0.75 and 4 inches) are associated with about 80% of the annual erosion potential. Because of the long rain record used here, these rain series include several rare events, including the “50-year” event. It may be impractical to design erosion controls that can effectively withstand the very large events. Except for Mobile, rains greater than 4 inches occur less than once a year in most parts of the state. If a “typical” rain year was examined (which would not include these extreme events), the effects of these very large rains would be diminished. When only the 1976 rain year for Birmingham was examined (a typical year for local rains), for example, the rain depth associated with the median erosion potential was reduced to about 1.75 inches. The longer rain records typically contain “rare” events that, while uncommon and difficult to plan for, may affect the erosion yield and cause damage to the site that would require substantial regrading.

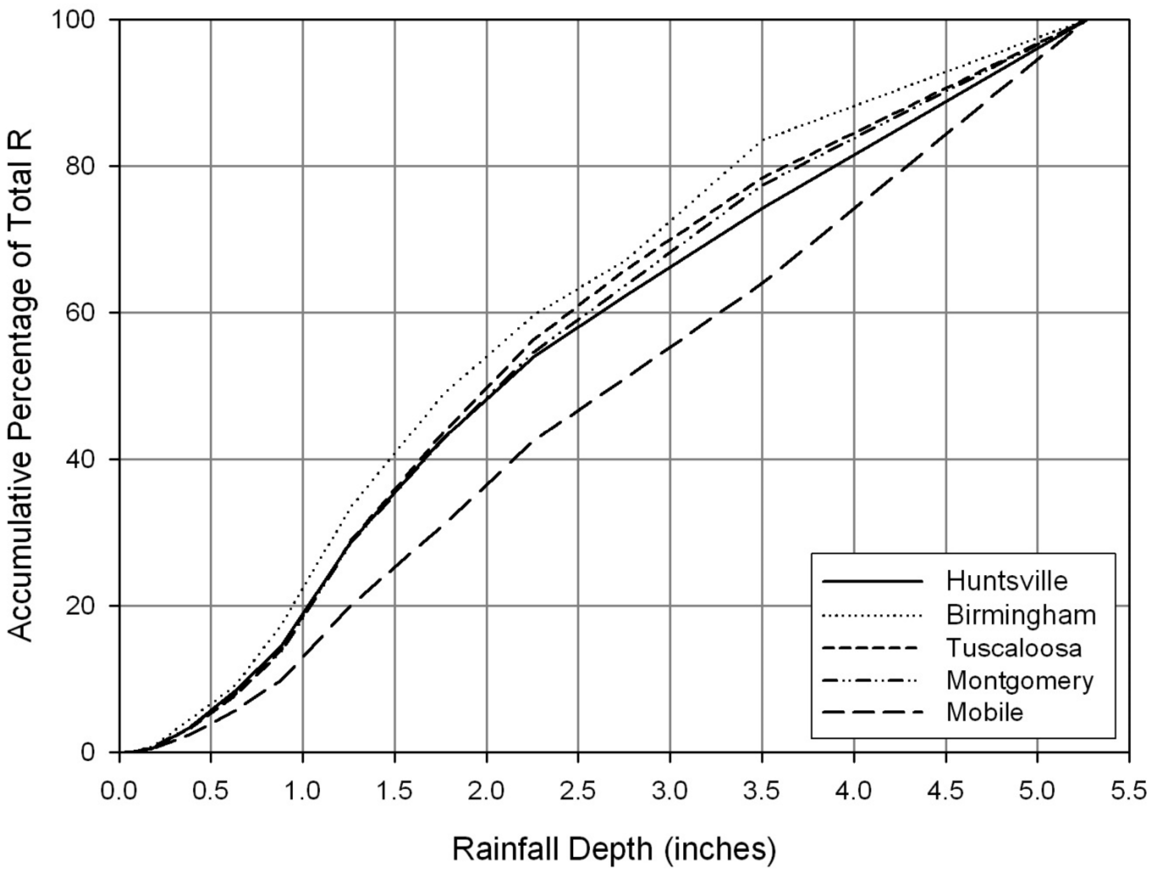


Figure 3-5. Distribution of erosion potential associated with different rains for major Alabama cities.

Table 3-4 shows the variation in frequency of large rains greater than 2 inches in depth for the 1948 through 1999 rain period for Birmingham (41.5 years of data due to some missing data periods). Between 1 and 8 (an average of 4.1) of these large rains occur each year, but no obvious pattern is indicated in the group in terms of predicting the number of large rains in any given year. Table 3-5 examines these highly erosive rains for each month of the year for this same Birmingham rain period. May through November appears to have fewer of these rains. However, September had the largest number of large rains of any month, which is not unexpected for any area whose rainfall distribution is influenced by tropical storms. August and September are considered the most-active months for the development and sustenance of tropical weather (the Atlantic hurricane season is considered to peak in September).

3-4. Number of Large Rains (>2 inches) per Year for Birmingham.

year	#/year	year	#/year	year	#/year
1948	4	1962	4	1976	7
1949	2	1963	6	1977	8
1950	7	1964	8	1988	3
1951	6	1965	2	1989	2
1952	2	1966	5	1990	3
1953	4	1967	6	1991	3
1954	3	1968	5	1992	5
1955	1	1969	6	1993	1
1956	3	1970	5	1994	4
1957	8	1971	4	1995	4
1958	2	1972	3	1996	5
1959	2	1973	5	1997	1
1960	1	1974	3	1998	6
1961	6	1975	5	1999	2

total = 172 large storms from 1948 through 1999
average = 4.1 large storms/year
minimum = 1 large storms/year
maximum = 8 large storms/year
standard deviation = 2.0
COV = 0.49

Table 3-5. Birmingham Rains by Month

	2.00 to 2.50	2.51 to 3.00	3.01 to 4.00	over 4.01	total
January	7	2	4	4	17
February	7	2	4	1	14
March	9	5	5	2	21
April	5	1	5	1	12
May	7	4	4	1	16
June	6	0	5	0	11
July	5	2	2	2	11
August	4	5	1	1	11
September	9	7	5	1	22
October	0	3	5	1	9
November	8	1	1	1	11
December	6	2	6	3	17
Total for 41.5 years of record	73	34	47	18	172
Average (#/year):	1.8	0.8	1.1	0.4	4.1

The pattern of these large rains is likely to change during other longer periods of time and in the future. Most analyses indicate greater numbers of the very large rains during recent years. The revised NOAA

Atlas 14 indicates this trend for many US areas; it does not show the data for the full rain set, but it does present revised IDF relationships (described below) using all available rain data.

Intensity, Duration and Frequency (IDF) Information for Rains Used to Design Erosion Controls

As noted above, rains having high intensities typically contribute the highest erosion yields. Individual rains that may occur at any time of the year can contribute excessive erosion losses. Very rare rains, occurring at most only once every year and usually much less frequently, typically receive the most attention for flooding and drainage studies. When these rare rains do occur, greater erosion yields will also occur, and most erosion and sediment control devices will fail. As an example, Figure 3-6 (the historical IDF curve for Birmingham, AL from Hydro-35) shows the relationship between rainfall duration, peak intensity, and return period. (NOTE: The return period of a storm is defined as the inverse of the probability [expressed as a decimal fraction] of a storm of a specific depth and duration being equaled or exceeded within a pre-specified time frame, typically one year. The IDF curve for Birmingham, as displayed in Figure 3-6, shows this relationship for durations up to 60 min. As seen in this figure, rains having average intensities of almost 3 inches per hour lasting for about 30 minutes are expected to occur with a 50 percent probability every year. Five-minute duration peak rain intensities of more than 6 inches per hour also occur with that same probability. It would be very difficult to design effective erosion and sediment control practices that can withstand the high runoff rates than may occur during many of the rarer “design storm” events.

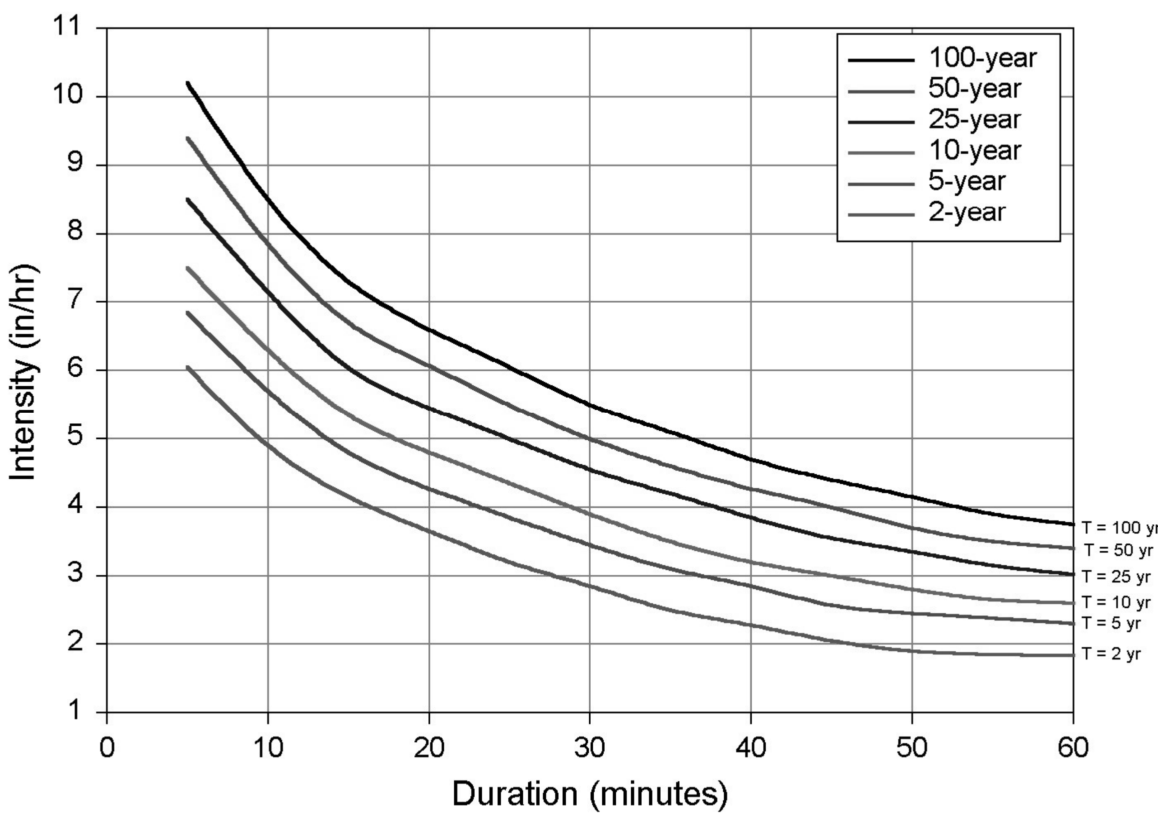


Figure 3-6. Historical Intensity, duration, and frequency (IDF) curve for Birmingham, AL (from National Weather Service, Hydro-35)

Over the past several years, NOAA has produced Atlas 14 (point precipitation frequency estimates) that supersedes the older rainfall atlases (Tech Paper 40, Tech Paper 49, and Hydro-35). The chapters for Atlas 14 are available at: http://nws.noaa.gov/oh/hdsc/currentpf.htm. Volumes 1 to 11 cover most of the US (Washington, Oregon. Idaho, Wyoming, and Montana are not yet available as of late 2018, but are included in the older Atlas 2), as shown on Figure 3-7. The NOAA Atlas 14 precipitation frequency maps are only available in digital form. The Precipitation Frequency Data Server is accessed at: http://hdsc.nws.noaa.gov/hdsc/pfds/. The user guide is available as a separate document at: http://www.nws.noaa.gov/oh/hdsc/PF_documents/NA14_Sec5_PFDS.pdf.

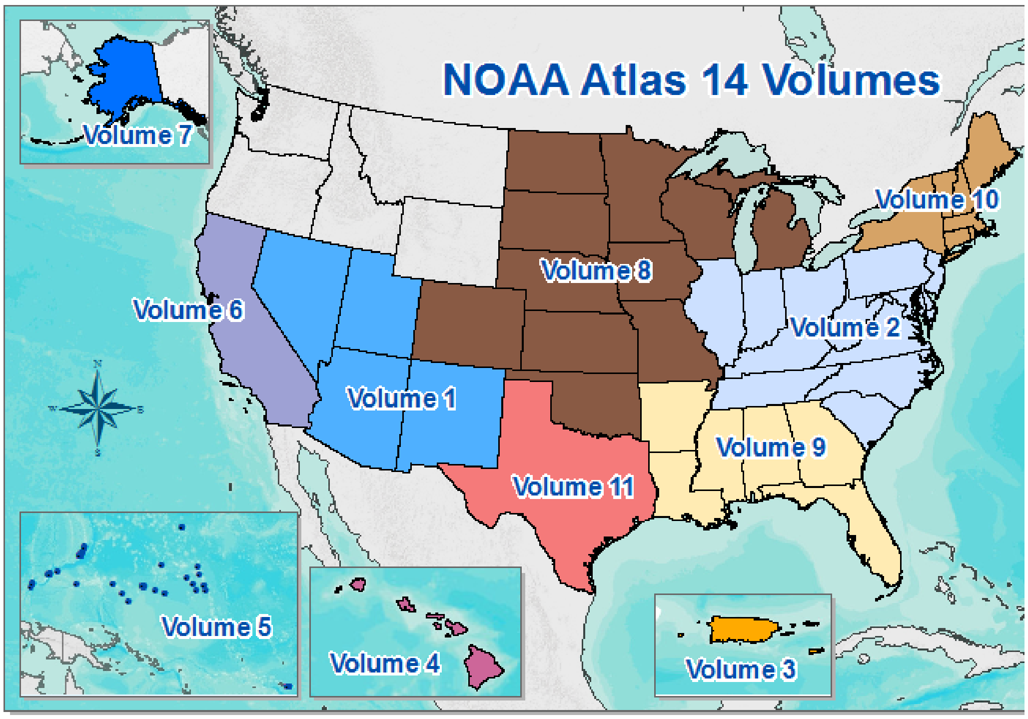


Figure 3-7. States in the NOAA Atlas 14 Volumes.

A main feature of Atlas 14 is the use of all available precipitation data for an area (after extensive QA/QC review) and the delineation of major rainfall regions in a state. As an example, Figures 3-8 and 3-9 show maps of all rainfall monitoring locations in New York and the resulting precipitation depths for a large rain for the region.

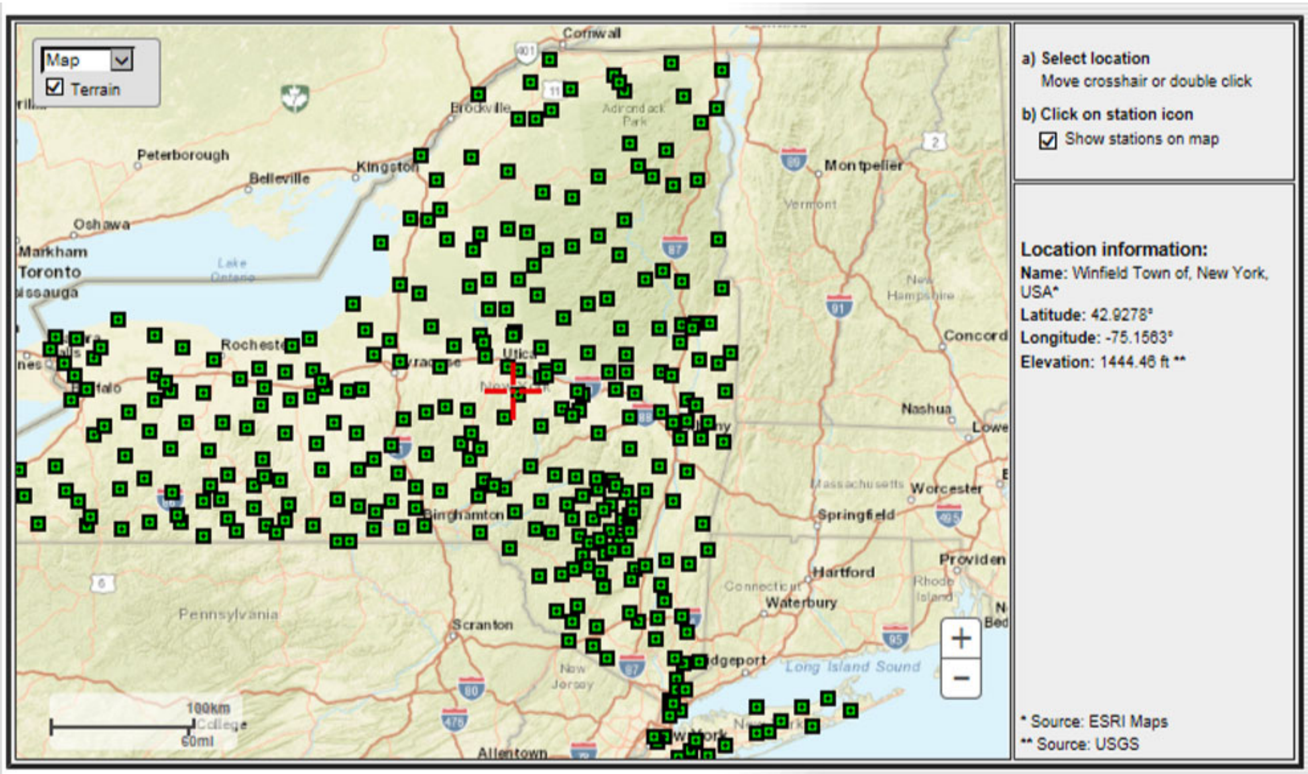


Figure 3-8. Atlas 14 precipitation locations available for New York.

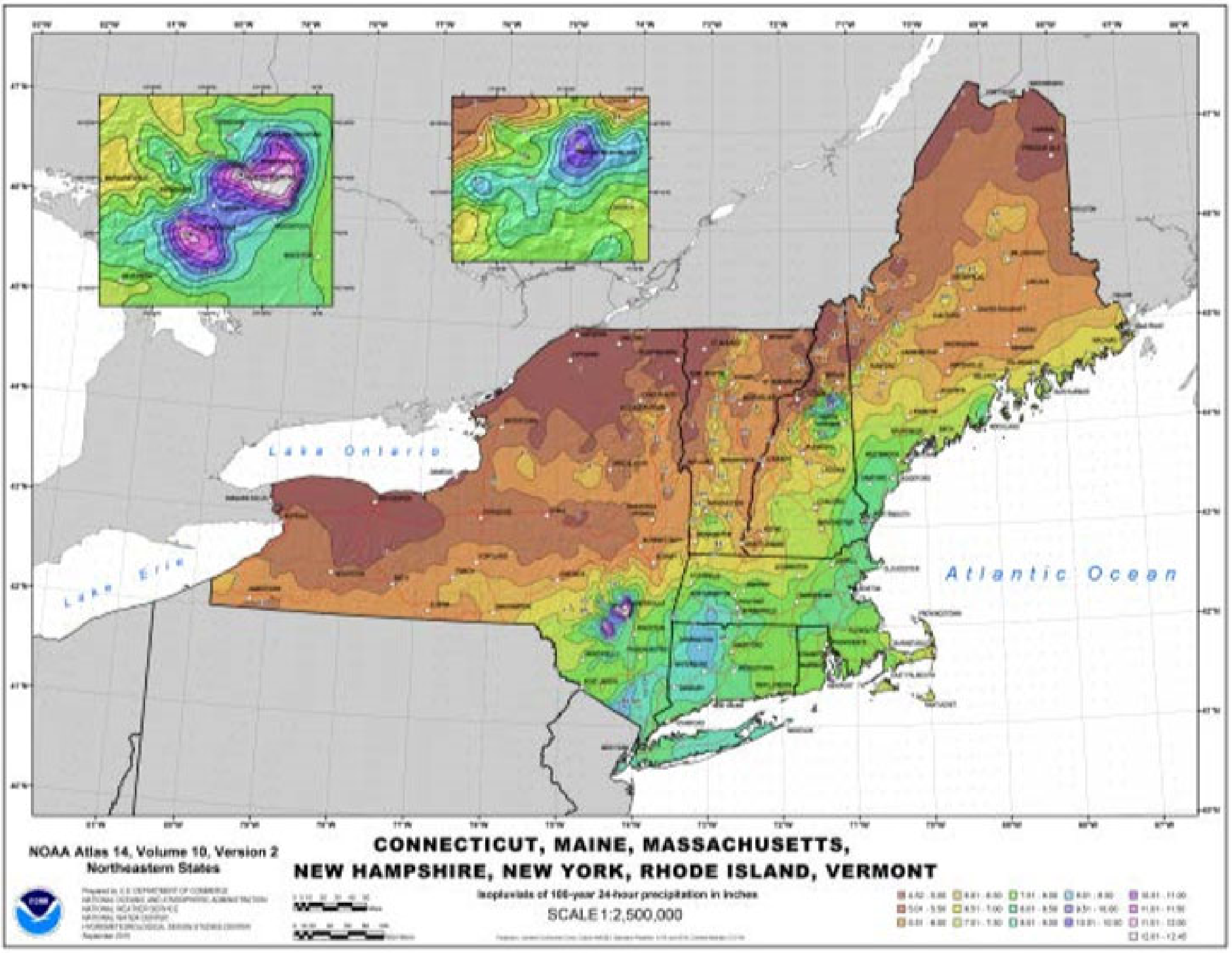


Figure 3-9. Cartographic map showing 100-yr frequency 24-hr duration total rain depths, from Atlas 14, Vol. 10.

Many products are available in Atlas 14, as described in the user manual. Of most interest for the design of erosion controls are classical IDF (intensity-duration-frequency) plots. These can be obtained by clicking on the state of interest on the Atlas 14 home page that then opens the correct volume and map of the region, as shown in Figure 3-10. The location of interest is then selected (anywhere on the map, as the Atlas will interpolate the resulting information based on the surrounding data). In this case, Buffalo, NY, was selected. The IDF data are available in different forms, and the graphical form was selected for this example, as shown on Figure 3-11.

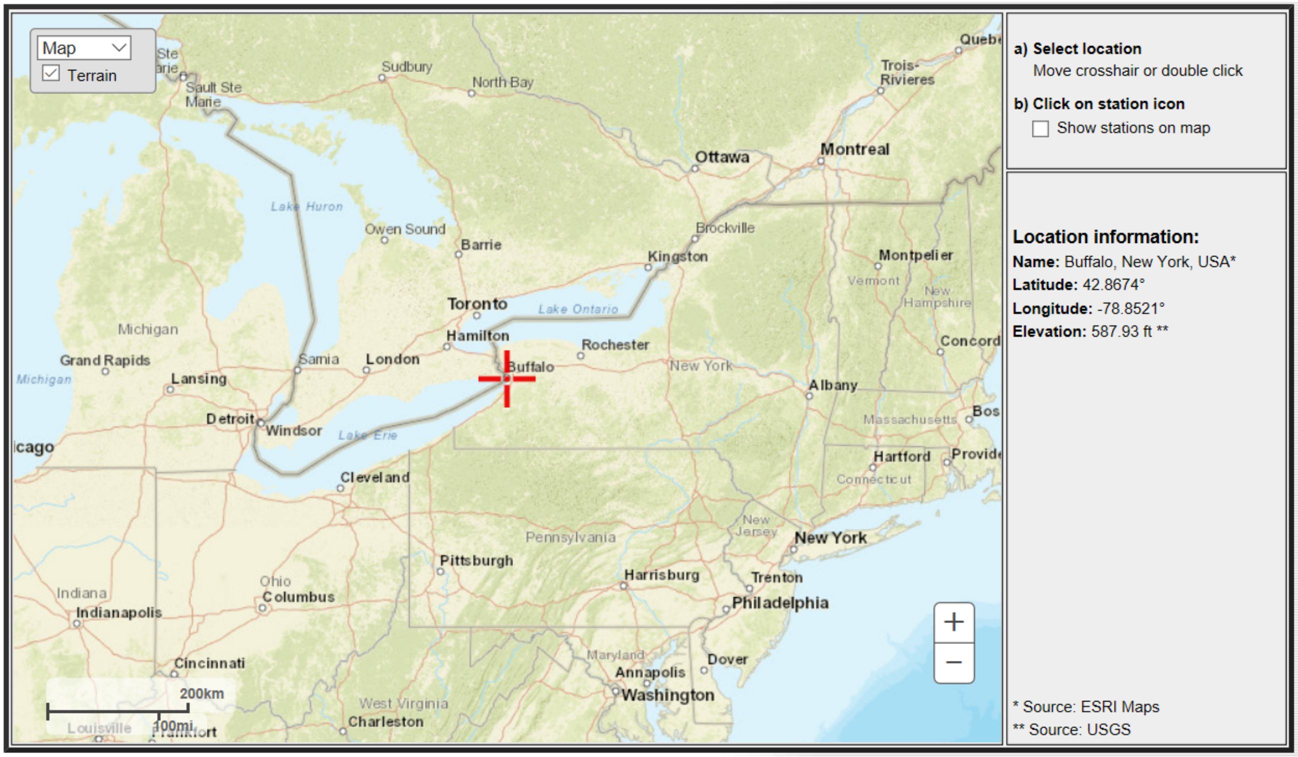


Figure 3-10. Regional map, with Buffalo, NY, selected (NOAA Atlas 14).

The Atlas 14 IDF plots show rain depth on the y-axis, while many other IDF curves show the intensity on the y-axis. If the intensity value is needed, simply divide the rain depth by the associated rain duration (equal to the time of concentration, discussed later) for the recurrence interval of interest. As an example, if the 60-minute, 25-yr rain depth is 1.8 inches, the corresponding rain intensity is 1.8 inches per hour. Also, the Atlas 14 IDF graphs have extended x-axis durations, well beyond the likely times of concentration of typical construction sites. In this case, the tabular values (as shown on Table 3-6 for Buffalo) may be more accurate than trying to interpolate from the crowded graphs. The tabular data also includes the 90% confidence intervals for the rain depths.

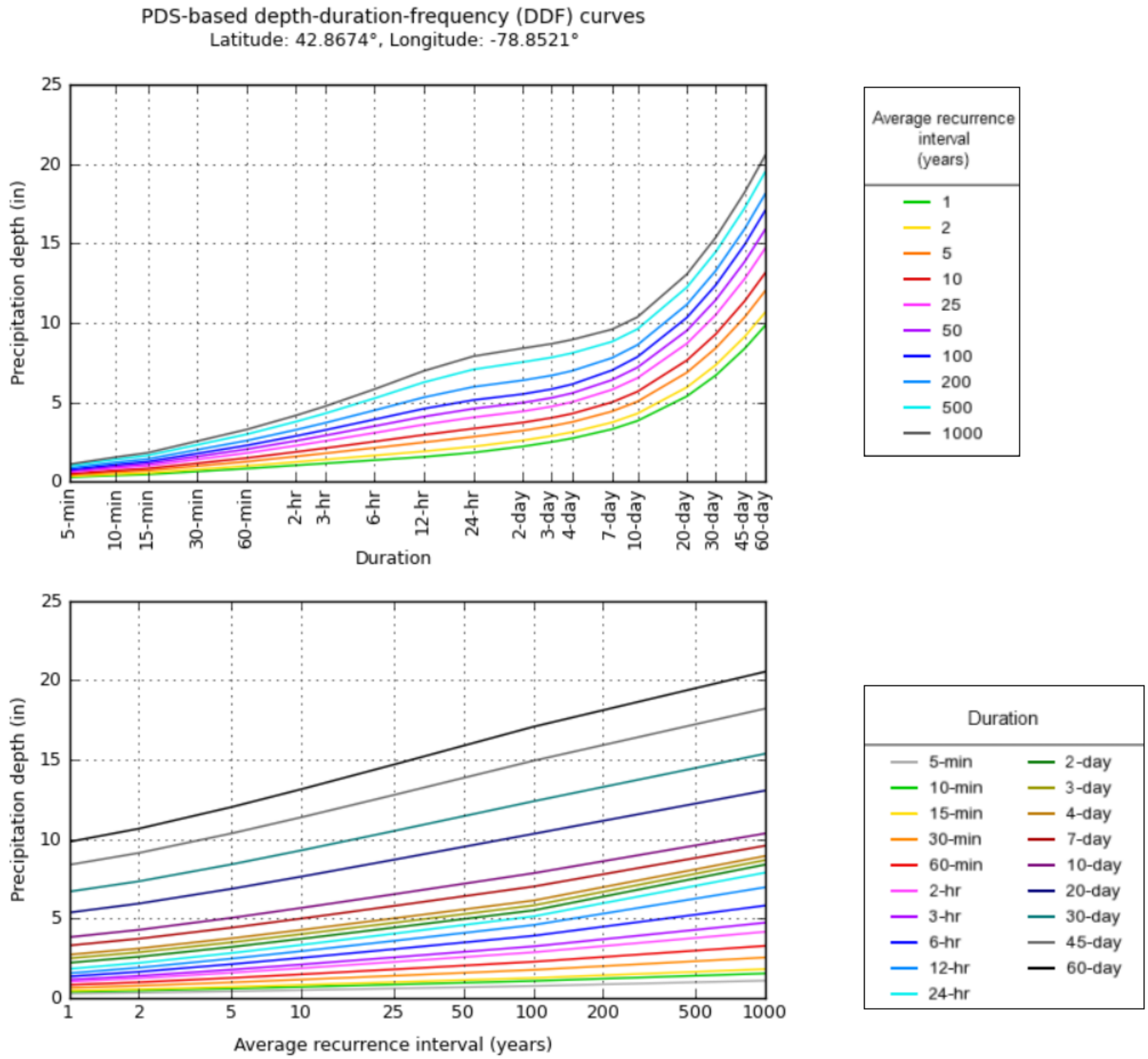


Figure 3-11. IDF curves for Buffalo, NY, from NOAA Atlas 14.

Table 3-6. Tabular IDF Values for Buffalo, NY, from NOAA Atlas 14

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]										
Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	**0.273** (0.224-0.333)	**0.328** (0.269-0.400)	**0.418** (0.342-0.512)	**0.493** (0.400-0.608)	**0.596** (0.464-0.771)	**0.676** (0.512-0.895)	**0.755** (0.551-1.04)	**0.855** (0.585-1.21)	**0.988** (0.644-1.45)	**1.09** (0.688-1.63)
10-min	**0.387** (0.318-0.471)	**0.465** (0.382-0.567)	**0.593** (0.484-0.726)	**0.699** (0.567-0.861)	**0.845** (0.657-1.09)	**0.957** (0.726-1.27)	**1.07** (0.781-1.48)	**1.21** (0.828-1.71)	**1.40** (0.912-2.06)	**1.54** (0.975-2.32)
15-min	**0.455** (0.374-0.555)	**0.547** (0.449-0.667)	**0.697** (0.570-0.854)	**0.822** (0.667-1.01)	**0.994** (0.773-1.29)	**1.13** (0.854-1.49)	**1.26** (0.919-1.74)	**1.43** (0.975-2.02)	**1.65** (1.07-2.42)	**1.81** (1.15-2.72)
30-min	**0.640** (0.525-0.779)	**0.769** (0.631-0.938)	**0.980** (0.801-1.20)	**1.16** (0.937-1.42)	**1.40** (1.09-1.81)	**1.58** (1.20-2.10)	**1.77** (1.29-2.44)	**2.00** (1.37-2.83)	**2.31** (1.51-3.40)	**2.55** (1.61-3.82)
60-min	**0.824** (0.677-1.00)	**0.991** (0.813-1.21)	**1.26** (1.03-1.55)	**1.49** (1.21-1.83)	**1.80** (1.40-2.33)	**2.04** (1.55-2.70)	**2.28** (1.66-3.14)	**2.58** (1.76-3.65)	**2.98** (1.94-4.37)	**3.28** (2.07-4.92)
2-hr	**1.03** (0.852-1.25)	**1.24** (1.02-1.50)	**1.59** (1.30-1.93)	**1.87** (1.53-2.29)	**2.27** (1.77-2.91)	**2.57** (1.96-3.38)	**2.87** (2.11-3.94)	**3.26** (2.24-4.58)	**3.77** (2.47-5.51)	**4.16** (2.64-6.21)
3-hr	**1.15** (0.956-1.39)	**1.39** (1.15-1.68)	**1.78** (1.47-2.16)	**2.11** (1.73-2.57)	**2.56** (2.01-3.27)	**[illegible]0** (2[illegible]3.81)	**3.25** (2.39-4.44)	**3.69** (2.54-5.17)	**4.28** (2.81-6.23)	**4.73** (3.01-7.03)
6-hr	**1.36** (1.13-1.62)	**1.65** (1.37-1.98)	**2.13** (1.77-2.56)	**2.52** (2.08-3.06)	**3.07** (2.43-3.91)	**3.49** (2.69-4.56)	**3.91** (2.90-5.34)	**4.49** (3.10-6.24)	**5.24** (3.44-7.57)	**5.81** (3.71-8.58)
12-hr	**1.56** (1.31-1.85)	**1.91** (1.60-2.27)	**2.47** (2.07-2.96)	**2.94** (2.44-3.54)	**3.59** (2.86-4.56)	**4.09** (3.18-5.33)	**4.59** (3.44-6.25)	**5.31** (3.68-7.34)	**6.26** (4.12-8.98)	**6.97** (4.46-10.2)
24-hr	**1.83** (1.54-2.16)	**2.20** (1.86-2.61)	**2.82** (2.37-3.35)	**3.34** (2.79-3.99)	**4.05** (3.24-5.11)	**4.59** (3.59-5.95)	**5.14** (3.88-6.98)	**5.97** (4.15-8.20)	**7.07** (4.67-10.1)	**7.90** (5.07-11.5)
2-day	**2.21** (1.89-2.60)	**2.59** (2.20-3.04)	**3.21** (2.71-3.78)	**3.72** (3.12-4.41)	**4.42** (3.57-5.54)	**4.96** (3.91-6.39)	**5.51** (4.19-7.44)	**6.38** (4.45-8.70)	**7.54** (5.00-10.7)	**8.41** (5.41-12.2)
3-day	**2.49** (2.13-2.92)	**2.88** (2.45-3.37)	**3.50** (2.97-4.11)	**4.01** (3.38-4.74)	**4.72** (3.82-5.88)	**5.27** (4.16-6.75)	**5.82** (4.43-7.80)	**6.68** (4.68-9.07)	**7.83** (5.21-11.0)	**8.69** (5.60-12.5)
4-day	**2.73** (2.34-3.18)	**3.12** (2.67-3.64)	**3.75** (3.20-4.39)	**4.28** (3.62-5.05)	**5.01** (4.06-6.21)	**5.57** (4.40-7.09)	**6.13** (4.66-8.16)	**6.98** (4.89-9.44)	**8.10** (5.40-11.4)	**8.95** (5.78-12.9)
7-day	**3.30** (2.85-3.83)	**3.73** (3.21-4.33)	**4.42** (3.79-5.15)	**5.00** (4.25-5.86)	**5.79** (4.71-7.10)	**6.40** (5.05-8.04)	**7.01** (5.30-9.17)	**7.79** (5.49-10.5)	**8.81** (5.90-12.3)	**9.58** (6.20-13.7)
10-day	**3.83** (3.31-4.42)	**4.29** (3.70-4.96)	**5.04** (4.33-5.85)	**5.67** (4.83-6.62)	**6.53** (5.31-7.96)	**7.19** (5.68-8.96)	**7.86** (5.92-10.2)	**8.61** (6.09-11.5)	**9.60** (6.44-13.3)	**10.3** (6.71-14.7)
20-day	**5.37** (4.68-6.16)	**5.94** (5.16-6.82)	**6.87** (5.94-7.92)	**7.64** (6.55-8.86)	**8.70** (7.12-10.5)	**9.52** (7.54-11.7)	**10.3** (7.80-13.2)	**11.2** (7.94-14.8)	**12.2** (8.25-16.9)	**13.1** (8.49-18.5)
30-day	**6.69** (5.84-7.64)	**7.34** (6.40-8.40)	**8.41** (7.30-9.65)	**9.29** (8.00-10.7)	**10.5** (8.63-12.6)	**11.4** (9.10-14.0)	**12.4** (9.36-15.7)	**13.3** (9.48-17.5)	**14.5** (9.79-19.9)	**15.4** (10.0-21.6)
45-day	**8.38** (7.35-9.53)	**9.13** (7.99-10.4)	**10.4** (9.02-11.8)	**11.4** (9.83-13.1)	**12.8** (10.5-15.3)	**13.9** (11.0-16.9)	**14.9** (11.3-18.8)	**15.9** (11.4-20.9)	**17.2** (11.7-23.6)	**18.2** (11.9-25.5)
60-day	**9.83** (8.64-11.1)	**10.7** (9.36-12.1)	**12.0** (10.5-13.7)	**13.1** (11.4-15.1)	**14.7** (12.1-17.5)	**15.9** (12.7-19.3)	**17.1** (12.9-21.4)	**18.1** (13.0-23.8)	**19.5** (13.2-26.6)	**20.5** (13.4-28.7)

The regional map can be enlarged in Atlas 14 to more accurately select a location of interest. Figure 3-12 is an example showing the selection for the campus of Penn State-Harrisburg, near Middletown, PA, with the resulting IDF curve on Figure 3-13.

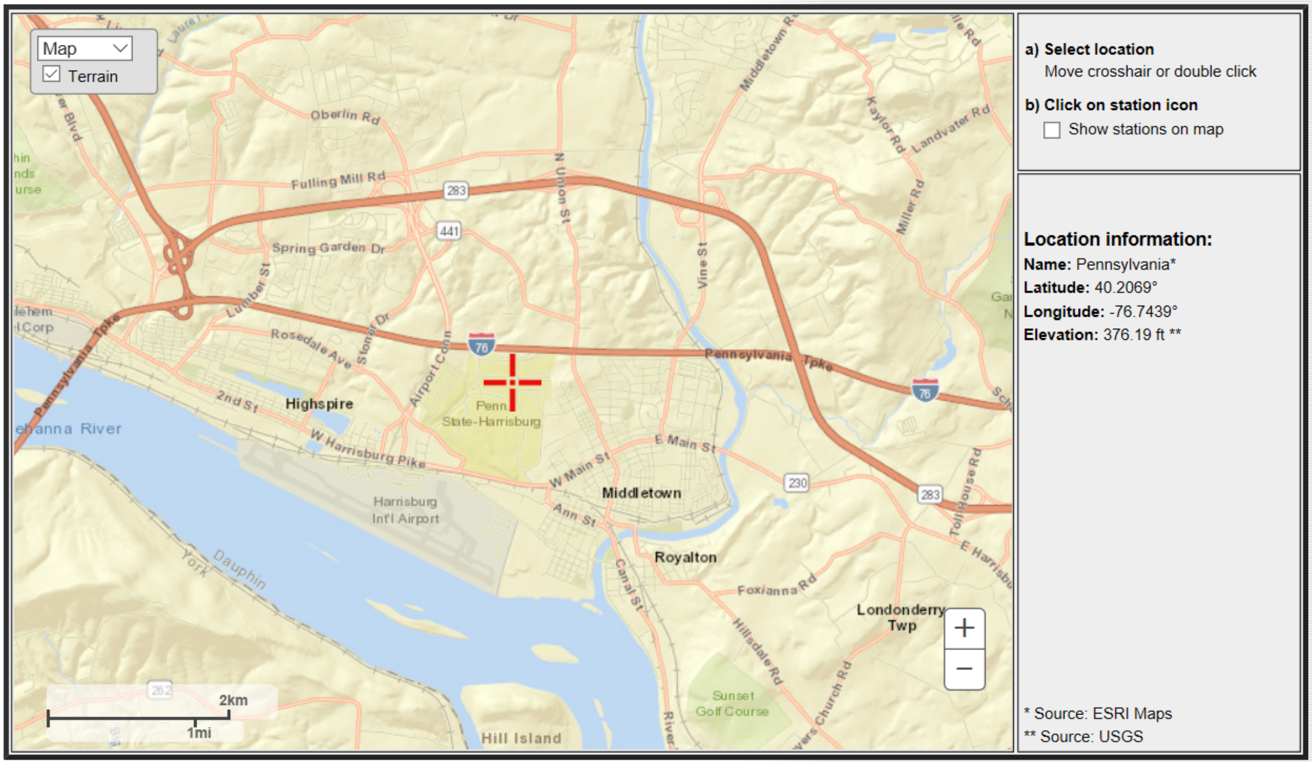


Figure 3-12. Selection of Penn State – Harrisburg for IDF information, enlarged map in NOAA Atlas 14.

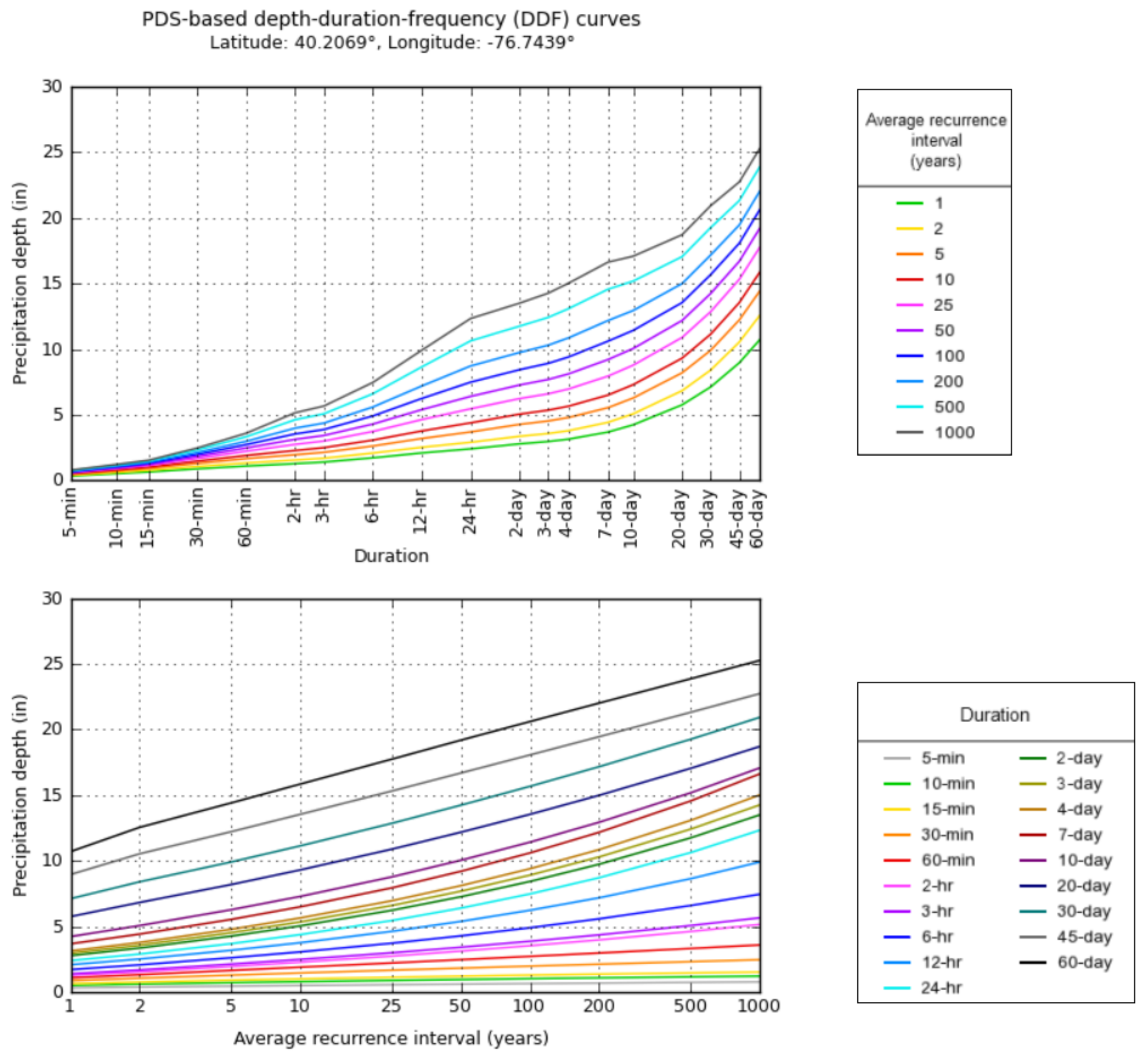


Figure 3-13. IDF graphs for Penn State – Harrisburg, NOAA Atlas 14.

Much additional information is also available, besides the IDF curves. Table 3-7 shows the supplementary information form available after a site is selected.

Table 3-7. Listing of Additional Information Available for a Selected Location in NOAA Atlas 14

PF tabular | PF graphical | **Supplementary information** | Print page

I. Document

Click here for this volume's document.

II. PF in GIS format

Spatially interpolated precipitation frequency estimates (with upper and lower bounds of the 90% confidence interval) area available in GIS compatible format (ascii file). For default download page click here.

Average recurrence interval: 2-year Duration: 60-minute Set: Precipitation frequency estimates Submit

III. PF cartographic maps

Cartographic maps of precipitation frequency estimates were created for selected average recurrence intervals and durations. We recommend that these color maps are used as visual aids only. For default cartographic maps' page click here.

The NOAA Atlas 14 Volume 2 is divided into 5 zones (cartographic maps). See the cartographic map zones for details.
Average recurrence interval: 2-year Duration: 60-min Submit

IV. Temporal distributions

Temporal distributions are provided for 6-hour, 12-hour, 24-hour, and 96-hour durations. The temporal distributions for the duration are expressed in probability terms as cumulative percentages of precipitation totals (see documentation for more information). To provide detailed information on the varying temporal distributions, separate temporal distributions were derived for four precipitation cases defined by the duration quartile in which the greatest percentage of the total precipitation occurred.

Duration: 24-hour Submit

V. Seasonality analysis

VI. Rainfall frequency estimates

Rainfall (liquid precipitation only) frequency estimates were not examined in Volumes 1 to 5 and so are not available for this state.

VII. Time series data

Annual maximum and partial duration time series precipitation data are available for download only for stations used in frequency analysis.

VIII. Climate data source

Precipitation frequency results are based on data from a variety of sources, but largely from the National Centers for Environmental Information - NCEI (formerly National Climatic Data Center - NCDC). For more information about observing sites in the area, regardless of if their data was used in this study, please visit NCEI's Climate Data Online.
For detailed information about the stations used in this study, please refer to NOAA Atlas 14 Document.

IX. Watershed information

Click here to get the watershed information for this location from the U.S. Environmental Protection Agency's (EPA) site.

Figure 3-14 shows an enlarged index map for the Birmingham, AL, area, with the locations of the monitoring stations located on the map. The Shuttlesworth International Airport is a monitoring station and was selected for the IDF curve shown on Figure 3-15.

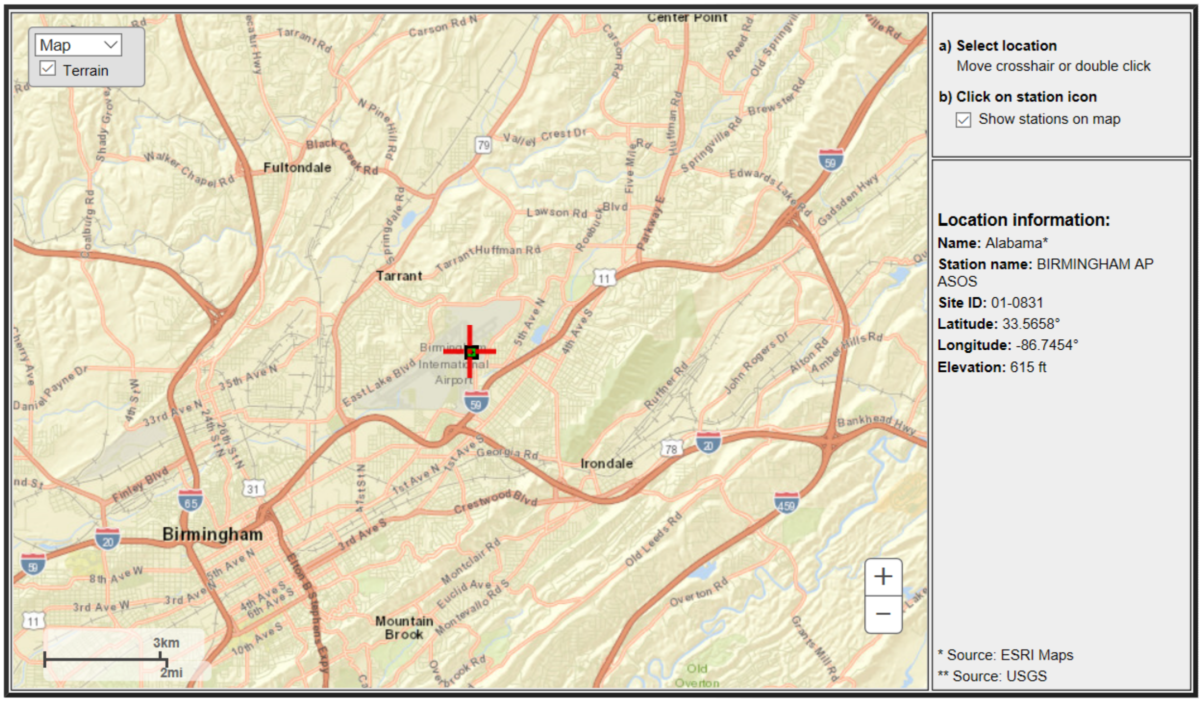


Figure 3-14. Selection of Birmingham, AL, Shuttlesworth International Airport for IDF information, enlarged map with station locations, from NOAA Atlas 14.

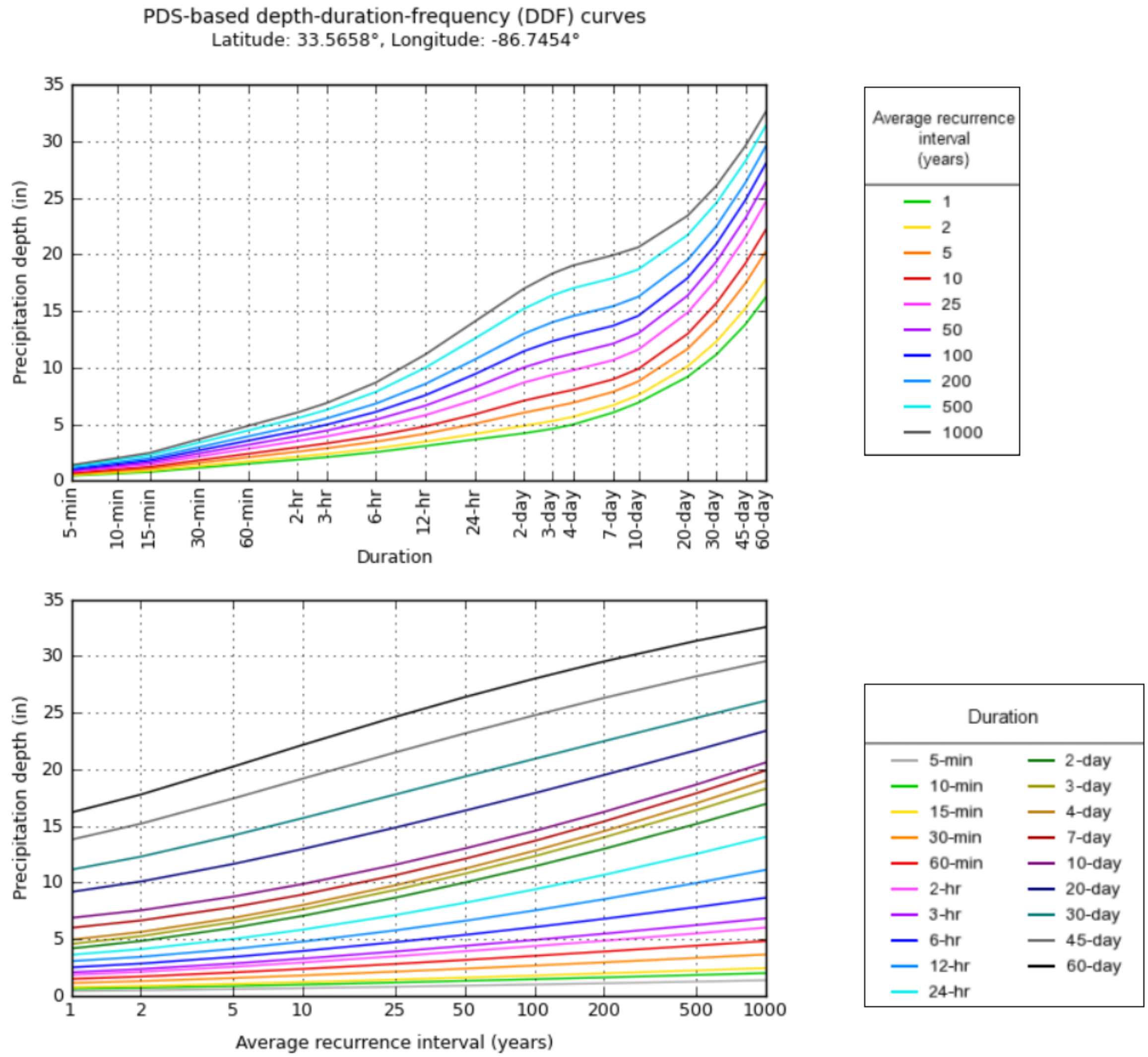


Figure 3-15. IDF graphs for Shuttlesworth International Airport, Birmingham, AL, from NOAA Atlas 14.

In addition, the Atlas 14 individual volumes include detailed documentation for each precipitation station used for the analyses, plus provide much additional information.

Rainfall Distributions

Figure 3-16 shows the historical SCS rain distribution types that are used in urban drainage design. These cumulative rain distributions show how the rain intensities vary throughout these hypothetical events. The slope of this curve, averaged over the time of concentration and multiplied by the rainfall depth, results in the rain intensity that would be plotted on an IDF curve for each hypothetical distribution. Most of the US were assigned type II rains, but the gulf coast and eastern seaboard used Type III rains. Types I and IA are used in some parts of the western states.

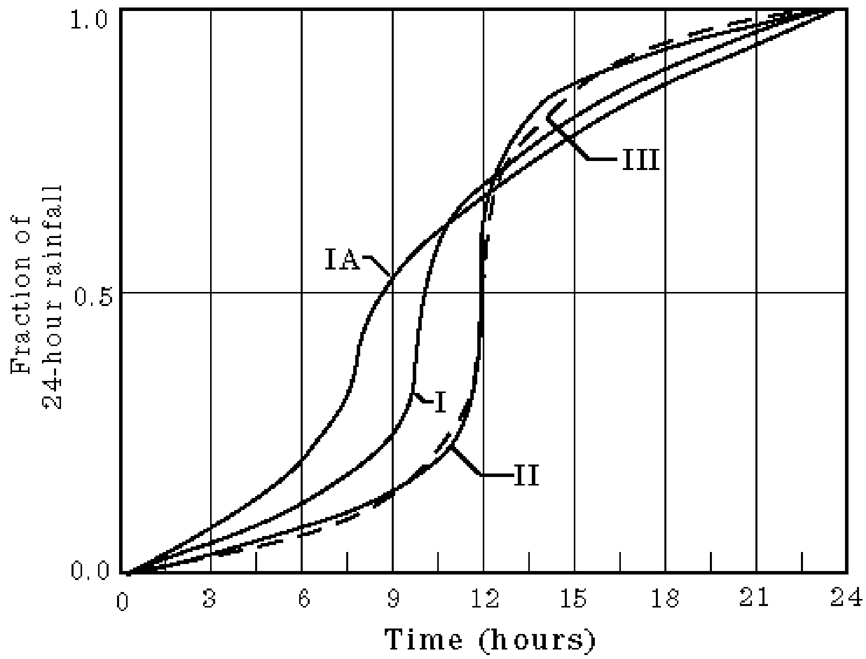


Figure 3-16. Cumulative distribution curves for different historical SCS rain types.

NRCS TR-55 includes maps showing these regions for most areas in the US. WinTR-55 also automatically selects the appropriate rainfall distribution based on the location description entered while using the program. As described later, the NRCS is currently revising the curve number hydrology methodology. As of late 2018, these revisions were still being reviewed and have not yet been released. It is not known when WinTR-55 will be revised. Use of the selected hydrology methodology supporting analyses and design of construction site erosion controls should be approved by the local review agency. It is likely that the regulatory authority will specify one or two hydrologic methods to be used in calculating peak runoff rates and volumes for construction sites.

Around 2006, the USDA NRCS completed a study showing that the long used SCS Type 2 and Type 3 rainfall distributions were no longer valid in the majority of the northeastern states. This was primarily due to the fact that the former distributions were based on the 1961 TP-40 rainfall data that only included 22.5 years of rainfall data. With at least 45 more years of rainfall data, and more powerful analytical capabilities, new rainfall distributions were developed indicating variations over smaller areas. In 2008, the USDA NRCS in New York spearheaded this effort, with some other state agencies, for all of the New England states to develop precipitation data for the Northeast. The resulting precipitation distribution regions for New York are shown on Figure 3-17. NOAA eventually completed an Atlas 14 update for the Northeast in 2017. Results between the two agencies do not always agree, which also occurs on boundaries between the different states in different Atlas 14 chapters. NOAA indicates that these differences are usually associated with slightly varying amounts of rainfall data available when the different chapters were prepared. It is expected that these new distributions and IDF data will be incorporated into computer-based hydrology tools in the coming years.

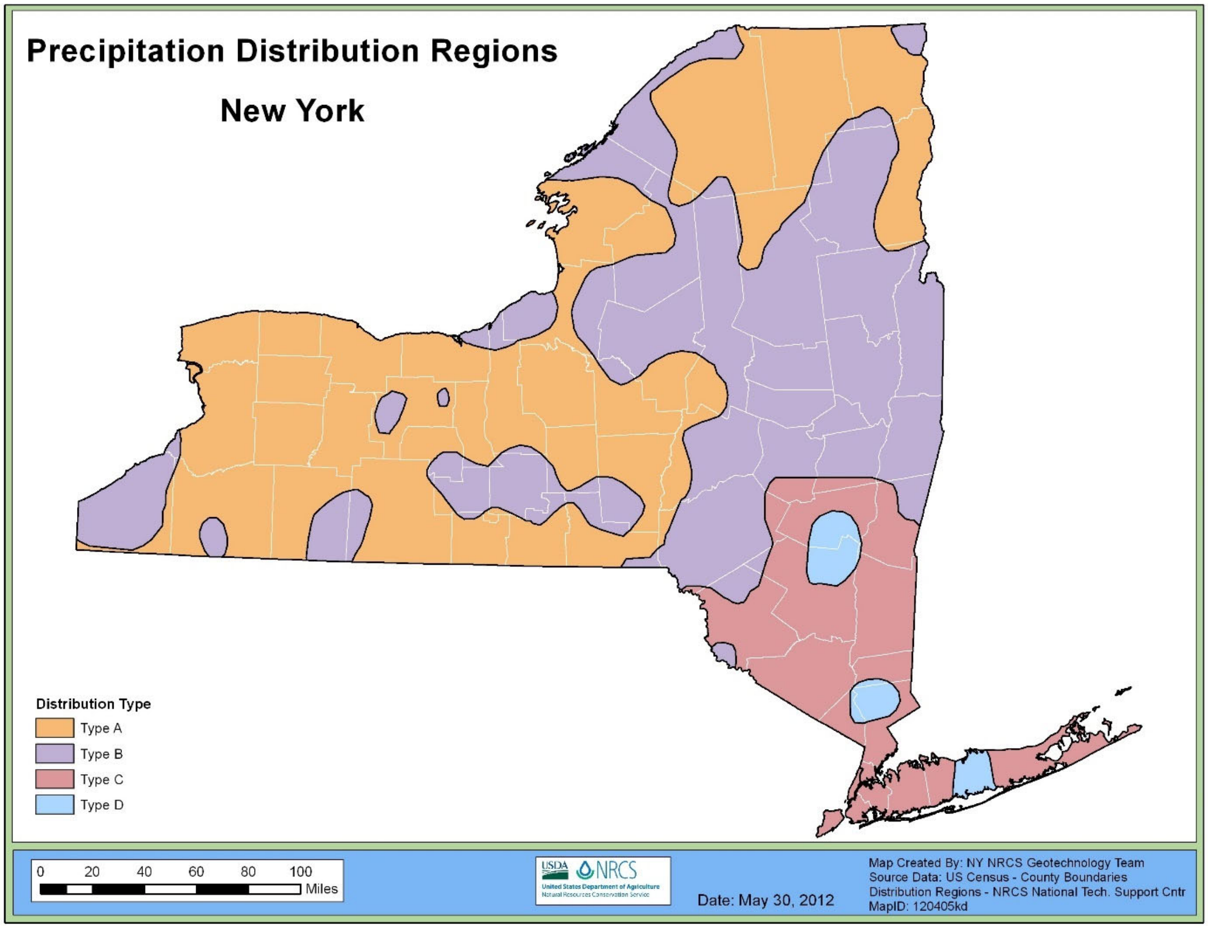


Figure 3-17. Rainfall distributions for New York.

Selection of Design Storms for Varying Risks and Project Durations

The selection of appropriate construction site erosion and sediment control practices must consider potentially high runoff flow rates corresponding to design storms in the 2-year frequency range, which are significantly larger than most runoff events. As an example, the use of silt fences is not recommended in channels due to the force of the water on the limited strength of silt fence systems. Silt fences are most suitable for controlling sheetflows originating from relatively small areas. More robust sediment control practices, such as wet detention ponds, are needed to treat runoff from large areas. Similarly, the use of unreinforced mulches can only be used on flat slopes with small contributing areas (and even then, the mulches can "float" away during moderate to large rains). The following describe how to select an appropriate design storm based on acceptable failure rates and exposure periods.

The following equation (from McGhee 1991) can be used to calculate the probability that a rain having a return period of "n" years, will occur at least once in "y" years:

$$P = 1 - \left(1 - \frac{1}{n}\right)^{y}$$

This equation can be reworked to relate the service life to the needed design return period and probability of exceedance (or failure).

$$P = 1 - \left(1 - \frac{1}{T_{needed}}\right)^{\text{design life}}$$

$$1 - P = \left(1 - \frac{1}{T_{needed}}\right)^{\text{design life}}$$

$$(1 - P)^{\left(1/\text{design life}\right)} = 1 - \frac{1}{T_{needed}}$$

$$(1 - P)^{\left(1/\text{design life}\right)} - 1 = -\frac{1}{T_{needed}}$$

$$1 - (1 - P)^{\left(1/\text{design life}\right)} = \frac{1}{T_{needed}}$$

$$T_{needed} = \frac{1}{1 - \left[(1 - P)^{\left(1/\text{design life}\right)}\right]}$$

Figure 3-18 is a plot illustrating this relationship, but modified to show the probability of an event not being exceeded during the design period. As an example, if one needs to be certain, with a 90% probability, that a failure would not occur during a 5-year project period (the exposure period, or T_d), the appropriate design storm frequency for this condition would be a storm having a 50 year return period (T).

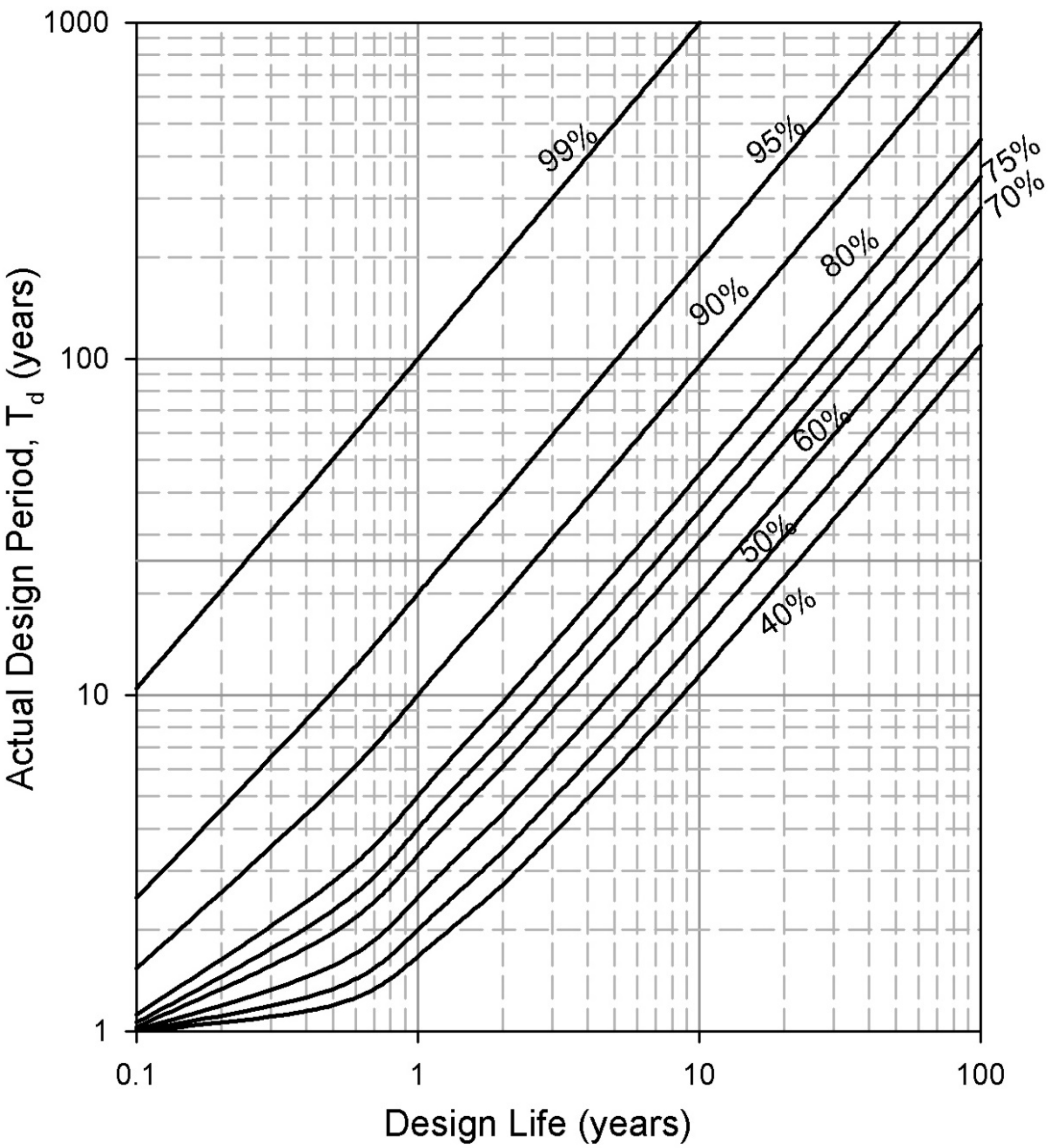


Figure 3-18. Probability, expressed as a percent, of a design storm (design return period) not being exceeded during the project life (design period) (from McGhee 1991).

Obviously, if failure could possibly lead to serious property damage or loss of life, then the probability of an event that may cause such failure not occurring during the project design life will need to be very large. Similarly, if only minor inconvenience will be associated with a failure, then the probability of that event not occurring during the design period can be much less. Table 3-8 illustrates several examples for a typical construction period of one year. The design storms could therefore vary greatly for different temporary elements on the same project site. A silt fence failure may not be very serious if the site runoff is also being captured by a downstream sediment pond. However, the failure of the pond could cause much greater problems. Similarly, the slope along a filled embankment near a building foundation could cause structural failure if massive erosion occurred on the slope. In these cases and for a one year construction period, the silt fence may be designed using a 2-year design storm (acceptable failure probability of 50% in the one year period), the pond may require a 10-year design storm (acceptable failure probability of 10% in the one year period), while the slope near the building may need a 20+-year design storm (acceptable failure probability of <5% in the one year period).

Table 3-8. Design Storm Return Periods Associated with Different Probability Levels for a 1-year Construction Period

Probability of storm not being exceeded in a one year (T_d on Fig 3.18) construction period	Design storm return period (T on Fig 3.18) (yr)
50%	2
75%	6.5
90%	10
95%	20

Methods of Determining Runoff

Many different methods of computing runoff have been developed. Some of the methods and limitations of each are summarized on Table 3-9 and in the paragraphs below (from Illinois 1989).

Table 3-9. Selection Criteria for Runoff Calculation Methods (Illinois 1988)

Output Requirements	Drainage Area	Appropriate Method				
Peak Discharge Only	Up to 20 acres	1		3	4	5
	Up to 2,000 acres		2	3	4	5
	Up to 5 square miles		2	3		5
	Up to 20 square miles		2	3		5
Peak Discharge and Total Runoff Volume	Up to 2,000 acres		2	3	4	5
	Up to 5 square miles		2	3		5
	Up to 20 square miles		2	3		5
Runoff Hydrograph	Up to 5 square miles		2	3		5
	Up to 20 square miles		2	3		5

1 Rational Method
2 SCS TR-20 Method
3 SCS TR-55 Tabular Method
4 SCS TR-55 Graphical Peak Discharge Method
5 COE HEC-HMS Method (replaced COE HEC-1)

1. The Rational Method

The Rational Method is an empirical formula used for computing peak rates of runoff that has been used in urban areas for over 100 years (Q=CiA). It is useful for estimating runoff on relatively small areas such as roof tops, parking lots, or other homogeneous areas. Use of the Rational equation should be limited to drainage areas less than 20 acres that do not vary in surface character and do not have branched drainage systems. The most serious drawback of the Rational Method is that it gives only the peak discharge and provides no information on the time distribution of the storm runoff, disallowing hydrograph routing through the drainage system or storage structures. Newer methods that would allow runoff hydrographs to be developed based on a modified Rational Method have been proposed. Furthermore, the choice of “C” and “T_c” when choosing “i” in the Rational Method is more an art of judgment than a precise account of the antecedent moisture condition. It also is not an aerial distribution of rainfall intensity. Many errors have been reported in the use of the Rational Method, and it cannot be easily verified. Modifications of the Rational Method have similar limitations. The Rational Method may be applicable in small, isolated sections of construction sites. For example, the Rational

Method will be used later in this chapter, and in the next chapter, for predicting sheetflow runoff depth needed for shear stress calculations for isolated slopes.

2. SCS TR-20 Method

The SCS-TR-20 computer program uses hydrologic soil and cover runoff curve numbers to determine runoff volumes, and it uses synthetic unit hydrographs to determine peak rates of discharge and combined hydrographs. Factors needed to use the method are the 24-hour rainfall amount, a given rainfall distribution, runoff curve numbers, time of concentration, travel time, and drainage area. This procedure probably should not be used for drainage areas less than 50 acres or more than 20 square miles. It is very useful for larger drainage basins, especially when there are a series of structures or several tributaries to be studied. A Windows version of TR-20 is available, making the method easier to use. As described later, the NRCS is currently revising the curve number hydrology methodology. As of late 2018, these revisions were still being reviewed and have not been released. It is not known when TR-20 routing will be revised. Use of the selected methodology should be approved by the local review agency.

3. SCS TR-55 Tabular Hydrograph Method

The SCS TR-55 Tabular hydrograph is an approximation of the more detailed SCS TR-20 method. The Tabular Method divides the watershed into subareas, computes an outflow hydrograph for each, and then combines and routes each subarea hydrograph to the outlet. It is especially useful for measuring the effects of changing land use in a part of a watershed. It can also be used to determine the effects of hydraulic structures and combinations of structures, including channel modifications, at different locations in a watershed. The Tabular Method should not be used when large changes in the curve number occur among subareas within a watershed and when runoff volumes are less than about 1.5 inches for curve numbers less than 60. For most watershed conditions, however, this procedure is adequate to determine the effects of urbanization on peak rates of discharge for subareas up to approximately 20 square miles in size. The Windows version of TR-55 has many improvements and is much easier to use than the older manual method or the original DOS computer version. It is applicable for many conditions at construction sites and will be described later in this chapter. As noted above, the NRCS is currently revising the curve number hydrology methodology. As of late 2018, these revisions were still being reviewed and have not yet been released.

4. SCS TR-55 Graphical Method

The SCS TR-55 Graphical Method calculates peak discharge using an assumed unit hydrograph and an evaluation of the soils, slope, and surface cover characteristics of the watershed. The assumed unit hydrograph is based on design considerations rather than meteorological factors. Correction factors for swampy or ponding conditions can be used. This method is a component of the older TR-55 procedures and is not included in the new Windows version of TR-55. It is not a very suitable tool, as it has most of the same limitations as the Rational Method (specifically no hydrograph routing capabilities). As noted above, the NRCS is currently revising the curve number hydrology methodology. As of late 2018, these revisions were still being reviewed and have not been released.

5. US Army Corps of Engineers HEC-1/HEC-HMS

The COE-HMS provides similar site evaluations as the SCS TR-20. It is a rainfall-runoff model that can be calibrated to gauge records. Like TR-20, it can be used on both simple and complex watersheds. Several years ago, the older HEC-1 was superseded by the HEC-HMS (Hydrologic Modeling System) that is a Windows-based program and much easier to use. Because of its complexity, it is not a very suitable tool for use at most construction sites. However, if complex conditions exist, like at some highway sites where relatively large streams are crossed by the construction activities, its use may be warranted.

6. HydroCAD Modeling
This commercially available software provides similar site evaluations as those noted above but has the additional flexibility to analyze hydrology using the SCS TR-20 and TR-55 methodology or the rational method. It also has optional routing methods and parameter selection to compare results of a wide variety of hydraulic structures. It can handle simple and complex watersheds, including small drainage areas such as parking lots. It provides results connected specifically to the site elevation datum.

Note on Current Revisions to Curve Number Rainfall-Runoff Methodology
The USDA NRCS began investigating their compilation and use of the runoff curve number process back in the mid 1990's. A preliminary report outlining some of the premises and processes was published as an internal document in 2002. The issues discussed primarily centered around the fact that initial abstraction, Ia, should be set at 0.05S instead of 0.2S, S being the maximum retention after runoff begins. In the fall 2017, internal draft documents supporting this Ia change were sent out for comments within the agency. As of late 2018, these changes are still being reviewed. This change would result in a significant change regarding hydrologic calculations, especially for small rains where the initial abstractions comprise a large portion of the total rain depth.

Perhaps an even bigger change has been the development of an additional twelve unit peak discharge factors ranging from 100 cfs to 600 cfs. This was published in the USDA NRCS Part 630, Chapter 16, Hydrographs, of the *National Engineering Handbook* (March 2007). Historically, the SCS unit peak discharge factor (Qp) was 484. This was based on nationwide examples of over 300 watersheds. This Qp was used by all initially and still used by most practitioners. Modification of this Qp were made in certain locales based on detailed hydrologic studies, such as the Delmarva area, New Mexico, Santa Barbara, and others. Obviously, the higher Qp used, the higher the total discharge will be, and conversely. The 2015 update to WinTR-55 (described later) contains a set of supplemental unit hydrographs that can be selected.

Watershed Delineation
One of the first steps in conducting a hydrologic evaluation of an area is to delineate the watershed area draining to the location of concern. For construction sites, this may include determining the area draining to a sediment pond, the area draining to a silt fence, the area draining to a diversion channel, etc. Most engineers now rely on computer generated watershed delineations as part of their GIS design packages. A basic understanding of how these are developed, as described below, is needed to review these automated tools. The following discussion outlines a general approach in determining the watershed boundaries.

Topographic Map Data Sources
The fundamental source of data for delineating and studying watersheds is the U.S. Geological Survey Quadrangle map. Each "Quad Sheet" map covers 7.5 minutes of longitude and latitude. These maps give a wealth of information including topographic contour lines, locations of cities, buildings, roads, road types, railroads, pipelines, water bodies, forested land, stream networks, and USGS stream gauging stations and benchmarks. The quad sheets typically have a scale of 1:24,000 (i.e., 1 inch on the map = 24,000 inches on the land). Depending on the age of the map, elevation data may be in US Customary or Metric units. Typically, in the Midwest, the contour intervals of the elevation data are 5 feet or 1.5

meter. In the south, the contour intervals may be 20 ft. For watershed delineation, quad sheets offer an important starting point. However, for detailed investigations, especially for small areas, more detailed site maps having 1 to 5 ft contour intervals are usually required for final analyses. Many of the quad sheets are available on the Internet, although at relatively low resolution and for small areas at a time. Internet aerial photographic sources are also valuable to understand cover and development conditions. Some of these available aerial photographic sources are quite dramatic, with increasing resolution and coverage being constantly added. Detailed site maps are usually produced by the site developer. These may be available to others from the regulatory reviewing agency.

Many states have map layers available for GIS at the 2-ft contour resolution. For example, in Pennsylvania, the Pennsylvania Spatial Data Access website (https://www.pasda.psu.edu/uci/SearchResults.aspx?Shortcut=topo) has multiple GIS layers, typically as kmz files, of topographic data. This data can be imported into software such as Google Earth® or ArcGIS software, thus improving the resolution of delineation and the understanding of flow paths in the area of interest. For Dauphin County, PA, the QL2 LIDAR from USGS were downloaded from PASDA and imported into ArcGIS® Online MapView to produce the map in Figure 3-19. The old 20-ft contour lines can be seen in the background as faint gray lines. The level of detail from the LIDAR can provide the site designer with a better understanding of the topography and flow paths on smaller sites.

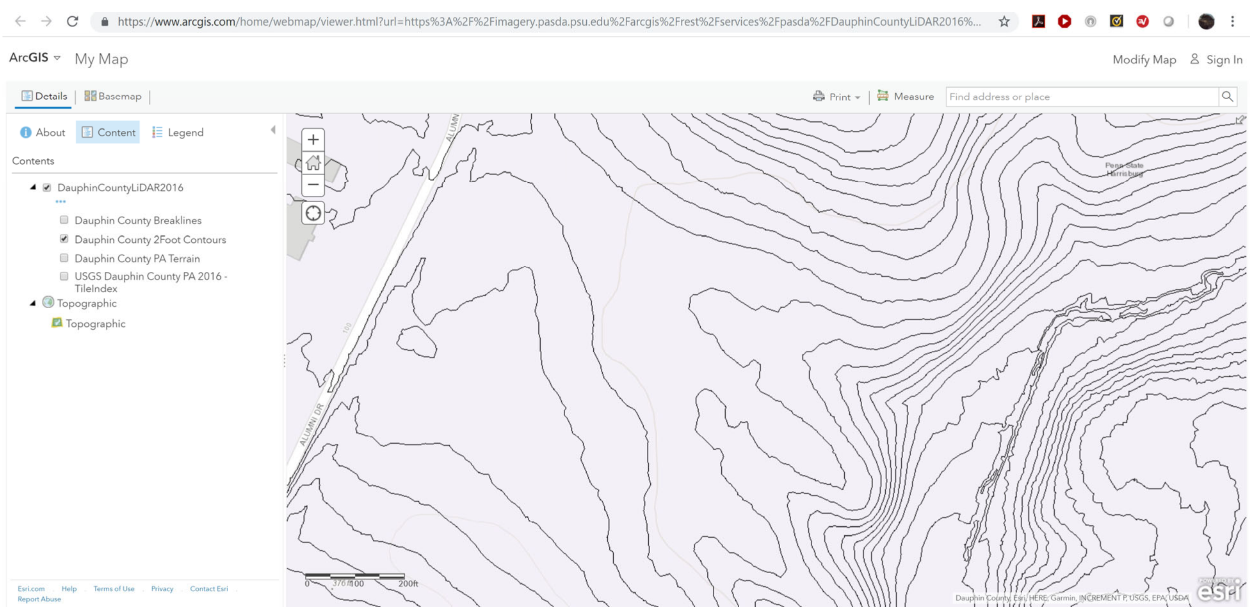


Figure 3-19. Comparison of USGS Quadrangle Contour Map (faint gray lines) versus USGS 2016 LIDAR information (black lines).

Steps in Determining the Watershed Boundaries

The wide availability of GIS and LIDAR data has encouraged the use of digital elevation modeling (DEM) to establish drainage area boundaries. However, it is important for the engineer to understand how to perform this task by hand because of mistakes that can be made by the computer in drawing the DEMs. One example of this is the use of StreamStats to delineate the watershed for the Penn State Harrisburg campus. Figure 3-20 shows the stream network in the PA layer (bold blue lines) on top of the National

Map, where the actual survey stream passing through the campus is shown in blue lines in the background.

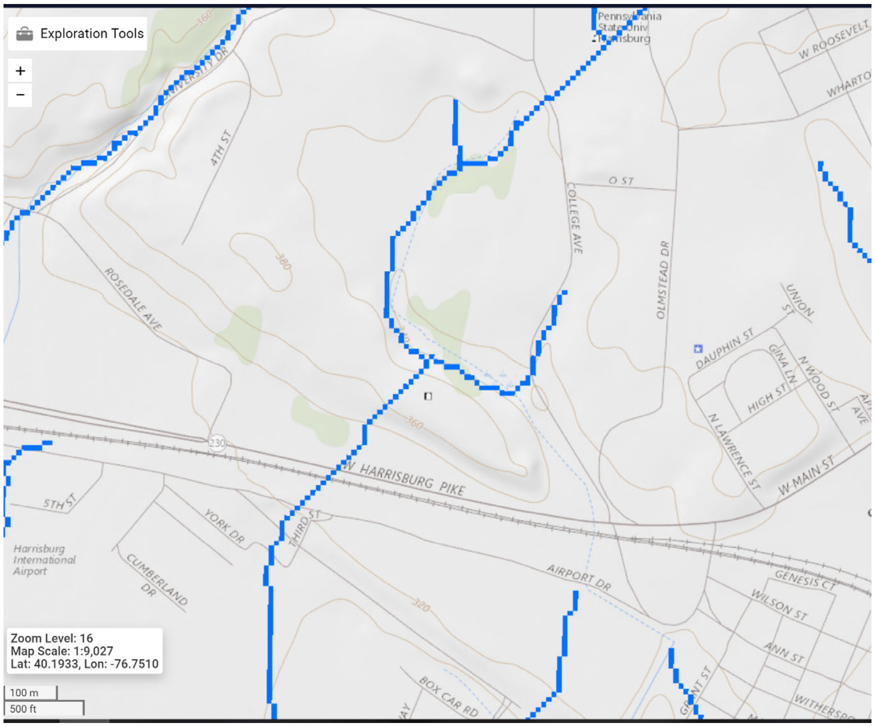
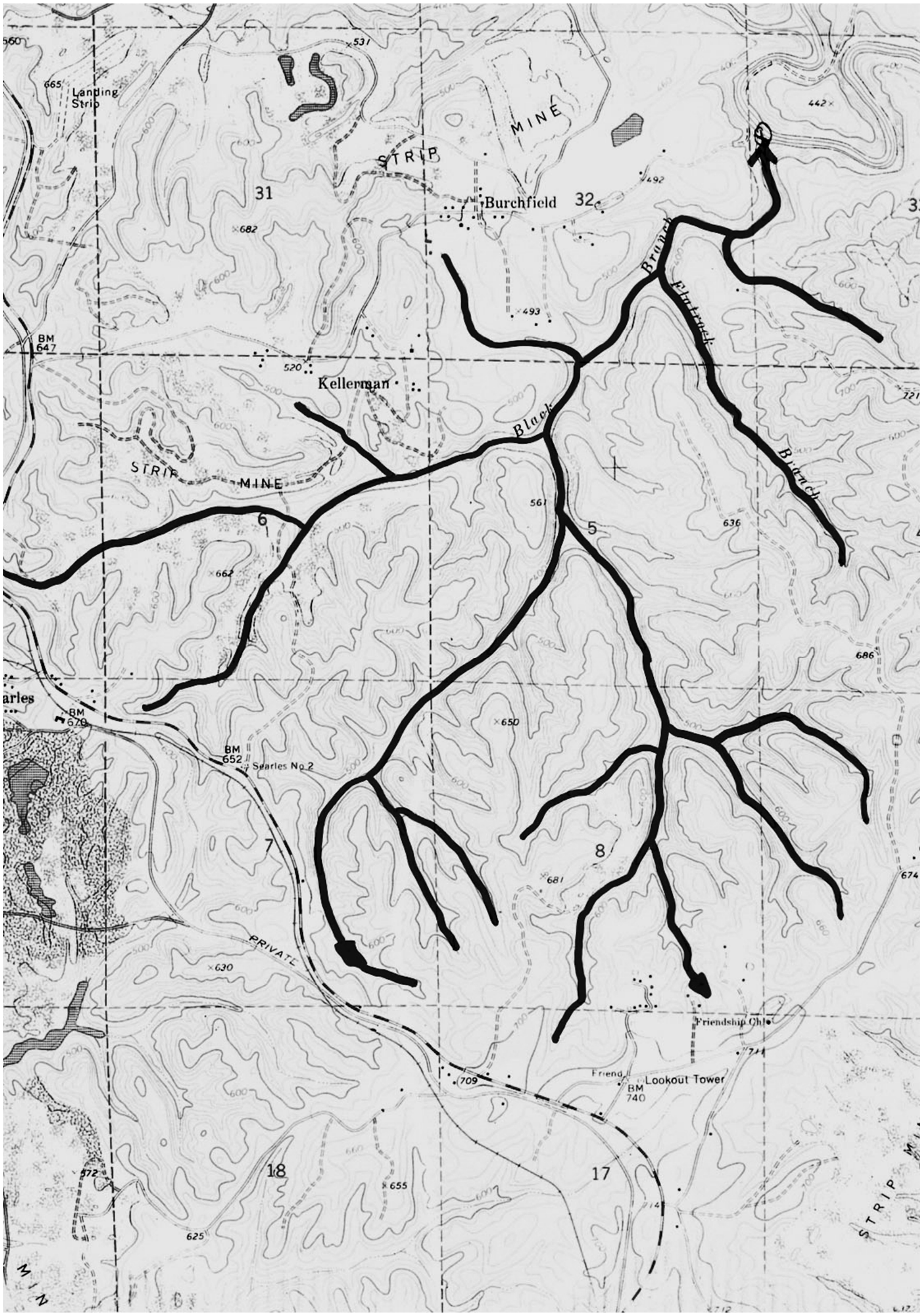


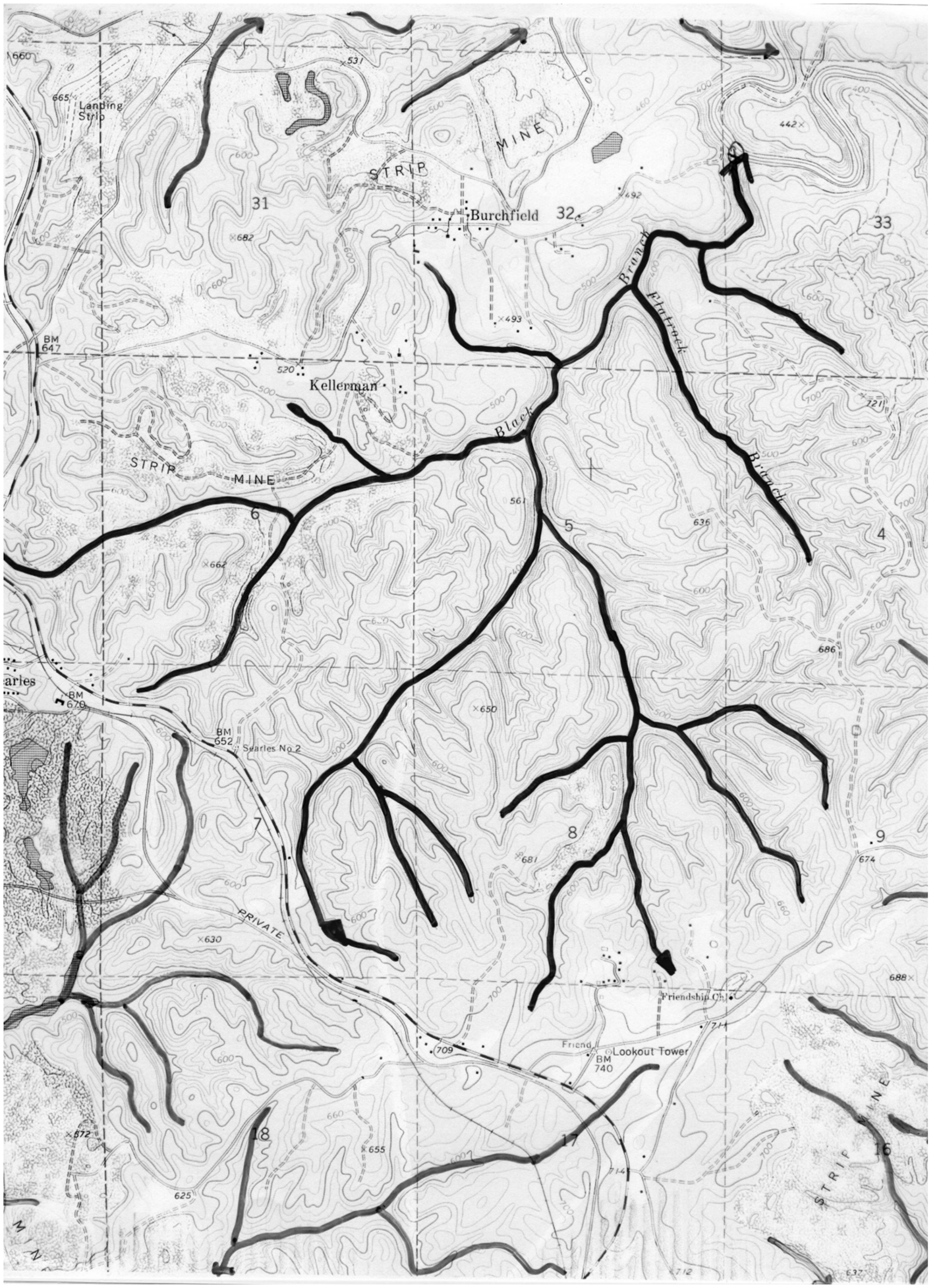
Figure 3-20. StreamStats stream mapping versus current stream network.

The following is a brief outline of the steps that can be followed to determine the watershed boundaries of a drainage area affecting a specific location.

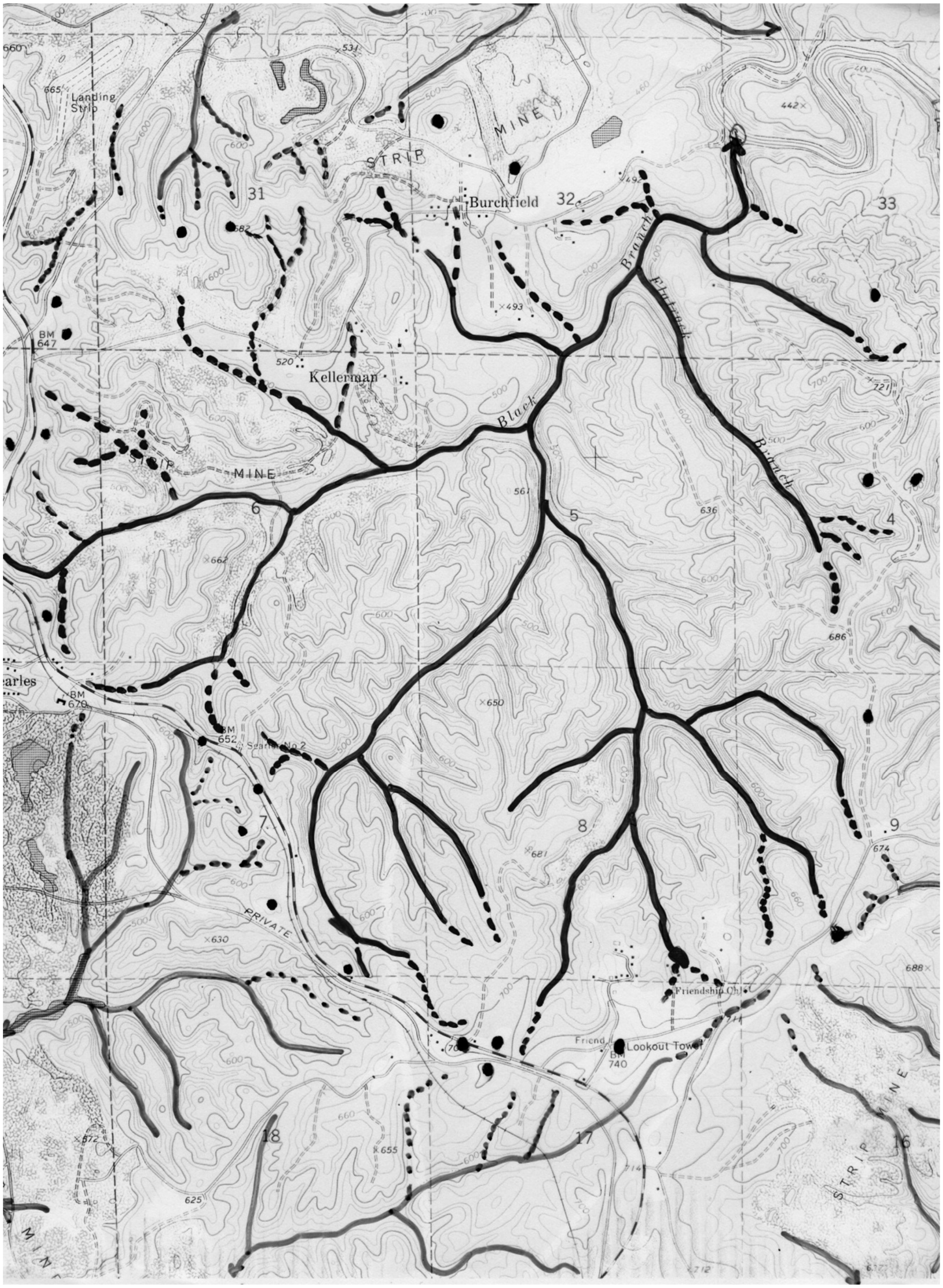
1. Trace out the main drainage pathways upstream from the point of concern. It is suggested that a medium point marker trace the blue line representing streams on the quad sheet upstream from the point of concern, as in the following map:



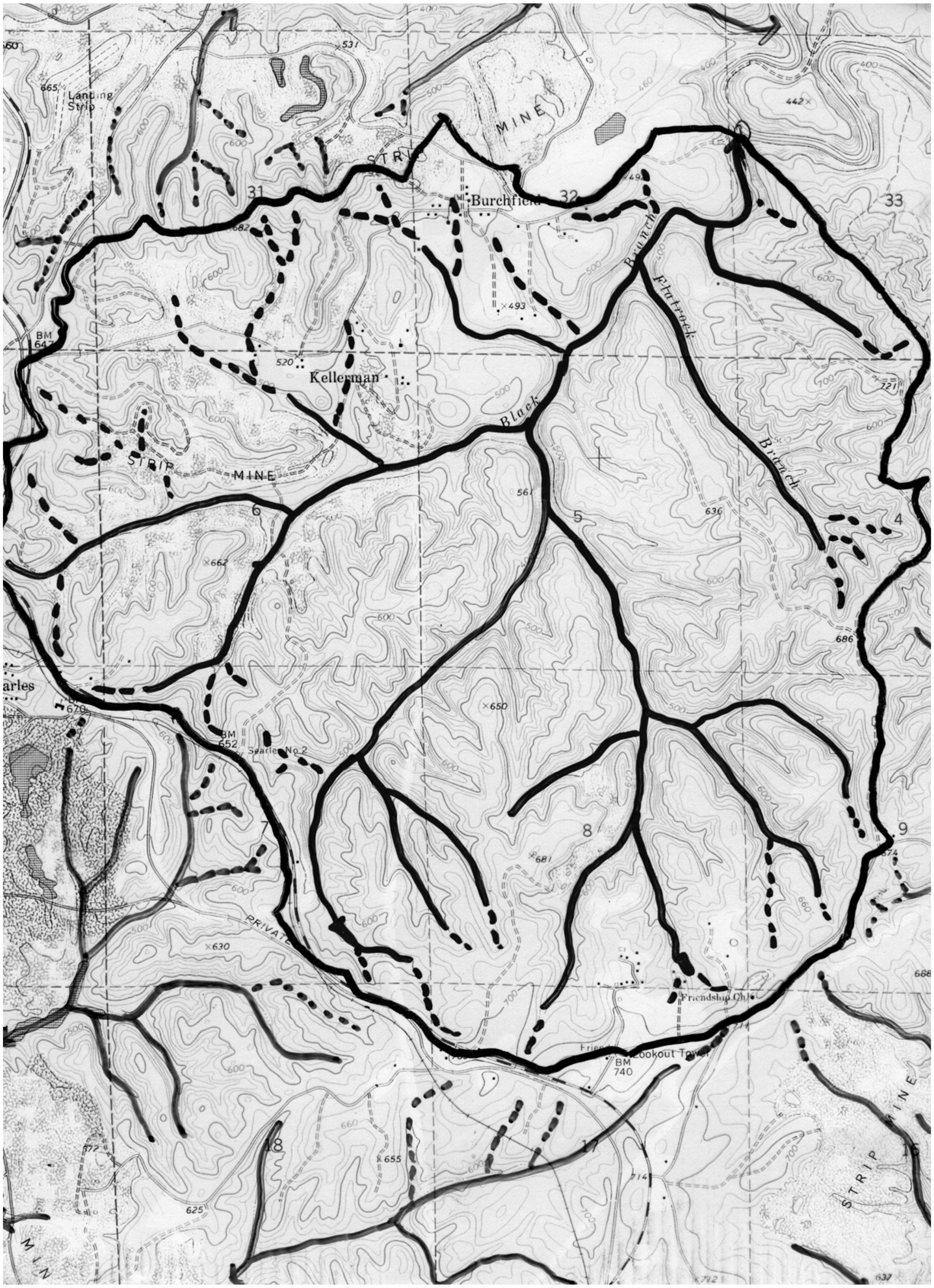
2. Using a different color, trace the drainage pathways marked on the quad sheet draining away from the area, as shown on the following map:



3. Extend the drainage way highlights along obvious drainage pathways, such as gullies/ravines. Also, locate the peaks along the ridges between these drainage systems with a large dot in the center of enclosed contours:



4. Starting at the bottom of the area at the location of interest, connect the peaks between the drainage systems along the ridges to delineate the watershed boundary. Make sure the watershed boundary line only crosses the topographic lines at 90 degree angles.



5. Make modifications to the watershed boundary to consider anthropogenic modifications to the landscape. A site survey should identify locations that are different than described on the

(usually outdated) quad sheets. In the above example, the site has been extensively strip mined. This example also has roads that are near the ridges that serve as watershed boundaries. Roads are notorious in affecting the local drainage patterns. Roadside ditches commonly collect water from the watershed of interest, but divert it alongside the road and then let it drain into an adjacent watershed. Also, culverts may collect water from parts of an adjacent drainage area and discharge the water into the watershed of interest. Finally, buildings may be constructed on the watershed divide itself (fairly common in small urban drainage areas). Roof drains, graded paved parking lots, and other disturbances can frequently divert small fractions of adjacent watersheds back and forth. In these areas, it is best to carefully examine the expected watershed boundary and account for these modifications, depending on the needed accuracy of the area calculations (most critical for small watersheds).

Use of the SCS (NRCS) TR55 Method for Construction Site Hydrology Evaluations

The NRCS curve number method and associated tools for calculating runoff characteristics is undergoing revisions and updates. These changes are still being reviewed by the agency and outside reviewers as of late 2018. Therefore, the use of these tools for the design of construction site sediment controls should be approved by the local agency.

The American Society of Civil Engineers (ASCE) and the American Society of Agricultural and Biological Engineers (ASABE), with NRCS support, have developed updates to the curve number rainfall-runoff hydrology methods as used in the NRCS National Engineering Handbook (NEH), part 630, chapters 8, 9, 10, and 12. The changes include much more guidance on the selection and use of the curve numbers, mostly to better match peak discharges for large events, and to better incorporate data for agricultural and forest land uses, and Karst areas. The changes also include guidance on modifying the curve numbers for green roofs and porous pavements. Curve number changes by season are also incorporated in the planned revisions, among many other modifications. As noted, these changes are still in draft form and not yet approved for release. Moglen, *et al.* (2018) show that the proposed NRCS methods indicate that existing stormwater drainage infrastructure are under-designed for smaller storms and lower curve numbers. The calculated peak flows for storms with return periods in the range of about 2 to 10 years may be low by as much as 3 times, depending on site and storm characteristics. However, larger storms having return periods of 25 to 100 years may be over-designed (with 0.8 to 1.0 peak flow ratios).

Most of the calculations for construction sites are in the smaller storm category, but with some controls needing consideration for larger storms. Therefore, special care needs to be taken considering possible under-designing of the hydraulic components associated with the smaller storms. Again, approval of the review agency is needed to verify the methods used and resulting calculated flows. The following subsections summarize the historical information, as a guide in the general application of the calculations.

General Description of TR55 for Small Watersheds

The complete User Guide for TR55 (1986 version) can be downloaded from: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf. According to the NRCS (2002), Technical Release 55 (TR55) Hydrology for Small Watersheds was first issued in January 1975 as a simplified procedure to calculate the storm runoff volume, peak rate of discharge, hydrographs and storage volumes required for storm water management structures (SCS 1975). This initial version involved manual methods and assumed the Type II rainfall distribution for all calculations. In June 1986, major revisions were made to TR55 by adding three additional rainfall distributions (Type I, IA and III) and developing a DOS-based computer program. Time of concentration was estimated by splitting the hydraulic flow path into separate flow phases (SCS 1986). This 1986 version is the last non-computerized version and has been widely used for drainage design in urban areas.

Even though the manual version of TR55 is currently being phased out, its use may still be of interest when examining construction sites and for review of computer assisted calculations. In addition, the User Guide for TR55 (SCS 1986) contains a more thorough description of the basic processes included in the model. A later discussion presents a description and example of the Windows version of the program.

Only the following site characteristics are needed to use TR55: drainage area, curve number (CN), and time of concentration (T_c). With this information, it is possible to develop a hydrograph for a specific design storm. In a complex drainage area, the watershed should be subdivided into relatively-homogeneous subwatersheds for routing the flows through the system. The following paragraphs describe the elements of TR55 that are of most interest for use on construction sites, and present examples for its use.

Selection of the Curve Number

The first part of using TR55 is to select the curve number. The curve number is simply the single parameter that relates runoff to rainfall. This is illustrated in Figure 3-21. The following equation shows how the CN is used to calculate the runoff depth, Q (in inches), from the precipitation depth, P (in inches), and the curve number, CN (dimensionless):

$$Q = \frac{\left[P - 0.2\left(\frac{1000}{CN} - 10\right)\right]^2}{P + 0.8\left(\frac{1000}{CN} - 10\right)}$$

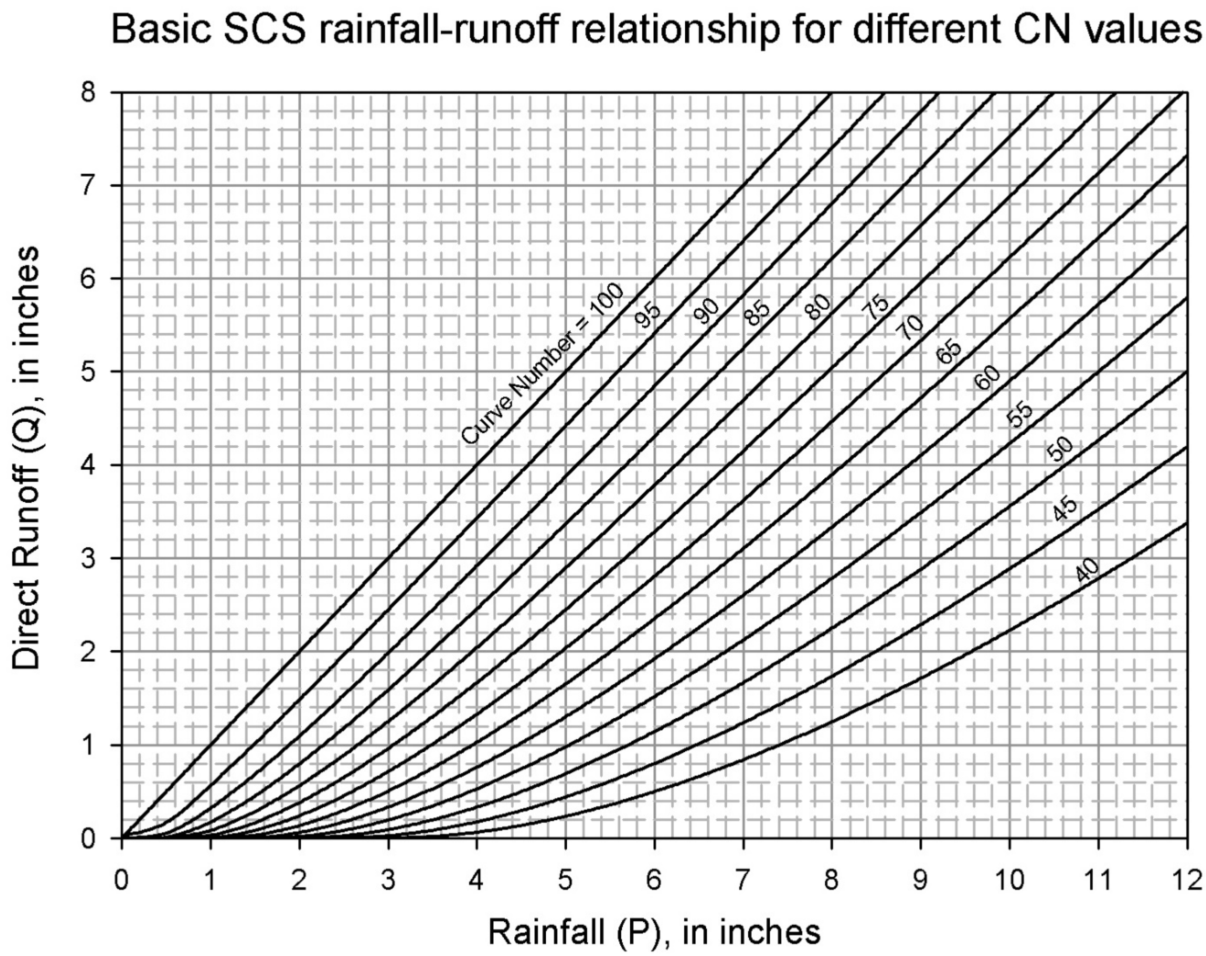


Figure 3-21. Basic SCS rainfall-runoff relationship for different CN values (SCS 1986).

Tables 3-10 and 3-11 are used to select the most appropriate curve numbers for an area. For construction sites, Table 3-10 shows that newly graded areas have curve numbers ranging from 77 for A type soils to 94 for D type soils. These are relatively high compared to typical pre-development conditions (woods ranging from 30 to 77), reflecting the increase in runoff volume during the period of construction and the associated increased runoff rate.

Table 3-10. Typical Curve Number Values for Urban Areas (SCS 1986)[1]

Land Use Description/Treatment	Hydrologic Condition	Hydrologic Soil Group			
		A	B	C	D
Residential[2]					
Average lot size:	Average Percent Imperviousness[3]				
1/8 acre or less	65	77	85	90	92
¼ acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
½ acre	25	54	70	80	85
1 acre	20	51	68	79	84
Paved parking lots, roofs, driveways, etc.[4]		98	98	98	98
Streets and roads					
Paved with curbs and storm sewers3		98	98	98	98
Gravel		76	85	89	91
Dirt		72	82	87	89
Commercial and business areas (85 percent imperviousness)		89	92	94	95
Industrial districts (72 percent imperviousness)		81	88	91	93
Open spaces, lawns, parks, golf courses, cemeteries, etc.					
Good condition: grass cover on 75 percent or more of the area		39	61	74	80
Fair condition: grass cover on 50 to 75 percent of the area		49	69	79	84
Poor condition: grass cover on less than 50 percent		68	79	86	89
Western Desert Urban Areas					
Natural desert landscaping (pervious areas only)[5]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Developing Urban Areas					
Newly developing areas (pervious areas only, no vegetation)[6]		77	86	91	94

[1]Average runoff condition, and Ia = 0.2S.
[2]Curve numbers are computed assuming the runoff from the house and driveway is directed toward the street with a minimum of roof water directed to lawns where additional infiltration could occur. Impervious areas have a CN of 98 and pervious space considered equivalent to open space in good hydrologic condition.
[3]The remaining pervious areas (lawn) are considered to be in good pasture condition for these curve numbers.
[4]In some warmer climates of the country, a curve number of 95 may be used.
[5]Composite curve numbers for natural desert landscaping should be computed using the following figures based on the impervious area percentage and the pervious area CN. The pervious area CNs are assumed equivalent to desert shrub in poor hydrologic condition.
[6]Composite CNs to use for the design of temporary measures during grading and construction should be computed using the following figures based on the degree of development (impervious area percentage) and the CNs for the newly graded pervious areas.

Table 3-11. Typical Curve Number Values for Pasture, Grassland, and Woods (SCS 1986)[1]

Cover Description		Curve Numbers for Hydrologic Soil Group			
Cover Type	Hydrologic Condition	A	B	C	D
Pasture, grassland, or range – continuous forage for grazing[2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow – continuous grass, protected from grazing and generally mowed for hay	--	30	58	71	78
Brush – brush-weed-grass mixture with brush the major element[3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30[4]	48	65	73
Woods-grass combination (orchard or tree farm)[5]	Poor	57	73	83	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods[6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30[4]	55	70	77
Farmsteads – buildings, lanes, driveways, and surrounding lots	--	59	74	82	86

[1]Average runoff condition, and Ia = 0.2S.
[2]Poor: < 50% ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.
[3]Poor: <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.
[4]Actual curve number is less than 30; use CN = 30 for runoff computations.
[5]CNs shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CNs for woods and pasture.
[6]Poor: Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed, but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Soil Characteristics

The hydrologic soil groups (HSG) shown on the curve number tables greatly affect the selected curve number for a specific cover type or land use type. The following are the descriptions for the four soil categories, as given by the SCS (1986):

> "Group A soils have low runoff potential and high infiltration rates, even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission (greater than 0.30 in/hr).
>
> Group B soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils, with moderately fine to moderately coarser textures. These soils have a moderate rate of water transmission (0.15 to 0.30 in/hr).
>
> Group C soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine textures. These soils have a low rate of water transmission (0.05 to 0.15 in/hr).

Group D soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly imperious material. These soils have a very low rate of water transmission (0 to 0.05 in/hr)."

Note that the definitions for the Hydrologic Soil Groups A through D were revised in Chapter 7 of Part 630 of the *NRCS National Engineering Handbook*, dated September 2009. These changes are now reflected in the data on the USDA NRCS web soil survey.

The transmission/percolation rates noted above are the rates that water moves within the soil and are controlled by the soil profile. These are not the same as the water infiltration rates which are the rates that water enters the soil at the soil surface and are therefore controlled by surface conditions. For undisturbed natural conditions, the soil characteristics are usually obtained from local county soil maps that are available from the county USDA offices for all areas of the US, or more commonly from the Web Soil Survey (described later). Consider the following example from a local county soil survey. Figure 3-22 is a small section of the soil survey map for the Cripple Creek Church area, adjacent to Cripple Creek and North River, in Tuscaloosa County, AL. The maps are also aerial photographs (usually several decades old) that show the presence of woods, agricultural operations, and land development features, along with waterways. The large numbers (15 and 22) are the county survey/deed record section numbers. For example, these sections are located in R. 10 W. and T. 18 S. The small numbers (21, 23, and 33) refer to the soil types within the dark outlines. These are the soils of interest for this area. About two soil samples per square mile were obtained and analyzed by USDA soil scientists in the preparation of these maps, so they are not absolutely accurate for small areas. They were able to extend the likely areas associated with each soil type based on surface features and aerial photographs. As an example, soil 21 (Montevallo) is generally in the bottom lands along the creeks. Table 3-12 lists some of the characteristics of these soils pertaining to erosion and runoff considerations, while Table 3-13 shows detailed particle-size information for samples obtained at different depths for Smithdale soil (the only one of these 3 with this information complete in the soil survey) and Table 3-14 lists some potential problems that may be encountered if the site is to be used for building development.

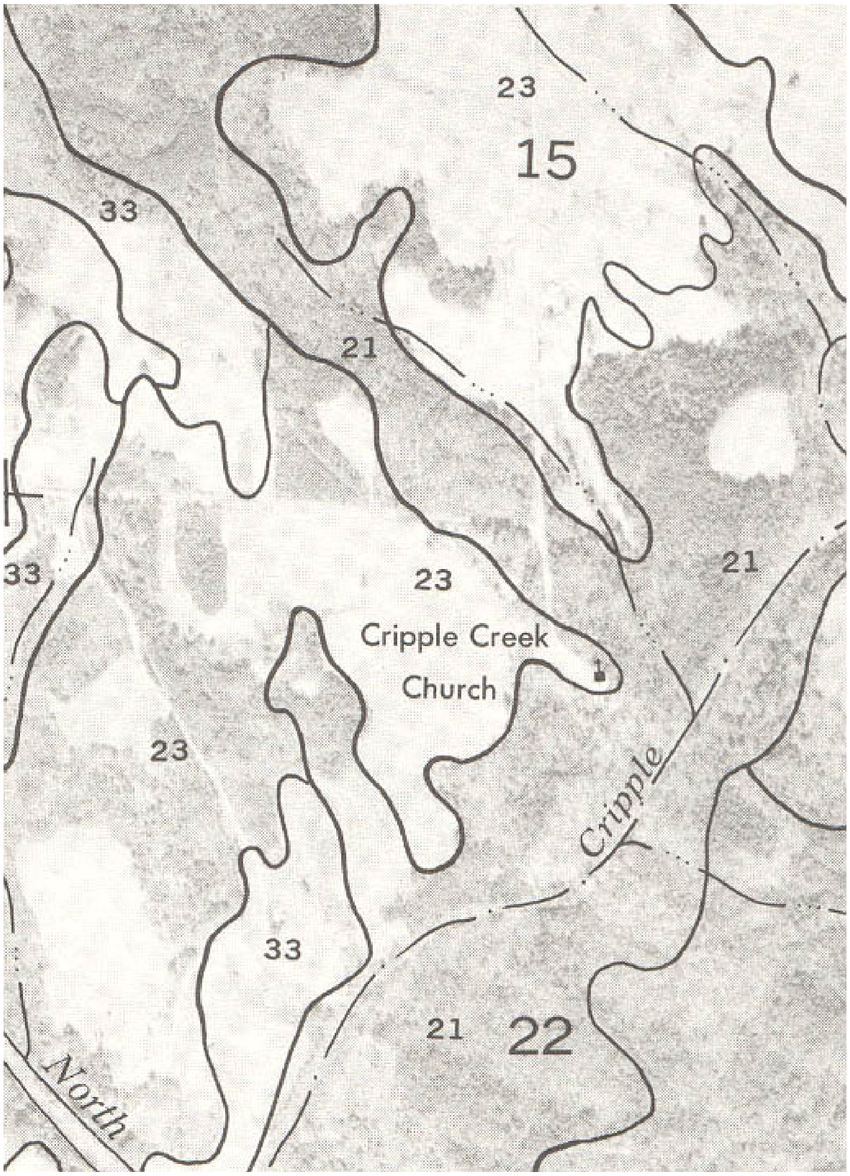


Figure 3-22. Cripple Creek Church, Tuscaloosa County, AL, soil survey.

Table 3-12. Soil Survey Characteristics for Area near Cripple Creek Church, Tuscaloosa County, AL

Soil number (name) and depth	Hydrologic Soil Group	Depth to Bedrock (inches)	Permeability (in/hr)	Erosion Factor, k	Tolerable Soil Loss, T (tons/ac/yr)	Organic Matter (%)
21 (Montevallo)	D	10-20			2	0.5-2
0-7			0.6-2.0	0.37		
7-12			0.6-2.0	0.32		
12-20			--	--		
23 (Nauvoo)	B	40-60			3	0.5-2
0-17			2.0-6.0	0.28		
17-35			0.6-2.0	0.32		
35-41			0.6-2.0	0.32		
41-60			--	--		
33 (Smithdale)	B	>60			5	0.5-2
0-5			2.0-6.0	0.28		
5-42			0.6-2.0	0.24		
42-72			2.0-6.0	0.28		

Table 3-13. Particle-Size Distribution for Smithdale Soil (percent in size category, less than 2 mm)

Sample Number	Depth (inches)	Horizon	Clay (<0.002 mm)	Silt (0.002 – 0.05 mm)	Sand (0.05 – 2.0 m)	Cation Exchange Capacity (meq/100 mL)
S77AL-125-11-1	0-5	Ap	2.8	29.2	68.0	3.65
S77AL-125-11-2	5-20	B21t	22.2	34.9	42.9	9.02
S77AL-125-11-3	20-42	B22t	20.2	29.1	50.7	5.36
S77AL-125-11-4	42-52	B23t	12.3	26.5	61.2	4.06
S77AL-125-11-5	52-72	B2t	21.2	12.8	66.0	3.52

Table 3-14. Building Site Development Limitations

Soil	Shallow Excavations	Local Streets and Roads	Dwellings with Basements	Lawns and Landscaping
21 (Montevallo)	Severe (depth to rock, slope)	Severe (slope)	Severe (depth to rock, slope)	Severe (droughty, slope, thin soil layer)
23 (Nauvoo)	Slight	Moderate (low strength)	Slight	Slight
33 (Smithdale)	Moderate (slope)	Moderate (slope)	Moderate (slope)	Moderate (slope)

The information summarized on these tables is only a small fraction of the tremendous amount of information in the soil surveys. Unfortunately, not all of this information can be used for developed areas, or for areas undergoing development. Soils are dramatically altered during construction projects. These changes range from stripping off the topsoil and compacting the remaining soil, to removing large amounts of native soils in cut operations, to bringing in large amounts of new material if fill is needed. The surface soils exposed to potential erosion and that affects the amount of runoff at the site can therefore vary for different construction phases.

Because of this, it is important to determine the native soils on the proposed construction site (an overlay of soil types is usually required for most erosion control plans). Widely varying soil characteristics on the site should be especially noted. Descriptions of how the soils (and topography) will be affected and changed are also needed, as is the description of the fill soil, if a fill soil will be used and if the description is known. The excavations and fills during different construction phases should be described by the depth of material to be removed, or brought in, as should the resulting surface soils. The SCS (1986) notes that due to urbanization, the soil profile may be considerably altered, and the soil survey data may not be applicable for final surface soil conditions. They recommend that the hydrologic soil group be estimated based on the soil texture. They provide the following list to estimate the soil groups, based on texture, provided that significant compaction has not occurred:

HSG	Soil Textures
A	Sand, loamy sand, or sandy loam
B	Silt, silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay

Figure 3-23 shows the standard USDA soil triangle with the hydrologic soil groups marked, based on the above categories.

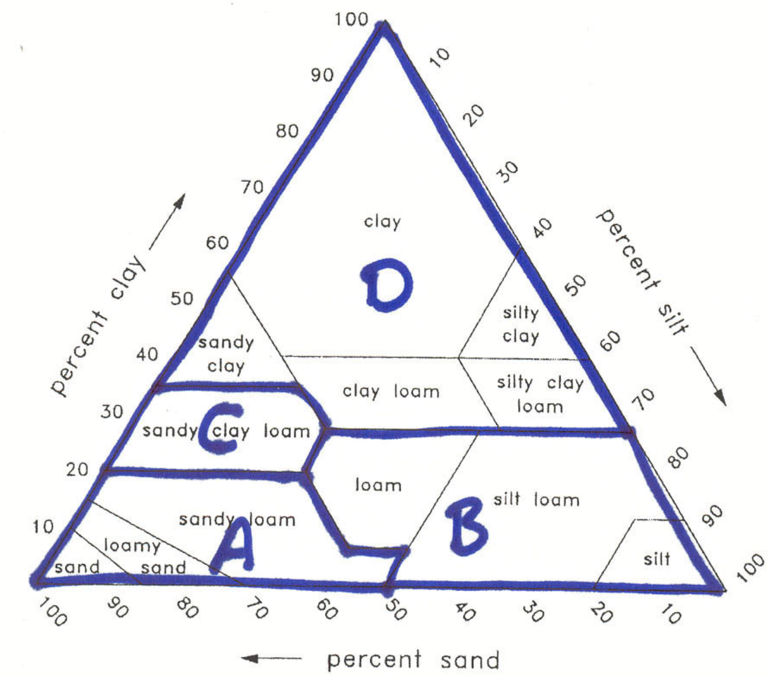


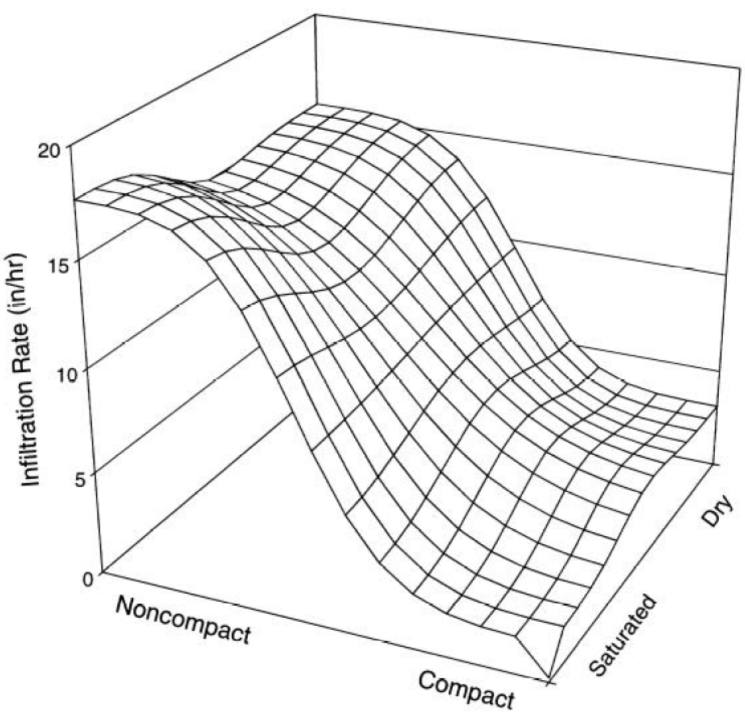
Figure 3-23. USDA standard soil triangle, with hydrologic soil groups for disturbed soils.

Soil characteristics for a site are most readily available from the USDA's Web Soil Survey (https://websoilsurvey.nrcs.usda.gov/app/HomePage.htm). As stated on the home page, "Web Soil Survey (WSS) provides soil data and information produced by the National Cooperative Soil Survey. It is operated by the USDA Natural Resources Conservation Service (NRCS) and provides access to the largest natural resource information system in the world. NRCS has soil maps and data available online for more than 95 percent of the nation's counties and anticipates having 100 percent in the near future. The site is updated and maintained online as the single authoritative source of soil survey information." This web service includes much information and guidance on its use. It must be remembered, however, that construction activities dramatically alter the soils at a construction site. Soil removal and importing new soil is common, in addition to extensive grading. Therefore, the Web Soil Survey information is best used to describe pre-development soil conditions, while the construction site geotechnical engineer would be most knowledgeable of soil conditions expected after development.

Even if the soil is not removed or replaced with other soils, other construction activities dramatically alter the soils characteristics. As an example, soil compaction can have severe effects on the runoff potential of soils and needs to be considered. As reported by Pitt, *et al*. (1999), unpublished double-ring infiltration tests conducted by the Wisconsin Department of Natural Resources (DNR) in Oconomowoc, Wisconsin, indicated highly variable infiltration rates for soils that were generally sandy (Natural Resources Conservation Service (NRCS) A/B hydrologic group soils) and dry. The median initial rate was about 75 mm/hr (3 in/hr), but ranged from 0 to 640 mm/hr (0 to 25 in/hr). The final rates also had a median value of about 75 mm/hr (3 in/hr) after at least 2 hr of testing, but ranged from 0 to 380 mm/hr (0 to 15 in/hr). Many infiltration rates actually increased with time during these tests. In about 1/3 of the cases, the infiltration rates remained very close to zero, even for these sandy soils. Areas that experienced substantial disturbances or traffic (such as school playing fields), and siltation (such as in some grass swales) had the lowest infiltration rates.

The data from this study indicated that a potential problem existed when of estimating the infiltration rate for typical urban soils. Therefore, the research team performed more than 150 infiltration tests (as a full factorial experimental design that allowed the researchers to investigate the effects of soil type, compaction, moisture content and age since development) on disturbed urban soils. Compaction alone had dramatic effects on infiltration rates through sandy soils, while compaction and moisture affected the infiltration rates in clayey soils. Figure 3-24 shows the impacts of both compaction and moisture on the infiltration rates of sandy and clayey soils.

Table 3-15 shows the results of controlled laboratory tests measuring the water transmission rates for different soil mixtures with varying levels of compaction. Also shown are the effects of duration for some of the test conditions. In all cases, except for the clay loam, the uncompacted soils behaved as predicted and as shown on the USDA soil triangle. Clay loam had a unexpectedly high water transmission rate for the uncompacted soil. In all cases, except for 100% sand, compaction resulted in significantly reduced water transmission rates, resulting in a different HSG than if uncompacted. All severely compacted soils, except for 100% sands, are in the D category. Sands remain in the A category for all compaction conditions. During the tests, the transmission rates for sands dropped significantly, but still remained in the HSG A category.



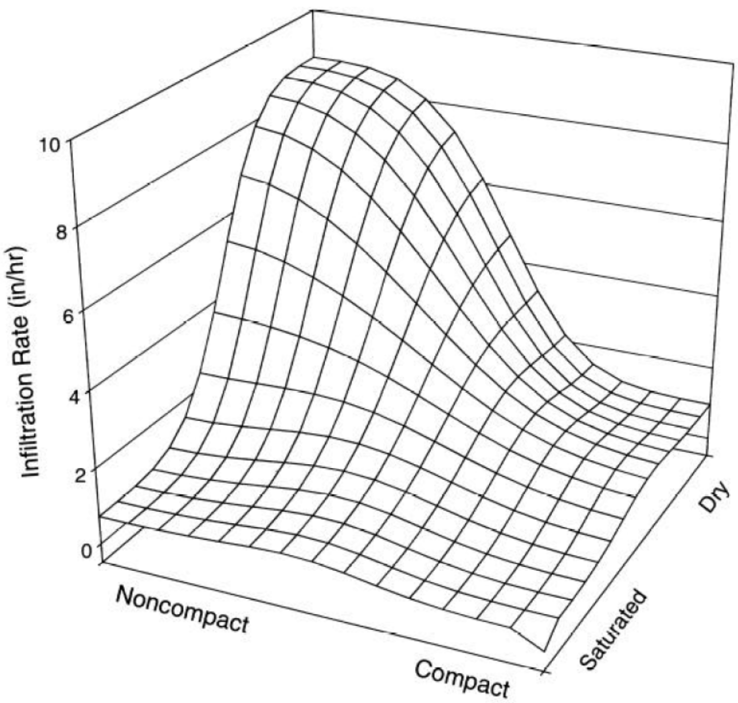


Figure 3-24. Three-dimension plots of infiltration rates for sandy and clayey soils, respectively (Pitt, *et al.* 1999).

Table 3-15. Laboratory Water Transmission Tests for Various Soil Textures and Densities (densities and observed infiltration rates for different durations) (Pitt, *et al.* 2002)

	Hand Compaction (gently pressed in test columns)	**Standard Proctor Compaction**	**Modified Proctor Compaction (maximum compaction expected)**
Sand (100% sand)	Density: 1.36 g/cc (ideal for roots) 0 to 1.6 hrs: A	Density: 1.71 g/cc (may affect roots) 0 to 2.7 hrs: A	Density: 1.70 g/cc (may affect roots) 0 to 2.7 hrs: A
Silt (100% silt)	Density: 1.36 g/cc (close to ideal for roots) 0 to 35 hrs: B	Density: 1.52 g/cc (may affect roots) 0 to 48 hrs: D	Density: 1.75 g/cc (will likely restrict roots) 0 to 48 hrs: D
Clay (100% clay)	Density: 1.45 g/cc (may affect roots) 0 to 48 hrs: D	Density: 1.62 g/cc (will likely restrict roots) 0 to 100 hrs: D	Density: 1.88 g/cc (will likely restrict roots) 0 to 100 hrs: D
Sandy Loam (70% sand, 20% silt, 10% clay)	Density: 1.44 g/cc (close to ideal for roots) 0 to 7.5 hrs: A	Density: 1.88 g/cc (will likely restrict roots) 0 to 3.82 hrs: A 3.82 to 24.32 hrs: B	Density: 2.04 g/cc (will likely restrict roots) 0 to 175 hrs: D
Silty Loam (70% silt, 20% sand, 10% clay)	Density: 1.40 g/cc (may affect roots) 0 to 7.22 hrs: B 7.22 to 47 hrs: C	Density: 1.64 g/cc (will likely restrict roots) 0 to 144 hrs: D	Density: 1.98 g/cc (will likely restrict roots) 0 to 144 hrs: D
Clay Loam (40% silt, 30% sand, 30% clay)	Density: 1.48 g/cc (may affect roots) 0 to 6.1 hrs: A	Density: 1.66 g/cc (will likely restrict roots) 0 to 93 hrs: D	Density: 1.95 g/cc (will likely restrict roots) 0 to 93 hrs: D

Time of Concentration (T_c or t_c) Calculations

The time of concentration needs to be determined for each subwatershed in the study area. It is usually necessary to investigate several candidate flow paths in order to be relatively certain of the one that takes the longest time to reach the end of the subwatershed area. There are many different time-of-concentration formulas typically presented in hydrology textbooks, usually for different conditions and locations. The SCS/NRCS method has become relatively common recently. It is necessary to use this method when using TR-55 (and TR-20). This method separates the flow path into three segments: sheetflow, shallow concentrated flow, and channel flow. The time of concentration is equal to the sum of travel times in each of these flow segments for the designated flow path. In some cases, especially for small sites, only sheetflow and possibly shallow concentrated flow may be evident.

The candidate flow paths are drawn on a site topographic map, originate on the subwatershed boundary, and proceed all the way to the bottom of the subwatershed. (NOTE: In rare circumstances, it is possible for the T_c flow path to originate at an internal elevated location and not along the subwatershed boundary. This should be investigated for all sites to confirm that the T_c pathway does not have an internal "starting point"). Sheetflow is usually the first element considered and normally is assumed to last for a maximum of 100 ft, see: "references on time of concentration with respect to sheet flow" on the WinTR-55 page for summaries of many literature references: https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/?cid=stelprdb1042901). The travel time for sheetflow is calculated using a kinematic solution to Manning's equation. Sheetflow ends when it is assumed that the depth of flow exceeds 0.1 ft (SCS 1986). The flow path is then assumed to occur as shallow concentrated flow, until a designated channel on the topographic map is reached (usually taken as a designated creek or stream on a USGS quadrangle map). When several candidate flow paths are evaluated, the one with the longest travel time is assumed to represent the time of concentration for the subwatershed. If a rain lasts for at least that time period, the runoff at the outlet will contain water from the complete area, resulting in maximum runoff rates.

The following discussions show how the travel times are calculated for each flow path element.

Sheetflow

The following equation (a kinematic solution to the Manning's equation) is used in the NRCS procedures to calculate the travel time along the sheetflow path segment:

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5} S^{0.4}}$$

Where:

T_t = travel time (hr)
n = Manning roughness coefficient (for sheet flow)
L = flow length (ft) (maximum of 100 ft before shallow concentrated flow occurs)
P_2 = 2-year, 24-hour rainfall depth (in), and
s = slope of hydraulic grade line (land slope, ft/ft)

The sheetflow Manning's n roughness coefficient values are different from the channel lining roughness coefficients. Table 3-16 lists these sheetflow values. These are all greater than the channel lining n values for the rougher surfaces, due to the shallow nature of the flows, which results in friction affecting more of the flow depth. As an example, a common channel-lining n value for grass is 0.024, while the sheetflow n value for grass is 0.24, or 10 times higher. Grass has a much greater effect on flow when the flow is shallow than when the flow is deep. However, the smooth surface sheetflow n values (0.011) are very similar to the values that would be used for these surfaces in channels. This is because these smooth surfaces have a minimal effect on both shallow and deeper flows due to their relatively low effective roughness heights. An important factor for construction sites is the roughness coefficient of 0.011 for bare soils, compared to cultivated soils (with mulch covers of >20%) of 0.17, and dense grasses of 0.24. Natural woods can have n coefficients of 0.4 to 0.8, depending on the height of the underbrush. Figure 3-25 includes graphs that can be used to estimate the travel time for different sheetflow conditions, calculated using the above NRCS sheetflow formula, using a P_2 value of 4.2 inches (appropriate for Birmingham, AL). These figures include flow lengths up to 300 ft, reflecting the historical limit of sheetflow lengths, while the current limit is set at 100 ft by the NRCS. If the P_2 ratio is not 4.2 inches, the Figure 3-25 values can be adjusted using the above sheetflow equation and the following factors:

Actual P_2 value (inches)	Multiplier for sheetflow travel times (if P_2 is not 4.2 inches)
1.0	2.0
1.5	1.7
2.0	1.4
2.5	1.3
3.0	1.2
3.5	1.1
4.0	1.0
4.5	1.0
5.0	0.9
5.5	0.9
6.0	0.8

Table 3-16. Sheetflow Manning's Equation Roughness Coefficients (SCS 1986)

Surface Description	Sheetflow Roughness Factor, n
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤ 20%	0.06
Residue cover >20%	0.17
Grass:	
Short grass prairie	0.15
Dense grass[1]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods[2]	
Light underbrush	0.40
Dense underbrush	0.80

[1] includes species such as weeping lovegrass, bluegrass, buffalo grass, blue gama grass, and native grass mixtures
[2] When selecting n for woods, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

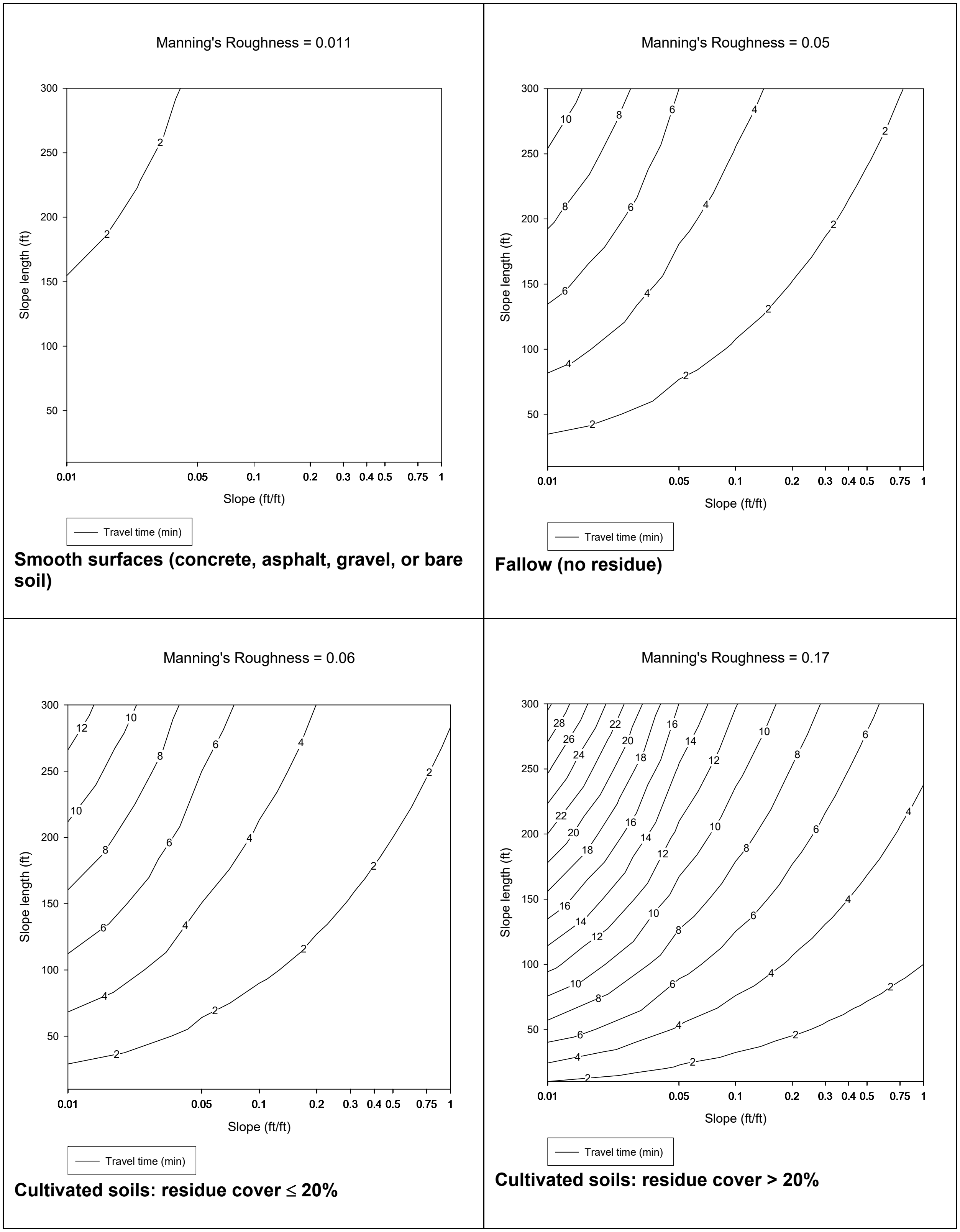
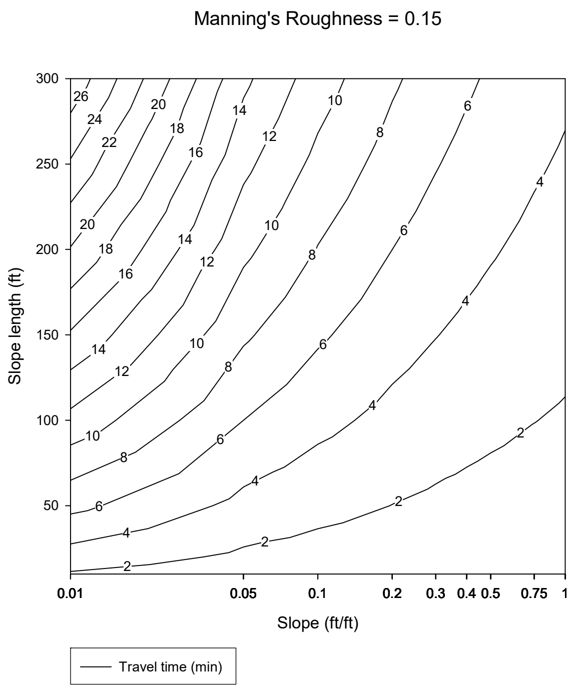
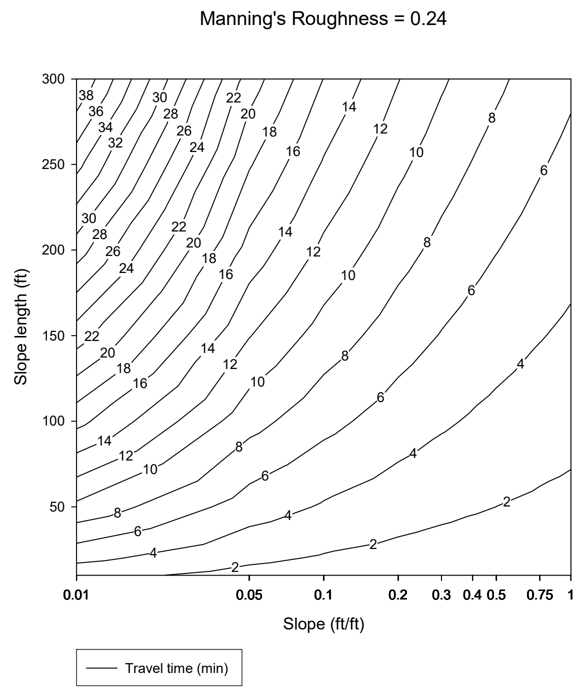


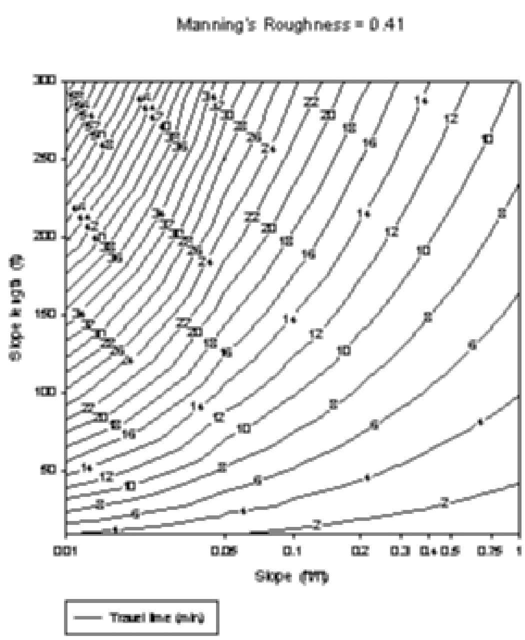
Figure 3-25. Sheetflow travel times.



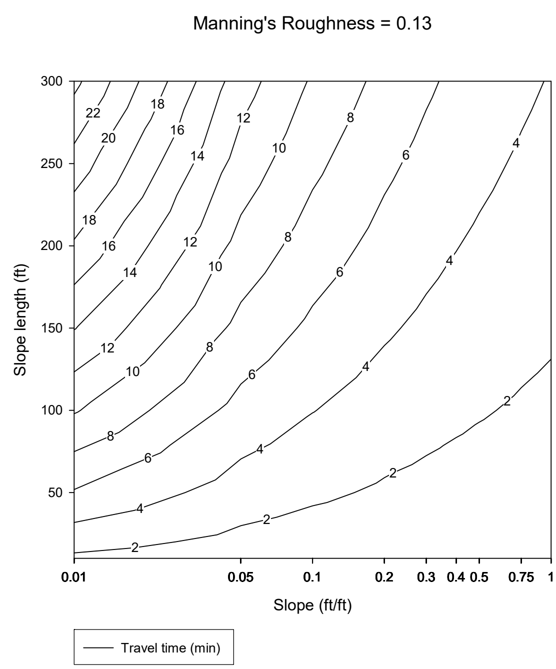
Grass: short grass prairie



Grass, dense (weeping lovegrass, bluegrass, buffalo grass, blue gama grass, and native grass mixtures

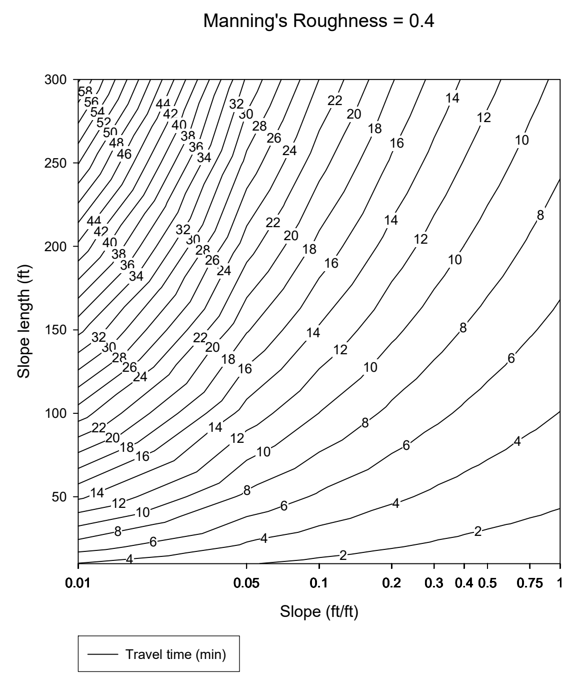


Grass: bermudagrass

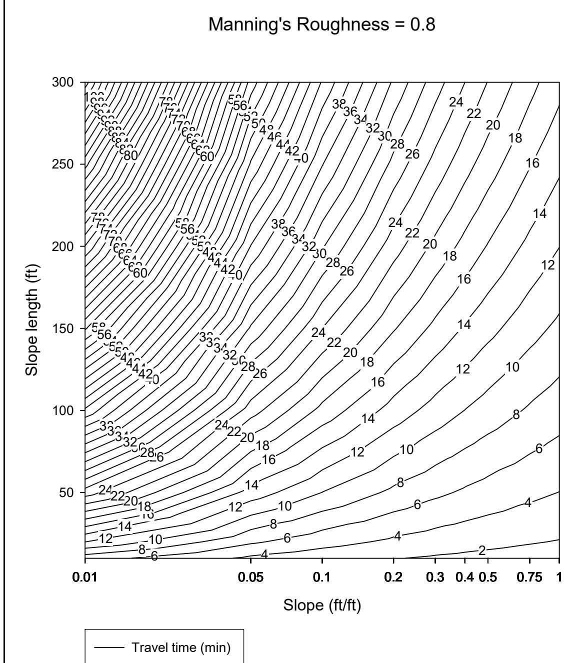


Range (natural)

Figure 3-25. Sheetflow travel times (cont).



Woods, light underbrush (considering cover to height of about 0.1 ft)



Woods: dense underbrush (considering cover to height of about 0.1 ft)

Figure 3-25. Sheetflow travel times (cont).

Shallow Concentrated Flow

After a maximum of 100 ft, sheetflow usually becomes shallow concentrated flow which is characterized by much narrower flow paths and faster flows. The flow depth also is greater than 0.1 ft, and therefore friction effects of the surface cover are not as dramatic. The following equations are used to calculate the velocities of this flow segment, based on the nature of the surface (paved or unpaved). Figure 3-26 contains graphical solutions for these equations.

$$V = 16.1345\sqrt{s} \qquad \text{(Unpaved)}$$

$$V = 20.3282\sqrt{s} \qquad \text{(Paved)}$$

Where:
V = average velocity (ft/s), and
s = slope of hydraulic grade line (watercourse slope, ft/ft)

These two equations are based on a solution of the Manning equation with different assumptions for *n* (Manning roughness coefficient) and R (hydraulic radius, ft). For unpaved areas, *n* is 0.05 and R is 0.4 ft; for paved areas, *n* is 0.025 and R is 0.2 ft. The travel time associated with the shallow-concentrated flow segment is calculated using this velocity and the flow-path length.

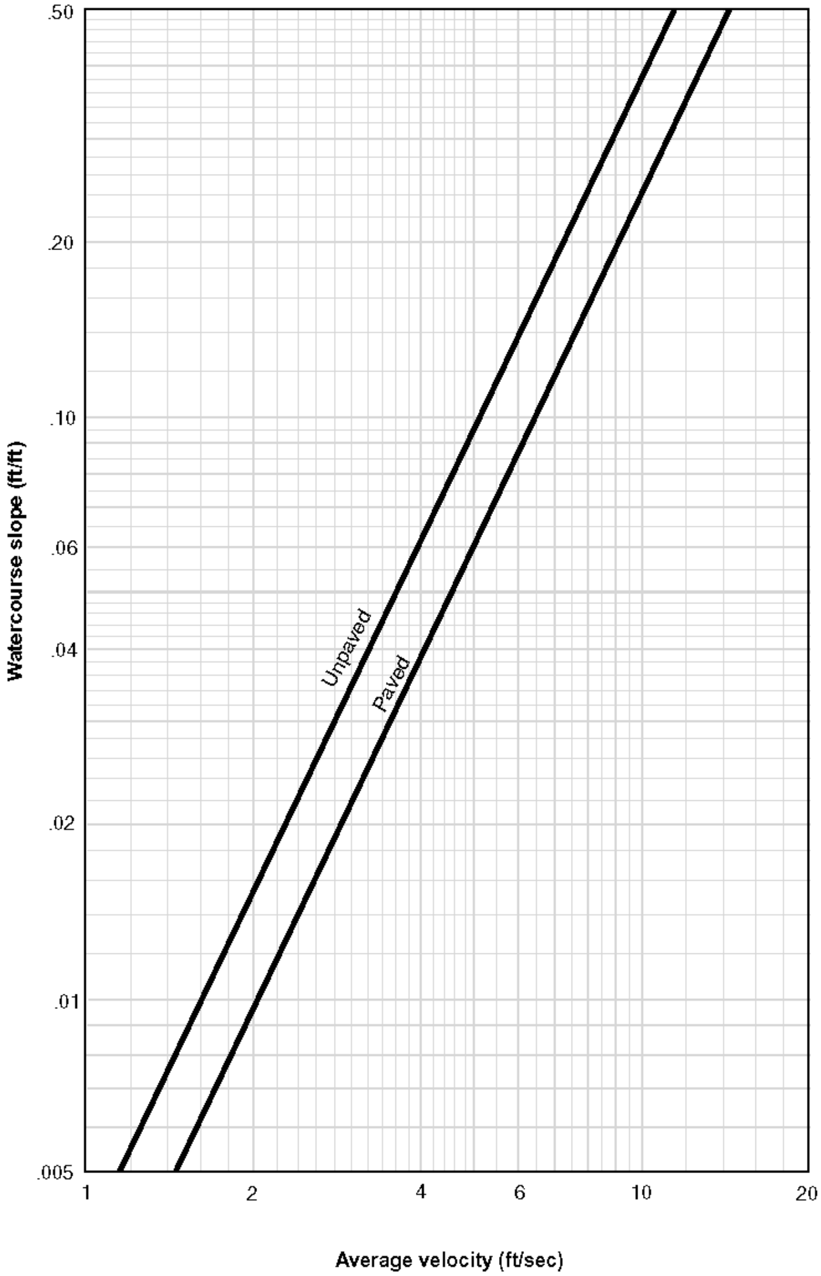


Figure 3-26 . Shallow concentrated flow velocities (SCS 1986).

The following empirical formula is given by CA DOT (http://www.dot.ca.gov/hq/oppd/hdm/pdf/chp0810.pdf) in their *Hydrology Design Manual*, chapter 810, as an alternative to estimate the flow velocity (in m/sec):

$V = kS^{1/2}$

Where S is the slope in percent and k (m/s) is an intercept coefficient depending on land surface cover as shown below:

Forest with heavy ground litter; hay meadow (overland flow): 0.076
Trash fallow or minimum tillage cultivation; contour or strip cropped; woodland (overland flow): 0.152
Short grass pasture (overland flow): 0.213
Cultivated straight row (overland flow): 0.274
Nearly bare and untilled (overland flow); alluvial fans: 0.305
Grassed waterway (shallow concentrated flow): 0.457
Unpaved (shallow concentrated flow): 0.491
Paved area (shallow concentrated flow); small upland gullies: 0.619

Channel Flow
If the flow path includes a designated channel shown on a USGS quadrangle map, the Manning's equation is used to calculate the velocity in the channel reach. The travel time in the reach is then calculated using this channel-full velocity and the length of the channel.

$$V = \frac{1.49 r^{2/3} \sqrt{s}}{n}$$

Where:

V = average velocity (ft/s), and
r = hydraulic radius (ft) and is equal to a/p_w
a = cross sectional flow area (ft^2)
p_w = wetted perimeter (ft)
s = slope of hydraulic grade line (channel slope, ft/ft)
n = Manning roughness coefficient (for open channel flow)

This is the conventional Manning's equation, and appropriate channel lining n coefficients are used. The depth of water in the channel equal to the depth at bankfull conditions, assumed by TR-55 to be the 2-year storm, to be consistent with the sheetflow calculations (SCS 1986).

The hydraulic radius (R) in the equation is the ratio of the cross-sectional flow area to the wetted perimeter length (the wet edge of the channel). For a fully-flowing circular pipe, this is equal to the diameter divided by 4, while for sheetflows (where the depth is less than about 10 times the flowwidth) the hydraulic radius is close to the depth of flow.

The Manning's roughness coefficients, n, for channel conditions where deep flow is typical, are substantially different than for the previously presented values for sheetflow. Table 3-17 is a set of typical Manning's n values for different channel (and conduit) conditions (Chow 1959):

Table 3-17. Manning's n values for different channel conditions (Chow 1959)

Type of Channel and Description of Closed Conduits	Minimum
Concrete Pipe:	
Culverts with bends, connections & debris	0.013
Storm sewer	0.013
Subdrain with open joints	0.016
PVC Pipe	0.011
Concrete Surfaces (bottom & sides):	
Smooth finish	0.015

Unfinished	0.017
Concrete Bottom (with sides made of): Mortared stone Dry rubble or riprap	 0.020 0.030
Gravel Bottom (with sides made of): Formed concrete Dry rubble or riprap	 0.020 0.040
Excavated or Dredged Channels and Ditches: Earthen, straight & uniform, no brush or debris: Grassed, less than 6” high with: Depth of flow < 2.0 ft Depth of flow > 2.0 ft Grassed, approximately 12” high with: Depth of flow < 2.0 ft Depth of flow > 2.0 ft Grassed, approximately 24” high with: Depth of flow < 2.0 ft Depth of flow > 2.0 ft Earth bottom with riprap on sides Rock or shale cuts: Smooth and uniform Jagged and irregular	 0.035 0.030 0.060 0.035 0.070 0.035 0.040 0.035 0.040
Curb and Gutter (Concrete)	0.016

The above table presents reasonable values for simple channels that are likely to be constructed at construction sites, including downslope pipe diversions. The USGS (Arcement and Schneider 1984) presents the following summary for determining Manning n values for the natural channels that may also be present on construction sites:

The most important factors that affect the selection of channel n values are the type and size of the materials that compose the bed and banks of the channel, and shape of the channel. Cowan (1956) developed a procedure for estimating the effects of these factors to determine the value of n for a channel. The value of n may be computed by

$$n = (n_b + n_1 + n_2 + n_3 + n_4)m$$

Where:

- n_b = a base value of n for a straight, uniform, smooth channel in natural materials
- n_1 = a correction factor for the effect of surface irregularities
- n_2 = a value for variations in shape and size of the channel cross section
- n_3 = a value for obstructions
- n_4 = a value for vegetation and flow conditions
- m = a correction factor for meandering of the channel

The following discussion on the basic n values and modifications for channels is summarized from Arcement and Schneider (1984).

Base n Values (n_b) for Channels

In the selection of a base n value for channel subsections, the channel must be classified as either a stable channel or as a sand channel. A stable channel is defined as a channel in which the bed is composed of firm soil, gravel, cobbles, boulders, or bedrock and the channel remains relatively unchanged throughout most of the range in flow. The following table is modified from Aldridge and Garrett 1973) and lists base n_b values for stable channels and sand channels. The base values of Benson and Dalrymple (1967) on this table apply to conditions that are close to average, while Chow's (1959) base values are for the smoothest reach attainable for a given bed material.

Table 3-18. Base n values for channels.

		Base n value	
Bed Material	**Median Size of Bed Material (mm)**	**Straight Uniform Channel[1]**	**Smooth Channel[2]**
Sand Channels			
Sand[3]	0.2	0.012	--
	0.3	0.017	--
	0.4	0.020	--
	0.5	0.022	--
	0.6	0.023	--
	0.8	0.025	--
	1.0	0.026	--
Stable Channels and Flood Plains			
Concrete	--	0.012-0.018	0.011
Rock Cut	--	--	0.025
Firm Soil	--	0.025-0.032	0.020
Coarse Sand	1-2	0.026-0.035	--
Fine Gravel	--	--	0.024
Gravel	2-64	0.028-0.035	--
Coarse Gravel	--	--	0.026
Cobble	64-256	0.030-0.050	--
Boulder	>256	0.040-0.070	--

(Modified from Aldridge and Garret 1973
-- No data
[1]Benson and Dalrymple
[2]For indicated material (Chow 1959)
[3]Only for upper regime flow where grain roughness is predominant

Barnes (1967) cataloged verified n values for stable channels having roughness coefficients ranging from 0.024 to 0.075. In addition to a description of the cross section, bed material, and flow conditions during the measurement, color photographs of the channels were provided.

A sand channel is defined as a channel in which the bed has an unlimited supply of sand. By definition, sand ranges in grain size from 0.062 mm (62 µm) to 2 mm. Resistance to flow varies greatly in sand channels because the bed material moves easily and takes on different configurations or bed forms. Bed form is a function of velocity of flow, grain size, bed shear, and temperature.

The flows that produce the bed forms are classified as lower regime flow and upper regime flow, according to the relation between depth and discharge. The lower regime flow occurs during low discharges, and the upper regime flow occurs during high discharges. An unstable discontinuity, called a transitional zone, appears between the two regimes in the depth to discharge relationship. In lower regime flow, the bed may have a plane surface and no movement of sediment, or the bed may be deformed and have small uniform waves or large irregular saw-toothed waves formed by sediment moving downstream. The smaller waves are known as ripples, and the larger waves are known as dunes. In upper regime flow, the bed may have a plane surface and sediment movement or long, smooth sand waves that are in phase with the surface waves.

Irregularity (n_1)

Where the ratio of width to depth is small, roughness caused by eroded and scalloped banks, projecting points, and exposed tree roots along the banks must be accounted for by fairly large adjustments. Chow

(1959) and Benson and Dalrymple (1967) showed that severely eroded and scalloped banks can increase n values by as much as 0.02. Larger adjustments may be required for very large, irregular banks that have projecting points.

Table 3-19 . Irregularity (n_1) Adjustment Values for Factors that Affect the Roughness of a Channel [modified from Aldridge and Garrett 1973]

Channel Conditions	n Value Adjustment	Example
Smooth	0.000	Compares to the smoothest channel attainable in a given bed material.
Minor	0.001-0.005	Compares to carefully degraded channels in good condition but having slightly eroded or scoured side slopes.
Moderate	0.006-0.010	Compares to dredged channels having moderate to considerable bed roughness and moderately sloughed or eroded side slopes.
Severe	0.011-0.020	Badly sloughed or scalloped banks of natural streams; badly eroded or sloughed sides of canals or drainage channels; unshaped, jagged, and irregular surfaces of channels in rocks.

Variation in Channel Cross Section (n_2)

The value of n is not affected significantly by relatively large changes in the shape and size of cross sections if the changes are gradual and uniform. Greater roughness is associated with alternating large and small cross sections and sharp bends, constrictions, and side-to-side shifting of the low-water channel. The degree of the effect of changes in the size of the channel depends primarily on the number of alternations of large and small sections and secondarily on the magnitude of the changes. The effects of abrupt changes may extend downstream for several hundred meters. The n value for a reach below a disturbance may require adjustment, even though none of the roughness-producing factors are apparent in the study reach. A maximum increase in n of 0.003 will result from the usual amount of channel curvature found in designed channels and in the reaches of natural channels used to compute discharge (Benson and Dalrymple 1967).

Table 3-20. Channel Cross Section (n_2) Adjustment Factor.

Channel Conditions	n Value Adjustment	Example
Gradual	0.000	Size and shape of channel cross sections change gradually.
Alternating occasionally	0.001-0.005	Large and small cross sections alternate occasionally, or the main flow occasionally shifts from side to side owing to changes in cross-sectional shape.
Alternating frequently	0.010-0.015	Large and small cross sections alternate frequently, or the main flow frequently shifts from side to side owing to changes in cross-sectional shape.

Obstructions (n_3)

Obstructions, such as logs, stumps, boulders, debris, pilings, and bridge piers, disturb the flow pattern in the channel and increase roughness. The amount of increase depends on the following: the shape of the obstruction; the size of the obstruction in relation to that of the cross section; and the number, arrangement, and spacing of obstructions. The effect of obstructions on the roughness coefficient is a function of the flow velocity. When the flow velocity is high, an obstruction exerts a sphere of influence that is much larger than the obstruction because the obstruction affects the flow pattern for considerable distances on each side. The sphere of influence for velocities that generally occur in channels that have gentle to moderately steep slopes is about three to five times the width of the obstruction. Several obstructions can create overlapping spheres of influence and may cause considerable disturbance, even though the obstructions may occupy only a small part of a channel cross section. Chow (1959) assigned adjustment values to four levels of obstruction: negligible, minor, appreciable, and severe.

Table 3-21. Obstruction (n_3) Adjustment Factors.

Channel Conditions	n Value Adjustment	Example
Negligible	0.000-0.004	A few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, piers, or isolated boulders, that occupy less than 5 percent of the cross-sectional area.
Minor	0.005-0.015	Obstructions occupy less than 15 percent of the cross-sectional area, and the spacing between obstructions is such that the sphere of influence around one obstruction does not extend to the sphere of influence around another obstruction. Smaller adjustments are used for curved smooth-surfaced objects than are used for sharp-edged angular objects.
Appreciable	0.020-0.030	Obstructions occupy from 15 percent to 50 percent of the cross-sectional area, or the space between obstructions is small enough to cause the effects of several obstructions to be additive, thereby blocking an equivalent part of a cross-section.
Severe	0.040-0.050	Obstructions occupy more than 50 percent of the cross-sectional area, or the space between obstructions is small enough to cause turbulence across most of the cross section.

Vegetation (n_4)

The extent to which vegetation affects n depends on the following: the depth of flow; the percentage of the wetted perimeter covered by the vegetation; the density of vegetation below the high-water line; the degree to which the vegetation is flattened by high water; and the alignment of vegetation relative to the flow. The adjustment values given in the following table apply to constricted channels that are narrow in width. In wide channels having small depth-to-width ratios and no vegetation on the bed, the effect of bank vegetation is small, and the maximum adjustment is about 0.005. If the channel is relatively narrow and has steep banks covered by dense vegetation that hangs over the channel, the maximum adjustment is about 0.03. The larger adjustment values given in the following table apply only in places where vegetation covers most of the channel.

Table 3-22. Vegetation (n_4) Adjustment Factors

Channel Conditions	n Value Adjustment	Example
Small	0.002-0.010	Dense growths of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation; supple tree seedlings such as willow, cottonwood, arrowhead, or saltcedar growing where the average depth of flow is at least three times the height of the vegetation.
Medium	0.010-0.025	Turf grass growing where the average depth of flow is from one to two times the height of the vegetation; moderately dense stemy grass, weeds, or tree seedlings where the average depth of flow is from two to three times the height of the vegetation; brushy, moderately dense vegetation, similar to 1-to-2-year-old willow trees in the dormant season, growing along the banks, and no significant vegetation is evident along the channel bottoms where the hydraulic radius exceeds 0.61 meters.
Large	0.025-0.050	Turf grass growing where the average depth of flow is about equal to the height of the vegetation; 8-to-10-year-old willow or cottonwood trees intergrown with some weeds and brush (none of the vegetation in foliage) where the hydraulic radius exceeds 0.60 m; bushy willows about 1 year old intergrown with some weeds along side slopes (all vegetation in full foliage), and no significant vegetation exists along channel bottoms where the hydraulic radius is greater than 0.61 m.

Very Large	0.050-0.100	Turf grass growing where the average depth of flow is less than half the height of the vegetation; bushy willow trees about 1 year old intergrown with weeds along side slopes (all vegetation in full foliage), or dense cattails growing along channel bottom; trees intergrow with weeds and brush (all vegetation in full foliage).

Meandering (m)
The degree of meandering, m, depends on the ratio of the total length of the meandering channel in the reach being considered to the straight length of the channel reach. The meandering is considered minor for ratios of 1.0 to 1.2, appreciable for ratios of 1.2 to 1.5, and severe for ratios of 1.5 and greater. According to Chow (1959), meanders can increase the n values by as much as 30 percent where flow is confined within a stream channel. The meander adjustment should be considered only when the flow is confined to the channel. There may be very little flow in a meandering channel when there is flood-plain flow.

Table 3-23. Meander (m) Adjustment Multiplier.

Channel Conditions	n Value Adjustment[1,2]	Example
Minor	1.00	Ratio of the channel length to valley length is 1.0 to 1.2
Appreciable	1.15	Ratio of the channel length to valley length is 1.2 to 1.5
Severe	1.30	Ratio of the channel length to valley length is greater than 1.5.

[1]Adjustments for degree of irregularity, variation in cross section, effect of obstructions, and vegetation are added to the base n value before multiplying by the adjustment for meander.
[2]Adjustment values apply to flow confined in channel and do not apply where downvalley flow crosses meanders.

Example (Manning's n Adjustment):
Consider the following:

Basic n value for channel in earth (straight uniform channel in firm soil), n_b = 0.030
Modification for channel irregularity (minor), n_1 = 0.002
Modification for channel cross section (alternating occasionally), n_2 = 0.003
Modification for obstructions (negligible), n_3 = 0.002
Modification for vegetation (small, grass), n_4 = 0.005

No meander correction

$n = n_b + n_1 + n_2 + n_3 + n_4$
$n = 0.042$

Chow (1959) would indicate a value between 0.030 and 0.050 for this channel.

For most streams, a field survey is needed to determine the appropriate Manning's roughness and hydraulic radius values for a site, as it is not possible to estimate these from a map.

Example Travel Time Calculation:
The TR-55 User Guide (SCS 1986) includes the following example. Figure 3-27 shows a watershed in Dyer County, which is located in northwestern Tennessee. The problem is to compute T_c at the outlet of the watershed (point D). The 2-year 24-hour rainfall depth is 3.6 inches. All three types of flow occur from the hydraulically most distant point (A) to the point of interest (D). To compute T_c, first determine T_t for each segment from the following information:

Segment AB: Sheetflow; dense grass; slope (s) = 0.01 ft/ft; and length (L) = 100 ft.
Segment BC: Shallow concentrated flow; unpaved; s = 0.01 ft/ft; and L = 1400 ft.
Segment CD: Channel flow; Manning's n = 0.05; flow cross-sectional area (a) = 27 ft^2;
wetted perimeter (p_w) = 28.2 ft; s = 0.005 ft/ft; and L=7300ft.

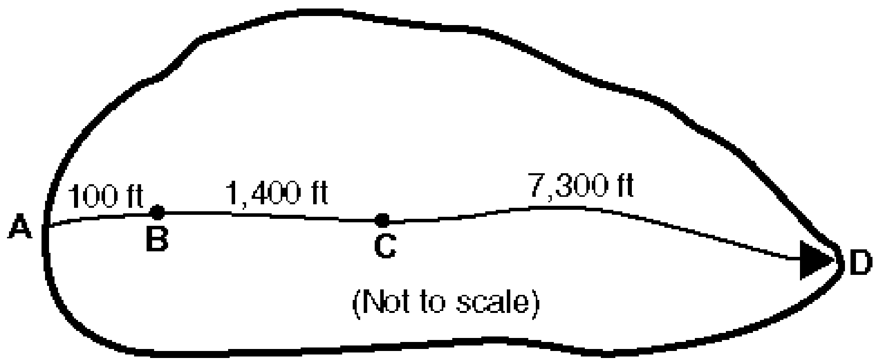


Figure 3-27. Watershed for TR-55 T_t calculation example (SCS 1986).

Figure 3-28 is the SCS worksheet showing the calculations for the above problem. In this case, each flow segment is comprised of a single condition of slope and cover. In many cases, the individual flow segments may need to be broken up into subunits to represent different slopes or roughness coefficients. The travel times for each of the segments are added. For the sheetflow segment, however, the total travel length must still be less than 100 ft, not 100 ft for each calculation interval. Worksheet 3 has two columns to facilitate two segments for each portion. Additional segments may be needed. In this example, the total travel time for this flow path from A to D is 1.53 hours, with almost 1 hour associated with the channel flow time. For small sites, including most construction sites, the sheetflow segment will likely comprise the largest portion of the total flow time.

Again, in order to determine the time of concentration for the watershed, several different candidate flow paths are usually needed to be evaluated and the one with the longest travel time is used as the time of concentration. This may not be the path with the longest travel distance, but may be a shorter path affected by shallower slopes and rougher covers.

Worksheet 3: Time of Concentration (T_c) or travel time (T_t)

Project: Heavenly Acres	By: DW	Date: 10/6/85
Location: Dyer County, Tennessee	Checked: NM	Date: 10/8/85

Check one: ☐ Present ☒ Developed

Check one: ☒ T_c ☐ T_t through subarea

Notes: Space for as many as two segments per flow type can be used for each worksheet.
Include a map, schematic, or description of flow segments.

Sheet flow (Applicable to T_c only)

		Segment 1	Segment 2	Total
	Segment ID	AB		
1.	Surface description (table 3-1)	Dense Grass		
2.	Manning's roughness coefficient, n (table 3-1)	0.24		
3.	Flow length, L (total L ≤ 300 ft) ... ft	100		
4.	Two-year 24-hour rainfall, P_2 ... in	3.6		
5.	Land slope, s ... ft/ft	0.01		
6.	$T_t = \frac{0.007\,(nL)^{0.8}}{P_2^{0.5}\, s^{0.4}}$ Compute T_t ... hr	0.30	+	= 0.30

Shallow concentrated flow

		Segment 1	Segment 2	Total
	Segment ID	BC		
7.	Surface description (paved or unpaved)	Unpaved		
8.	Flow length, L ... ft	1400		
9.	Watercourse slope, s ... ft/ft	0.01		
10.	Average velocity, V (figure 3-1) ... ft/s	1.6		
11.	$T_t = \frac{L}{3600\,V}$ Compute T_t ... hr	0.24	+	= 0.24

Channel flow

		Segment 1	Segment 2	Total
	Segement ID	CD		
12.	Cross sectional flow area, a ... ft^2	27		
13.	Wetted perimeter, p_w ... ft	28.2		
14.	Hydraulic radius, $r = \frac{a}{p_w}$ Compute r ... ft	0.957		
15	Channel slope, s ... ft/ft	0.005		
16.	Manning's roughness coefficient, n ...	0.05		
17.	$V = \frac{1.49\, r^{2/3}\, s^{1/2}}{n}$ Compute V ... ft/s	2.05		
18.	Flow length, L ... ft	7300		
19.	$T_t = \frac{L}{3600\,V}$ Compute T_t ... hr	0.99	+	= 0.99
20.	Watershed or subarea T_c or T_t (add T_t in steps 6, 11, and 19) ... Hr			1.53

Figure 3-28. Calculation example for travel time problem (SCS 1986).

Tabular Hydrograph Method

The SCS TR-55 tabular hydrograph method (SCS 1986) can be used to develop a hydrograph for each subwatershed area that can then be routed through the downstream project segments. This method will also produce the total runoff volume and the peak flow rate. This method is not used in the new WinTR-55; this computerized version uses the more complete routing procedures from TR-20. However, the following is still presented as an optional method and to illustrate the sensitivity of Tc and CN selections. Appendix 4A includes all of the tabular hydrograph tables that can be used to calculate hydrographs for all locations in the US.

Example (Tabular Hydrograph Calculation):

The following example is from the TR-55 manual (SCS 1986) and illustrates how the Tc, CN, and other site characteristics are used to develop and route hydrographs for a complex watershed.

This example computes the 25-year frequency peak discharge at the downstream end of subarea 7 shown in Figure 3-29. This example is for present conditions and uses the worksheets presented in SCS (1986). The CN, Tc, and Tt for each subarea must be determined or calculated using the procedures in TR-55 chapters 2 and 3. These values are entered on worksheet 5a (Figure 3-30). Then, the tabular hydrograph tables are used to determine the normalized hydrograph for downstream locations.

The hydrograph tables are presented in SCS (1986) according to rain type (there are sections of tables for types I, Ia, II, and III rain distributions). The first step is to find the table section pertaining to the rain distribution for the study area. In this case, the area has type II rains. The type II rain hydrograph tables are further grouped according to the Tc for the subarea, ranging from 0.1 to 2 hours. In the case for subarea #1, the Tc is 1.5 hours, so page 5-37 from SCS (1986) is used (Table 3-24). Each page is further divided into three segments, corresponding to Ia/P ratios of 0.10, 0.30, and 0.50. The Ia is the initial abstractions for the area (not to be confused with rain distribution type Ia) and are a direct function of the CN value. These are given in the User Guide (SCS table 5-1). The P is the total rain depth being evaluated. The top set of values are used for Ia/P ratios of ≤ 0.2, the middle set for ratios from 0.2 to 0.4, while the bottom set is used for ratios of > 0.4 and < 0.5 (interpolation is not used; WinTR-55 and TR-20 calculate more precise values based on actual site conditions). In this case, the #1 subarea Ia/P is 0.18, so the top set of values are used. Finally, each segment has 12 lines representing different travel times from the bottom of the subwatershed area to the location of interest (typically the outlet). The largest unit peak runoff rate values (csm/in, or cubic feet per second of runoff per square mile of drainage area, per inch of direct runoff) on each line start close to 12 hours for the top time, and shift to the right as the travel time increases. The shift between the largest values for each row is equal to the differences in the travel times between each line, representing routing of the hydrographs as they travel downstream. For the #1 subarea, the Tt is 2.5 hours. Therefore, the line near the bottom of the top segment, representing 2.5 hours, is used. The values in the table represent normalized hydrographs and are multiplied by A_mQ (the factor of the watershed area, in mi^2, and the direct runoff in inches) to obtain the flow values in traditional units of ft^3/sec, or cfs. These final cfs values are written on worksheet 5b (Table 3-10). As an example, the appropriate values for the peak discharge (q) for subarea 4 at 14.6 hr is:

$$q = q_t(A_mQ) = (274)(0.70) = 192 \text{ cfs}$$

Once all the prerouted subarea hydrographs have been tabulated on worksheet 5b, they are summed to obtain the composite hydrograph. The resulting 25-year frequency peak discharge is 720 cfs at 14.3 hr, as shown on Table 3-26.

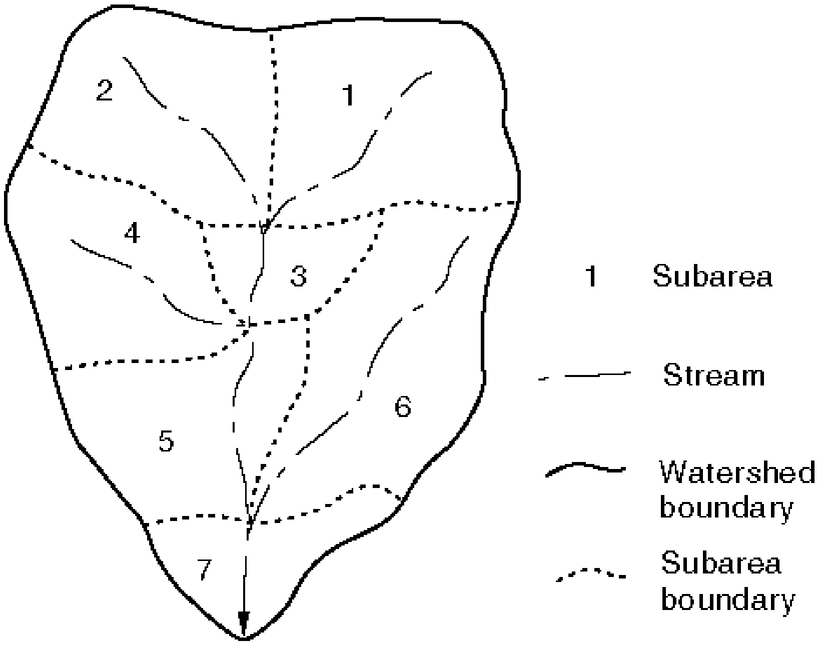


Figure 3-29. Example watershed for tabular hydrograph calculations (SCS 1986).

Table 3-24. Initial Abstraction (I_a) Values for Runoff Curve Numbers (SCS 1986)

Curve Number	I_a (inch)	Curve Number	I_a (inch)	Curve Number	I_a (inch)
40	3.000	60	1.333	80	0.500
41	2.878	61	1.279	81	0.469
42	2.762	62	1.226	82	0.439
43	2.651	63	1.175	83	0.410
44	2.545	64	1.125	84	0.381
45	2.444	65	1.077	85	0.353
46	2.348	66	1.030	86	0.326
47	2.255	67	0.985	87	0.299
48	2.167	68	0.941	88	0.273
49	2.082	69	0.899	89	0.247
50	2.000	70	0.857	90	0.222
51	1.922	71	0.817	91	0.198
52	1.846	72	0.778	92	0.174
53	1.774	73	0.740	93	0.151
54	1.704	74	0.703	94	0.128
55	1.636	75	0.667	95	0.105
56	1.571	76	0.632	96	0.083
57	1.509	77	0.597	97	0.062
58	1.448	78	0.564	98	0.041
59	1.390	79	0.532		

Figure 3-30. Worksheet 5a for showing basic watershed data (SCS 1986).

Worksheet 5a: Basic watershed data

Project Fallswood	Location Dyer County, Tennessee	By DW	Date 10/1/85
Check one: [X] Present [ ] Developed	Frequency (yr) 25	Checked NM	Date 10/3/85

Subarea name	Drainage area A_m (mi^2)	Time of concentration T_c (hr)	Travel time through subarea T_t (hr)	Downstream subarea names	Travel time summation to outlet ΣT_t (hr)	24-hr rainfall P (in)	Runoff curve number CN	Runoff Q (in)	A_mQ (mi^2—in)	Initial abstraction I_a (in)	I_a/P
1	0.30	1.50	– –	3, 5, 7	2.50	6.0	65	2.35	0.71	1.077	0.18
2	0.20	1.25	– –	3, 5, 7	2.50	6.0	70	2.80	0.56	0.857	0.14
3	0.10	0.50	0.50	5, 7	2.00	6.0	75	3.28	0.33	0.667	0.11
4	0.25	0.75	– –	5, 7	2.00	6.0	70	2.80	0.70	0.857	0.14
5	0.20	1.50	1.25	7	0.75	6.0	75	3.28	0.66	0.667	0.11
6	0.40	1.50	– –	7	0.75	6.0	70	2.80	1.12	0.857	0.14
7	0.20	1.25	0.75	– –	0	6.0	75	3.28	0.66	0.667	0.11
		From worksheet 3					From worksheet 2			From table 5-1	

Table 3-25. Tabular Hydrograph Table for Example Problem (SCS 1986, pg 5-37)

Exhibit 5-II: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution—continued

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
IA/P = 0.10														* * * TC = 1.5 HR * * *														IA/P = 0.10				
0.0	9	11	15	21	25	31	41	58	82	112	147	184	216	255	275	236	198	159	129	98	76	57	43	35	30	25	23	21	18	16	12	1
.10	8	10	13	18	20	23	28	37	51	72	98	131	166	226	265	254	226	187	151	113	86	63	46	37	31	26	23	21	19	16	13	2
.20	8	10	13	17	19	22	26	33	45	63	87	116	149	212	259	259	233	197	160	119	90	66	48	38	32	27	24	22	19	16	13	2
.30	7	9	12	16	18	21	24	30	40	55	76	103	134	197	244	255	238	206	169	125	95	68	49	38	32	27	24	22	19	17	13	2
.40	7	8	11	14	15	17	19	23	28	36	49	67	91	151	208	247	252	230	196	146	109	77	54	41	34	29	25	22	19	17	13	3
.50	6	8	10	13	15	16	18	21	26	33	43	59	80	136	194	238	249	235	204	154	115	81	56	42	34	29	25	23	20	17	13	3
.75	5	7	8	11	12	13	14	16	18	21	25	32	42	76	125	179	222	240	233	193	148	102	67	48	38	32	27	24	20	18	13	5
1.0	4	5	7	8	9	10	11	12	13	14	16	18	22	34	59	101	152	201	236	230	193	135	86	59	44	35	30	26	21	18	14	7
1.5	3	4	5	6	6	7	8	8	9	10	11	12	13	16	22	34	58	95	141	203	226	197	131	84	58	43	35	29	23	20	15	10
2.0	1	2	3	4	4	5	5	6	6	7	7	8	9	10	12	16	22	34	56	110	172	218	187	126	82	57	43	34	25	21	16	11
2.5	1	1	2	2	3	3	3	4	4	4	5	5	6	7	8	9	11	14	18	34	69	141	210	190	133	87	60	44	30	23	17	12
3.0	0	0	1	1	2	2	2	2	3	3	3	3	4	5	5	6	8	9	11	16	27	66	149	204	181	128	85	58	35	25	18	12
IA/P = 0.30														* * * TC = 1.5 HR * * *														IA/P = 0.30				
0.0	0	0	0	0	0	1	6	15	31	53	80	112	144	193	225	208	186	157	134	108	89	70	56	48	42	37	34	31	28	25	20	2
.10	0	0	0	0	0	0	1	4	12	25	43	68	97	157	198	219	203	178	151	120	98	77	60	50	44	38	35	32	28	25	20	3
.20	0	0	0	0	0	0	0	1	3	9	19	35	57	114	168	201	213	196	171	135	108	84	64	53	46	40	36	33	29	26	20	4
.30	0	0	0	0	0	0	0	1	2	7	15	29	48	100	155	193	210	200	177	140	113	87	66	54	46	41	36	33	29	26	20	5
.40	0	0	0	0	0	0	0	0	2	5	12	23	39	87	141	184	207	202	182	146	117	89	68	55	47	41	36	33	29	26	20	5
,50	0	0	0	0	0	0	0	0	0	1	4	9	18	51	101	153	190	205	197	164	131	99	73	58	49	43	38	34	30	26	20	7
.75	0	0	0	0	0	0	0	0	0	0	2	4	9	30	68	116	160	189	197	179	147	110	80	62	52	45	39	35	30	27	21	8
1.0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	20	49	92	138	175	195	178	137	97	72	57	48	42	37	31	28	21	12
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	21	47	85	145	187	178	133	95	71	57	48	42	34	29	23	16
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	13	45	97	162	180	138	99	74	58	49	38	32	25	18
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	8	31	89	161	174	133	97	72	58	42	34	26	18
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	29	98	160	169	129	95	71	48	37	28	19
IA/P = 0.50														* * * TC = 1.5 HR * * *														IA/P = 0.50				
.0	0	0	0	0	0	0	0	3	8	16	27	42	59	92	116	128	130	121	112	100	90	78	67	60	55	50	46	43	39	35	29	4
.10	0	0	0	0	0	0	0	2	6	12	22	35	51	84	110	125	128	123	114	102	91	79	68	61	55	50	46	43	39	35	29	4
.20	0	0	0	0	0	0	0	0	1	4	10	18	29	60	91	114	126	128	120	108	97	83	71	63	57	52	47	44	40	36	29	5
.30	0	0	0	0	0	0	0	0	1	3	8	14	24	52	83	108	123	126	122	110	98	85	72	63	57	52	48	44	40	36	29	6
.40	0	0	0	0	0	0	0	0	0	1	2	6	12	31	60	90	112	124	126	116	104	90	75	66	59	54	49	45	41	37	29	8
.50	0	0	0	0	0	0	0	0	0	0	2	4	9	26	53	83	106	121	125	118	106	91	77	67	60	54	49	46	41	37	29	8
.75	0	0	0	0	0	0	0	0	0	0	1	2	5	16	36	62	88	108	119	122	112	97	81	69	62	56	51	47	42	38	30	11
1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	10	26	49	75	98	118	121	108	90	76	66	59	54	49	43	39	31	16
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	11	25	45	80	107	118	106	89	75	65	59	53	45	41	32	23
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	11	32	63	100	115	104	87	74	65	58	48	42	34	26
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	16	48	94	113	105	89	76	66	53	45	36	27
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	15	54	96	111	103	88	75	58	48	38	28

RAINFALL TYPE = II   * * * TC = 1.5 HR * * *   SHEET 9 OF 10

Table 3-26. Worksheet 5b for Example Hydrograph Calculation (SCS 1986)

Worksheet 5b: Basic watershed data

Project: Fallswood	Location: Dyer County, Tennessee	By: DW	Date: 10/1/85
Check one: ☒ Present ☐ Developed	Frequency (yr): 25	Checked: NM	Date: 10/3/85

Subarea name	Basic watershed data used 1/				Select and enter hydrograph times in hours from exhibit 5-II 2/											
	Subarea T_c (hr)	ΣT_t to outlet (hr)	I_a/P	A_mQ (mi²—in)	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5
					Discharges at selected hydrograph times 3/ (cfs)											
1	1.50	2.50	0.10	0.71	4	4	5	6	6	8	10	113	24	49	100	149
2	1.25	2.50	0.10	0.56	3	4	4	6	7	8	11	16	32	64	110	127
3	0.50	2.00	0.10	0.33	5	5	6	8	12	21	41	67	98	92	60	29
4	0.75	2.00	0.10	0.70	8	9	11	14	20	34	62	106	172	192	149	81
5	1.50	0.75	0.10	0.66	21	28	50	83	118	147	158	154	127	98	67	44
6	1.50	0.75	0.10	1.12	36	47	85	140	200	249	269	261	216	166	114	75
7	1.25	0	0.10	0.66	169	187	205	176	140	108	85	69	51	40	31	24
Composite hydrograph at outlet					246	284	366	433	503	575	636	686	720	701	631	529

1/ Worksheet 5a. Rounded as needed for use with exhibit 5.
2/ Enter rainfall distribution type used.
3/ Hydrograph discharge for selected times is A_mQ multiplied by tabular discharge from appropriate exhibit 5.

Example (Tabular Hydrograph for Urban Watershed):

The following example is for a typical urban watershed, having four subareas that are quite different in their development characteristics. The following lists the procedure for evaluating this area:

1. Subdivide the watershed into relatively homogeneous subareas (as shown in Figure 3-31).

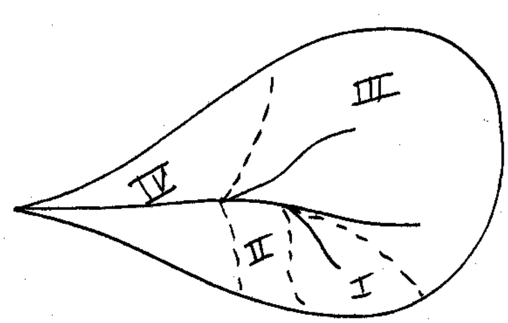


Figure 3-31. Relatively homogeneous subareas in example urban watershed.

2. Calculate the drainage for each subarea.

I	0.10 mi^2
II	0.08
III	0.6
IV	0.32
Total:	1.12

3. Calculate the time of concentration (Tc) for each subarea (TR-55 chapter 3).

I	0.2 hrs
II	0.1
III	0.3
IV	0.1

4. Calculate the travel time (Tt) from each subarea discharge location to the location of interest (outlet of total watershed in this example) (TR-55 chapter 3).

I	0.1 hrs
II	0.05
III	0.05
IV	0

5. Select the curve number (CN) for each subarea.

I	Strip commercial, all directly connected	CN = 97
II	Medium density residential area, grass swales	CN = 46
III	Medium density residential area, curbs and gutters	CN = 72
IV	Low density residential area, grass swales	CN = 40

6. Determine the appropriate rainfall distribution (Type II for all areas in this example).

7. Find the 24-hour rainfall depth for storm, equal to 4.1 inches for this example.

8. Calculate total runoff (inches) from CN and rain depth (from SCS fig. 2-1).

I	CN = 97	P = 4.1 in.	Q = 3.8 in.
II	CN = 46	P = 4.1 in.	Q = 0.25
III	CN = 72	P = 4.1 in.	Q = 1.5
IV	CN = 40	P = 4.1 in.	Q = 0.06

9. Determine I_a for each subarea (SCS assumes $I_a = 0.2$ S, where S is the total rainfall abstractions) (SCS table 5-1).

I	CN = 97	I_a = 0.062 in.
II	CN = 46	I_a = 2.348 in.
III	CN = 72	I_a = 0.778 in.
IV	CN = 40	I_a = 3.000 in.

10. Calculate the ratio of Ia to P.

I	Ia/P = 0.062/4.1 = 0.015
II	Ia/P = 2.348/4.1 = 0.57
III	Ia/P = 0.778/4.1 = 0.19
IV	Ia/P = 3.000/4.1 = 0.73

11. Use worksheets SCS 5a and 5b to summarize above data and to calculate the composite hydrograph. These are shown in Tables 3-27 and 3-28.

Table 3-27. SCS Worksheet 5a for Urban Example

Worksheet 5a: Basic watershed data

Project: EXAMPLE - URBAN	Location: JEFFERSON COUNTY, AL	By: XYZ	Date
Check one: ☐ Present ☒ Developed	Frequency (yr): 2 YR	Checked	Date

Subarea name	Drainage area A_m (mi²)	Time of concen-tration T_c (hr)	Travel time through subarea T_t (hr)	Downstream subarea names	Travel time summation to outlet ΣT_t (hr)	24-hr rain-fall P (in)	Runoff curve number CN	Runoff Q (in)	A_mQ (mi²—in)	Initial abstraction I_a (in)	I_a/P
I	0.10	0.2	–	–	0.1	4.1	97	3.8	0.38	0.062	0.015
II	0.08	0.1	–	–	0.05	4.1	46	0.25	0.02	2.348	0.57
III	0.62	0.3	–	–	0.05	4.1	72	1.5	0.93	0.778	0.19
IV	0.32	0.1	–	–	∅	4.1	40	0.06	0.019	3.000	0.73
Σ =	1.12										
		From worksheet 3	From worksheet 3				From worksheet 2	From worksheet 2		From table 5-1	

Table 3-28. SCS Worksheet 5b for Urban Example

Worksheet 5b: Basic watershed data

Project: EXAMPLE - URBAN	Location: JEFFERSON CTY., AL	By: XYZ	Date:
Check one: ☐ Present ☒ Developed	Frequency (yr): 2 YR.	Checked:	Date:

Subarea name	Subarea T_c (hr)	ΣT_t to outlet (hr)	I_a/P	A_mQ (mi^2—in)			11.0	11.6	12	12.2	12.3	13	14	16	18	26	
	Basic watershed data used 1/				Select and enter hydrograph times in hours from exhibit 5-II 2/ — Discharges at selected hydrograph times 3/ (cfs)												
I	0.2	0.1	~~0.015~~ 0.10	0.38	csm/in:		19	39	168	601	733	83	43	25	18	∅	p.5-30
					cfs:		7.2	14.2	63.8	228	278	31.5	16.3	9.5	6.8	∅	
II	0.1	~~0.65~~ ∅	~~0.67~~ 0.50	0.02	csm/in:		∅	∅	70	377	196	99	67	46	38	∅	p.5-29
					cfs:		∅	∅	1.4	7.5	3.9	2.0	1.3	0.9	0.8	∅	
III	0.3	~~0.05~~ ∅	~~0.19~~ 0.10	0.93	csm/in:		20	41	235	676	676	80	42	24	18	∅	p.5-31
					cfs:		18.6	38.1	218	628	628	74.4	39.1	22.3	16.7	∅	
IV	0.1	∅	~~0.73~~ 0.50	0.019	csm/in:		too small for calculation/contribution										
Composite hydrograph at outlet							25.8	52.3	283	863	910	108	56.7	32.7	24.3	∅	

1/ Worksheet 5a. Rounded as needed for use with exhibit 5.
2/ Enter rainfall distribution type used.
3/ Hydrograph discharge for selected times is A_mQ multiplied by tabular discharge from appropriate exhibit 5.

The peak flow is seen to be 910 cfs, occurring at 12.3 hours. Figure 3-32 is a plot of the three main components, plus the total hydrograph. Subarea III contributed most of the peak flow to the total hydrograph, while subareas II and IV contributed insignificant flows. The following section introduces WinTR55 and presents this same example. The main difference is that WinTR55 requires a description of the channel as it calculates the travel times and conducts the channel routing using a more precise procedure. In addition, the hydrograph development uses TR20, instead of the tabular hydrograph method.

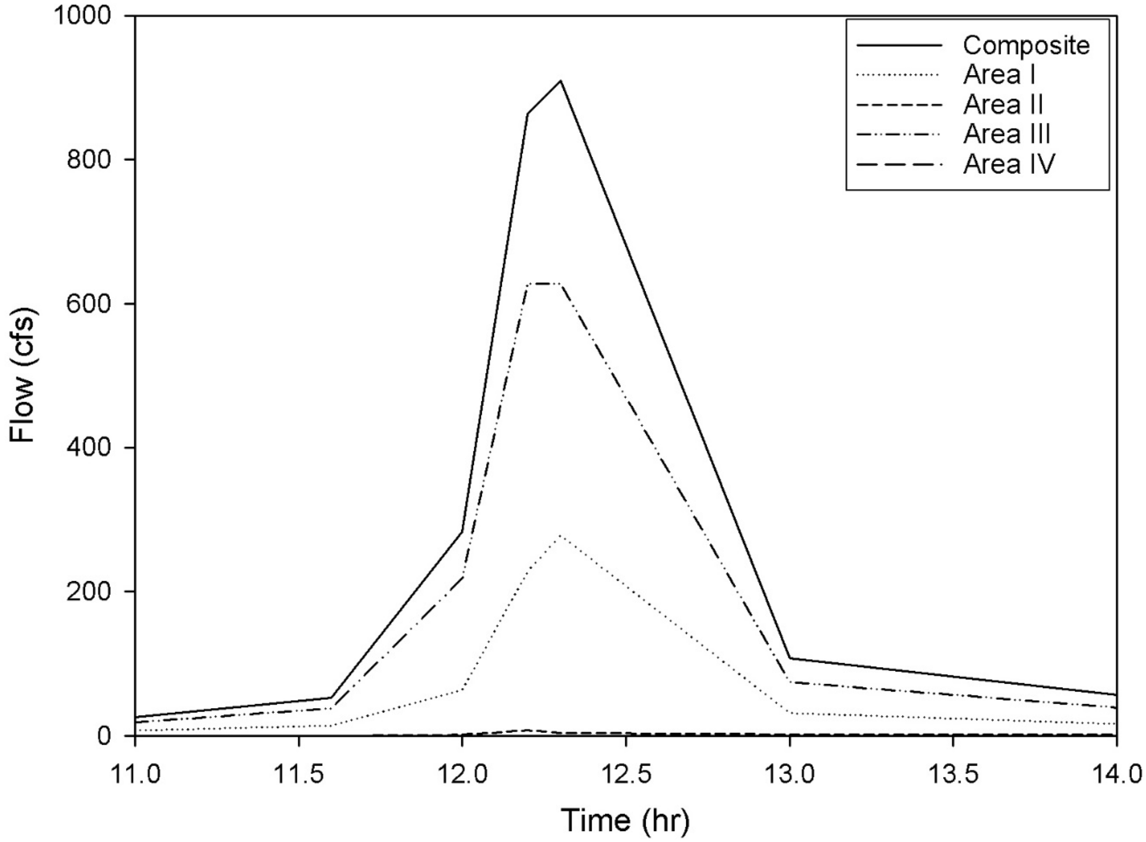


Figure 3-32. Plot of individual and composite hydrograph for urban example.

WinTR55

The following discussion is summarized from the WinTR-55 user guide information, while the example uses the previously described information. Current information for the most recent version of WinTR-55 is available at: https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/hydrology/?cid=stelprdb1042901. The newest (Jan 2009) user guide for WinTR55 is located at: file://synologyds1817/Data/current%20files/pubs%20and%20projects/Construction%20Erosion%20Control%20Book/second%20edition/New%20inserts%20for%202nd%20edition/ch%203%20rain%20and%20runoff/WinTR55/WinTR55UserGuide.pdf. It may be best to search for WinTR55 instead of trying to type in this complex URL. Also government agency URLs seem to frequently change! The most recent WinTR55 is version 1.00.10, last updated February 7, 2013. An updated database was available since April 20, 2015, which includes special rainfall distributions and several dimensional hydrographs, along with example files.

A WinTR55 work group was formed in the spring of 1998 to modernize and revise TR-55 and the computer software. The current changes included the following: upgrading the source code to Visual Basic, changing the philosophy of data input, developing a Windows interface and output post-processor, enhancing the hydrograph-generation capability of the software, and improving the generated flood-route hydrographs through stream reaches and reservoirs.

The WinTR55 user manual (NRCS 2002a) covers the procedures used in and the operation of the WinTR55 computer program. Part 630 of the *Natural Resources Conservation Service* (NRCS) National Engineering Handbook provides detailed information on NRCS hydrology and is the technical reference for WinTR55.

WinTR-20 can be used for situations beyond the limitations of WinTR55 (usually large areas with complex drainage patterns). The NOAA Atlas 14 data are included in the WinTR55 rainfall database. These generally represent mean values for the various return periods from 1-year to 100-years. The most recent version of WinTR-55 is from 2015. WinTR55 does not yet incorporate the revised CN rainfall-runoff hydrology modifications to NEH 630 which are currently being reviewed (as of late 2018). For more complex situations (and for likely rapid implementation of the updated hydrology methodology), the commercial program HydroCad (https://hydrocad.net/) should be considered. It is not known when WinTR55 and WinTR20 will be updated to reflect the changes in the curve number method currently being reviewed.

The following subsections review the 2015 version of WinTR55. Again, the local review agency should approve the calculation methods used for the design of construction site controls.

Program Description
WinTR55 is a single-event rainfall-runoff small watershed hydrologic model. The model generates hydrographs from both urban and agricultural areas and at selected points along the stream system. Hydrographs are routed downstream through channels and/or reservoirs. Multiple sub-areas can be modeled within the watershed.

Model Overview
A watershed is composed of subareas (land areas) and reaches (major flow paths in the watershed). Each subarea has a hydrograph generated from the land area based on the land and climate characteristics provided. Reaches can be designated as either channel reaches where hydrographs are routed based on physical reach characteristics or as storage reaches where hydrographs are routed through a reservoir based on temporary storage and outlet characteristics. Hydrographs from sub-areas and reaches are combined as needed to accumulate flow as water moves from the upland areas down through the watershed reach network. The accumulation of all runoff from the watershed is represented at the watershed outlet. Up to ten sub-areas and ten reaches may be included in the watershed.

WinTR55 uses the TR20 (NRCS 2002b) model for all of the hydrograph procedures: generation, channel routing, storage routing, and hydrograph summation. Figure 3-33 is a diagram showing the WinTR55 model, its relationship to TR20, and the files associated with the model.

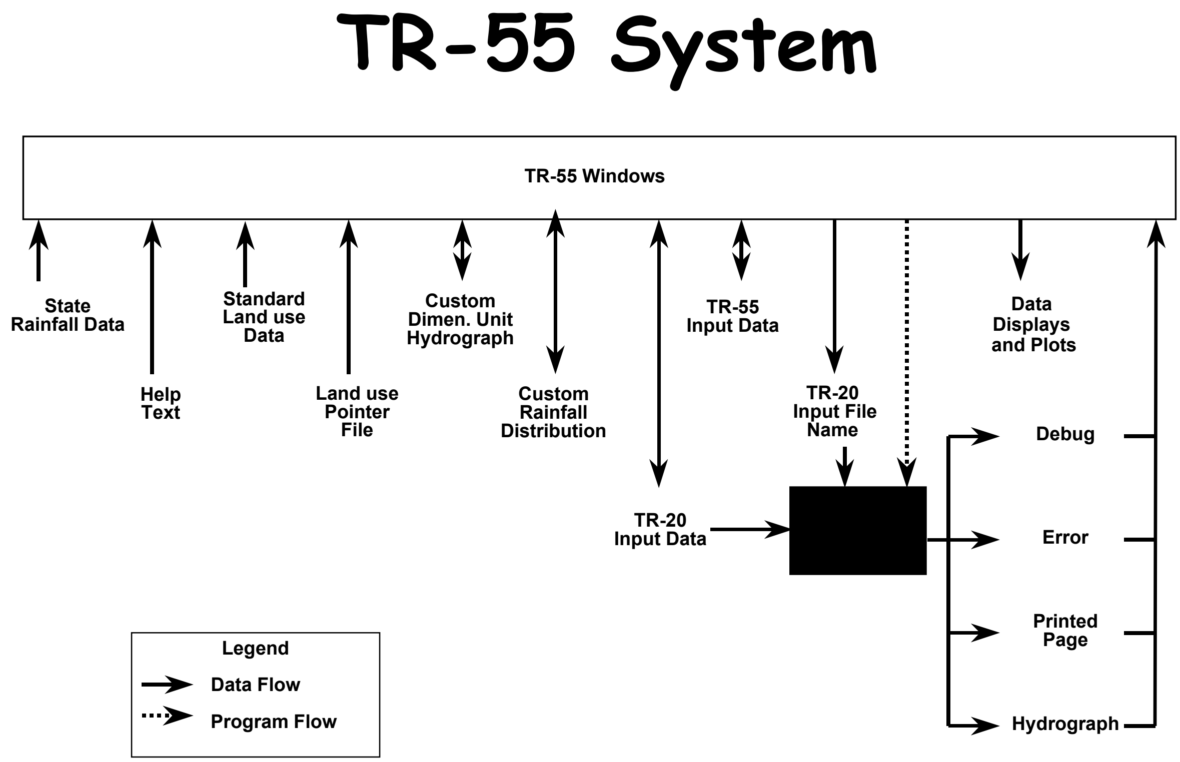


Figure 3-33. WinTR55 system schematic (NRCS 2009).

Capabilities and Limitations

WinTR55 hydrology has the capability to analyze watersheds that meet the criteria listed in Table 3-29:

Table 3-29. WinTR55 Capabilities & Limitations (NRCS 2009)

Variable	Limits
Minimum area	No absolute minimum is included in the software. However, carefully examine results from sub-areas less than 1 acre.
Maximum area	25 square miles (6,500 hectares)
Number of Subwatersheds	3-10
Time of concentration for any sub-area	0.1 hour $\leq T_c \leq$ 10 hour
Number of reaches	0-10
Types of reaches	Channel or Structure
Reach Routing	Muskingum-Cunge
Structure Routing	Storage-Indication
Structure Types	Pipe or Weir
Structure Trial Sizes	3-3
Rainfall Depth[1]	Default or user-defined 0 – 50 inches (0-1,270 mm)
Rainfall Distributions	NRCS Type I, IA, II, III, NM60, NM65, NM70, NM75, or user-defined
Rainfall Duration	24-hour
Dimensionless Unit Hydrograph	Standard peak rate factor 484, or user-defined (e.g. Delmarva—see Example 3)
Antecedent Moisture Condition	2 (average)

[1] Although no minimum rain depth is listed by the NRCS in the above table, it must be recognized that the original SCS curve number methods, incorporated in this newer version, are not accurate for small storms. In most cases, larger storms used for drainage design are reasonably well suited to this method. Pitt (1987) and Pitt, *et al.* (2002) showed that rain depths less than 2 or 3

inches can have significant errors when using the CN approach. For sites outside of these WinTR55 limits, the NRCS recommends the use of WinTR20. Also, commercial programs such as HydroCad implement these processes in an useful interface.

Model Input

The various data used in the WinTR55 procedures are user entered via a series of input windows in the model. A description of each of the input windows follows the figure. Data entry is needed only on the windows that are applicable to the watershed being evaluated.

Minimum Data Requirements. While WinTR55 can be used for watersheds with up to ten sub-areas and up to ten reaches, the simplest run involves only a single sub-area. Data required for a single sub-area run can be entered on the TR55 Main Window. These data include**: Identification Data**-User, -State, -County, -Project, and -Subtitle; **Dimensionless Unit Hydrograph**; **Storm Data; Rainfall Distribution**; and **Subarea Data.** The subarea data can be entered directly into the Subarea Entry and Summary table**: Subarea name, subarea description, subarea flows to reach/outlet**, **area**, **runoff curve number** (RCN), and **time of concentration** (T_c). Detailed information for the subarea RCN and T_c can be entered here or on other windows; if detailed information is entered elsewhere the computational results are displayed in this window.

Watershed Subareas and Reaches. To properly route stream flow to the watershed outlet, the user must understand how WinTR55 relates watershed subareas and stream reaches. Figure 3-34 and Table 3-30 show a typical watershed with multiple sub-areas and reaches.

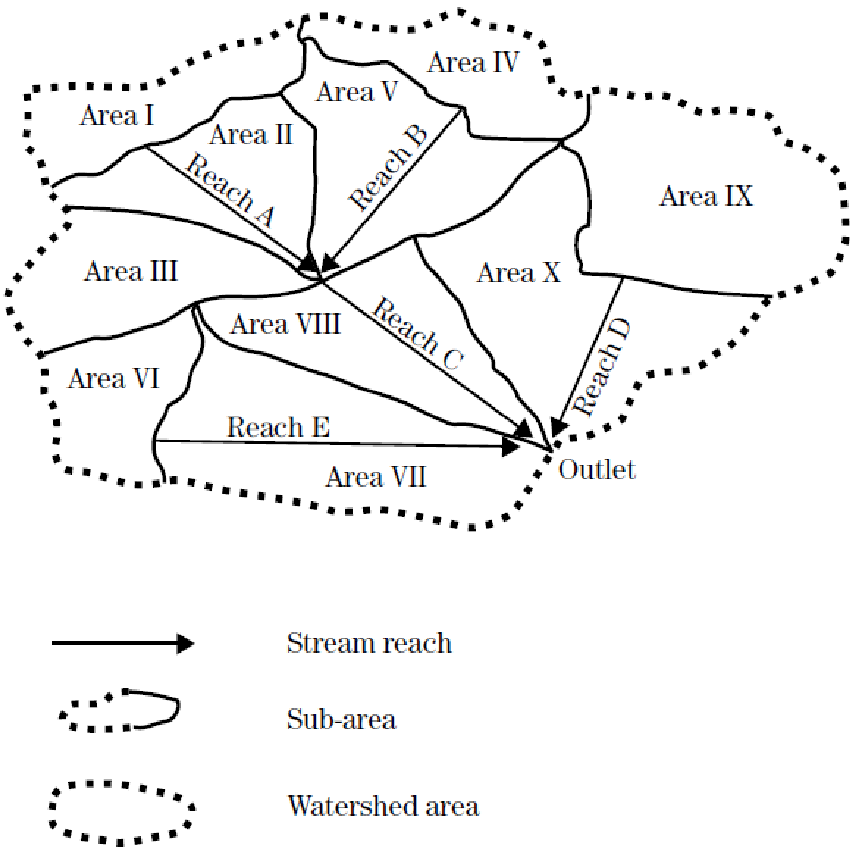


Figure 3-34. Sample Watershed Schematic (NRCS 2009)

Table 3-30. Sample Watershed Flows (NRCS 2009)

Subarea	Flows into Upstream End of		Reach	Flows into
Area I	Reach A		Reach A	Reach C
Area II	Reach C		Reach B	Reach C
Area III	Reach C		Reach C	OUTLET
Area IV	Reach B		Reach D	OUTLET
Area V	Reach C		Reach E	OUTLET
Area VI	Reach E			
Area VII	OUTLET			
Area VIII	OUTLET			
Area IX	Reach D			
Area X	OUTLET			

Reaches define flow paths through the watershed to its outlet. Each subarea and reach contribute flow to the upstream end of a receiving reach or to the Outlet. Accumulated runoff from all sub-areas routed through the watershed reach system, by definition, is flow at the watershed outlet.

Processes

WinTR55 relies on the TR20 model for all hydrograph process calculations, including hydrograph generation, combining hydrographs, channel routing, and structure routing. The program uses a

Muskingum-Cunge method of channel routing (Chow, *et al.* 1988; Maidment 1993; Ponce 1989). The storage-indication method (NRCS NEH Part 630, Chapter 17) is used to route structure hydrographs.

Example: WinTR-55 Setup and Operation

An application using WinTR55 and the previously presented urban watershed example is shown on Figure3-35 to 3-45. Figures 3-46 and 3-47 are other screens available in WinTR55 that can be used to aid in the calculation of some of the site data, while Figure 3-48 is used for detention facilities (structures).

Figure 3-35. WinTR55 opening screen.

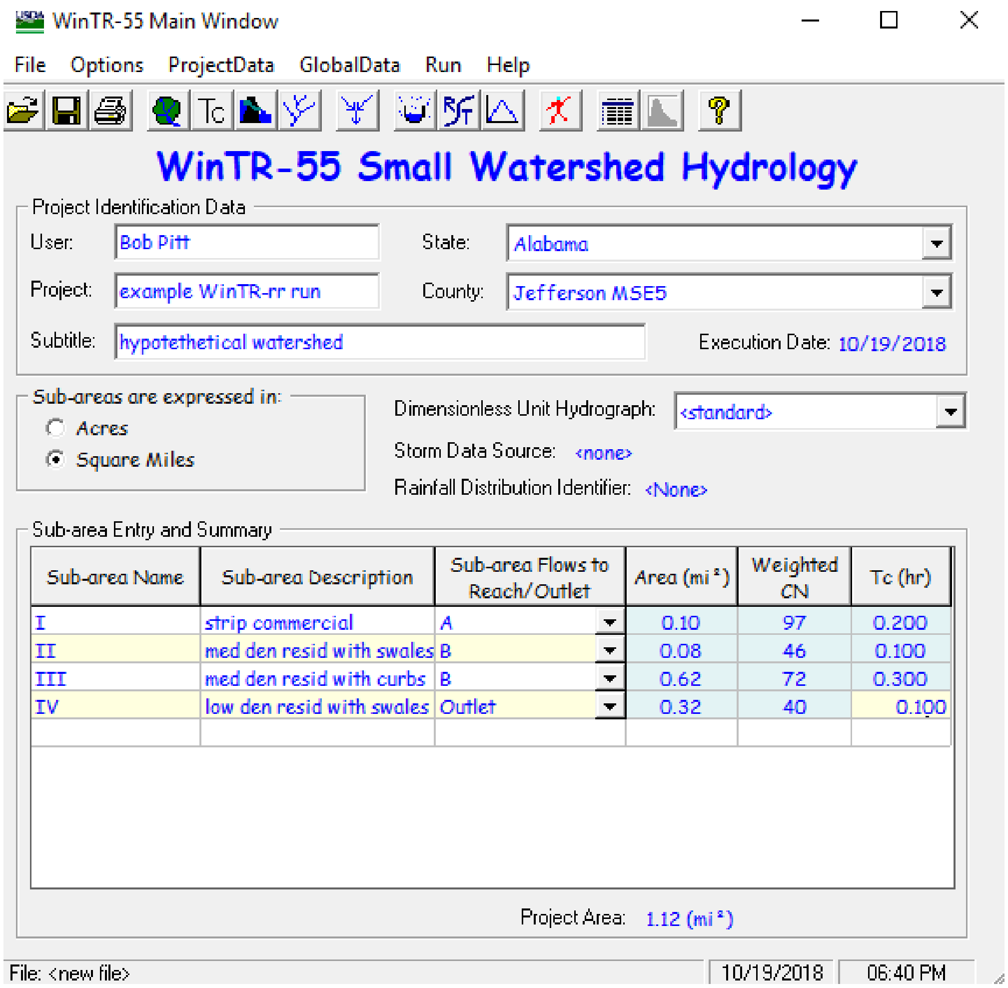


Figure 3-36. WinTR-55 small watershed basic information screen.

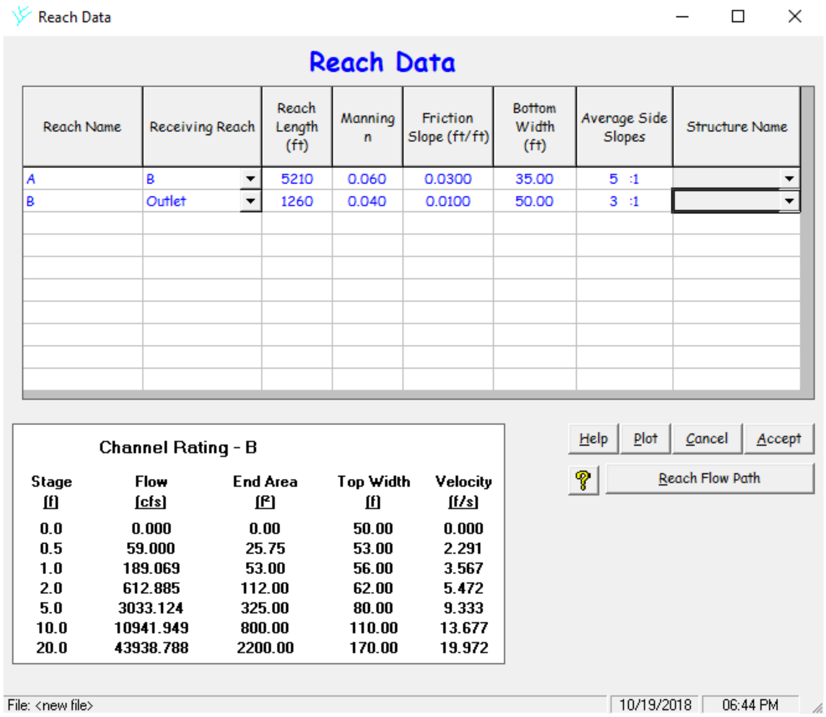


Figure 3-37. WinTR55 reach data screen.

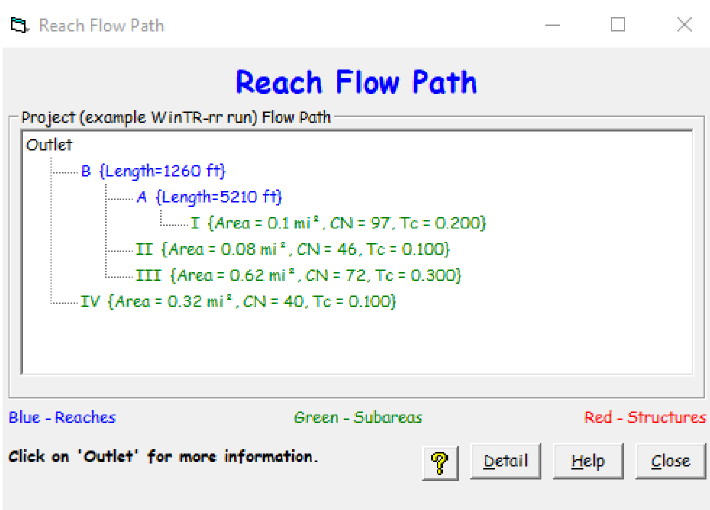


Figure 3-38. WinTR55 reach flow path screen.

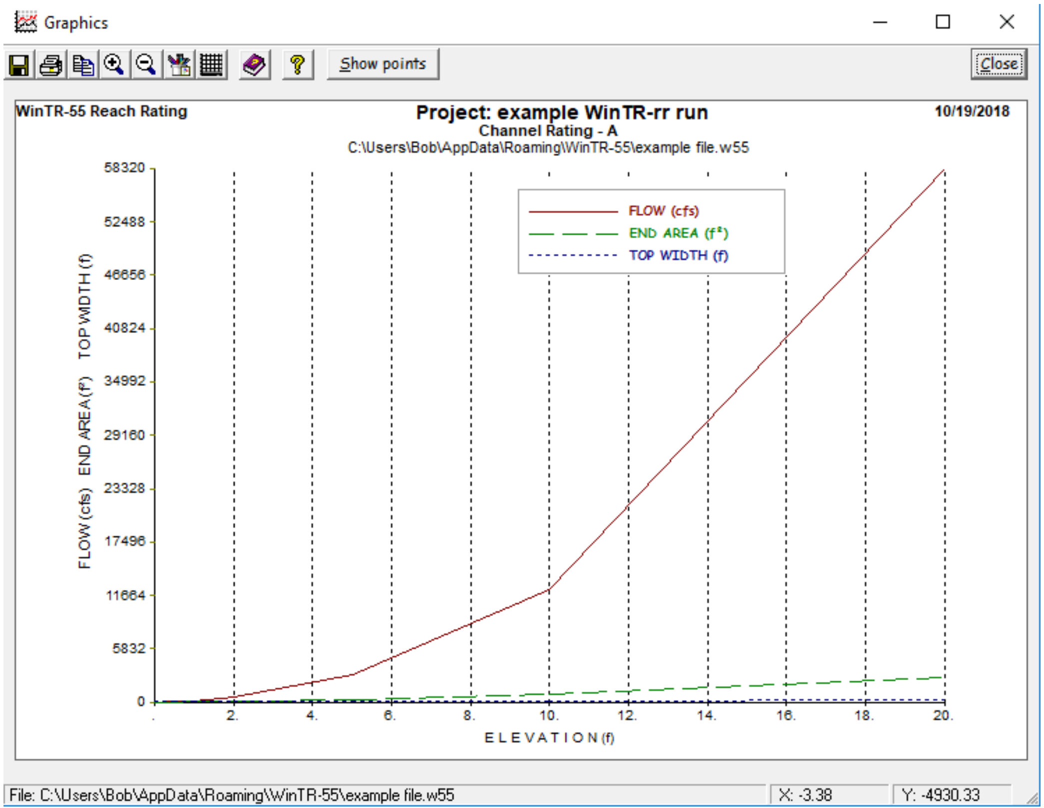


Figure 3-39. WinTR55 reach routing screen.

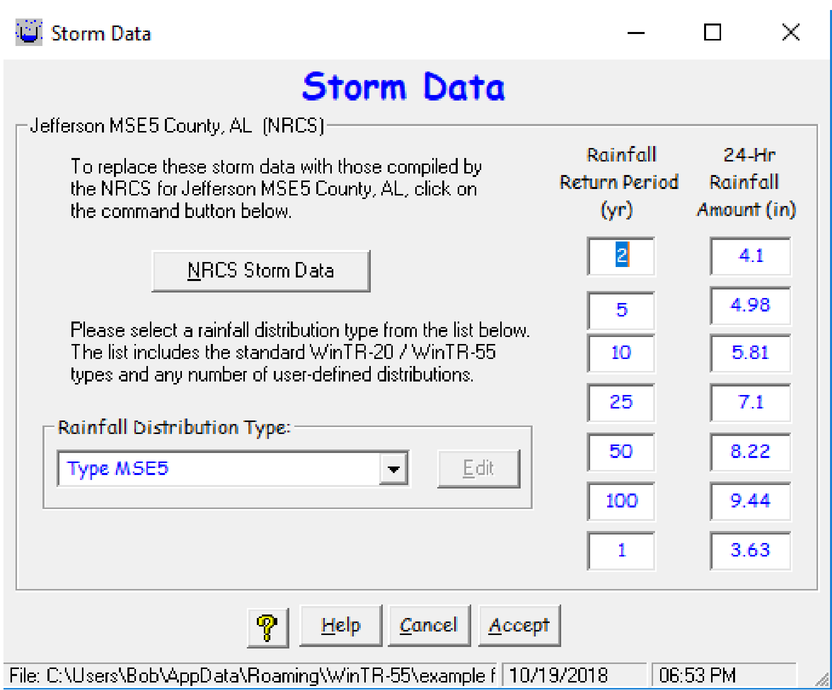


Figure 3-40. WinTR55 storm data screen (information automatically determined by location).

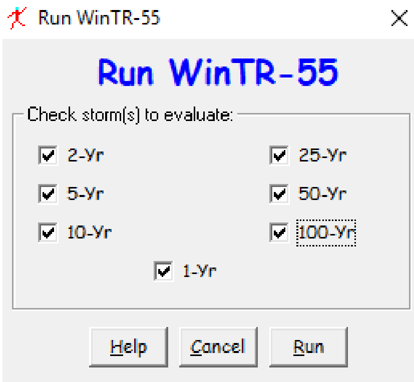
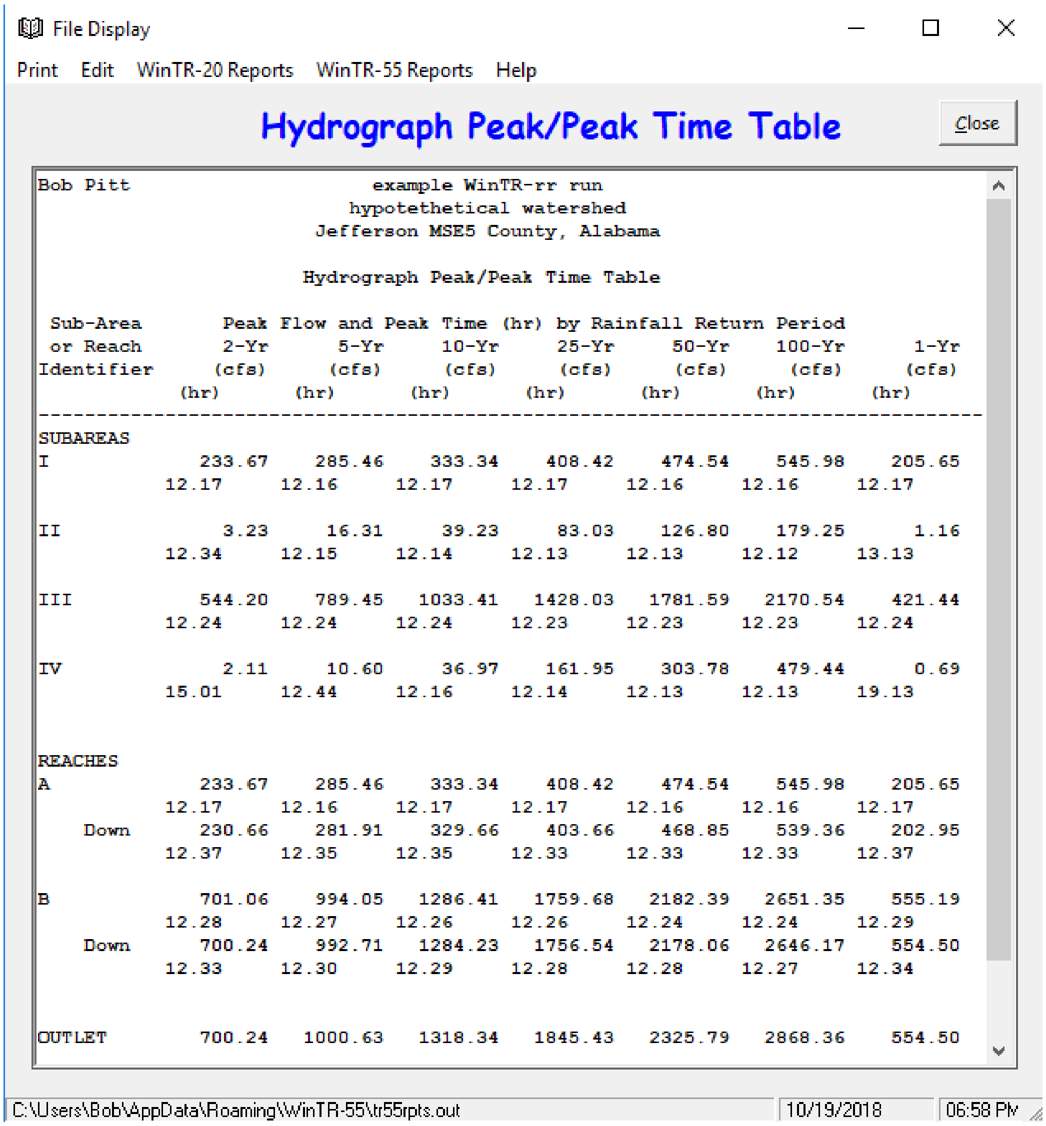


Figure 3-41. WinTR55 event selection/run screen.



Bob Pitt

example WinTR-rr run
hypotethetical watershed
Jefferson MSE5 County, Alabama

Hydrograph Peak/Peak Time Table

Sub-Area or Reach Identifier	Peak Flow and Peak Time (hr) by Rainfall Return Period 2-Yr (cfs) (hr)	5-Yr (cfs) (hr)	10-Yr (cfs) (hr)	25-Yr (cfs) (hr)	50-Yr (cfs) (hr)	100-Yr (cfs) (hr)	1-Yr (cfs) (hr)
SUBAREAS							
I	233.67	285.46	333.34	408.42	474.54	545.98	205.65
	12.17	12.16	12.17	12.17	12.16	12.16	12.17
II	3.23	16.31	39.23	83.03	126.80	179.25	1.16
	12.34	12.15	12.14	12.13	12.13	12.12	13.13
III	544.20	789.45	1033.41	1428.03	1781.59	2170.54	421.44
	12.24	12.24	12.24	12.23	12.23	12.23	12.24
IV	2.11	10.60	36.97	161.95	303.78	479.44	0.69
	15.01	12.44	12.16	12.14	12.13	12.13	19.13
REACHES							
A	233.67	285.46	333.34	408.42	474.54	545.98	205.65
	12.17	12.16	12.17	12.17	12.16	12.16	12.17
Down	230.66	281.91	329.66	403.66	468.85	539.36	202.95
	12.37	12.35	12.35	12.33	12.33	12.33	12.37
B	701.06	994.05	1286.41	1759.68	2182.39	2651.35	555.19
	12.28	12.27	12.26	12.26	12.24	12.24	12.29
Down	700.24	992.71	1284.23	1756.54	2178.06	2646.17	554.50
	12.33	12.30	12.29	12.28	12.28	12.27	12.34
OUTLET	700.24	1000.63	1318.34	1845.43	2325.79	2868.36	554.50

Figure 3-42. WinTR55 calculated hydrograph summary screen.

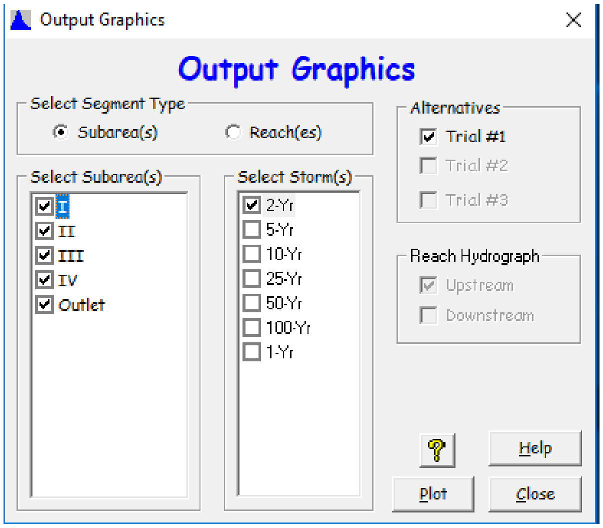


Figure 3-43. Output graphics selection.

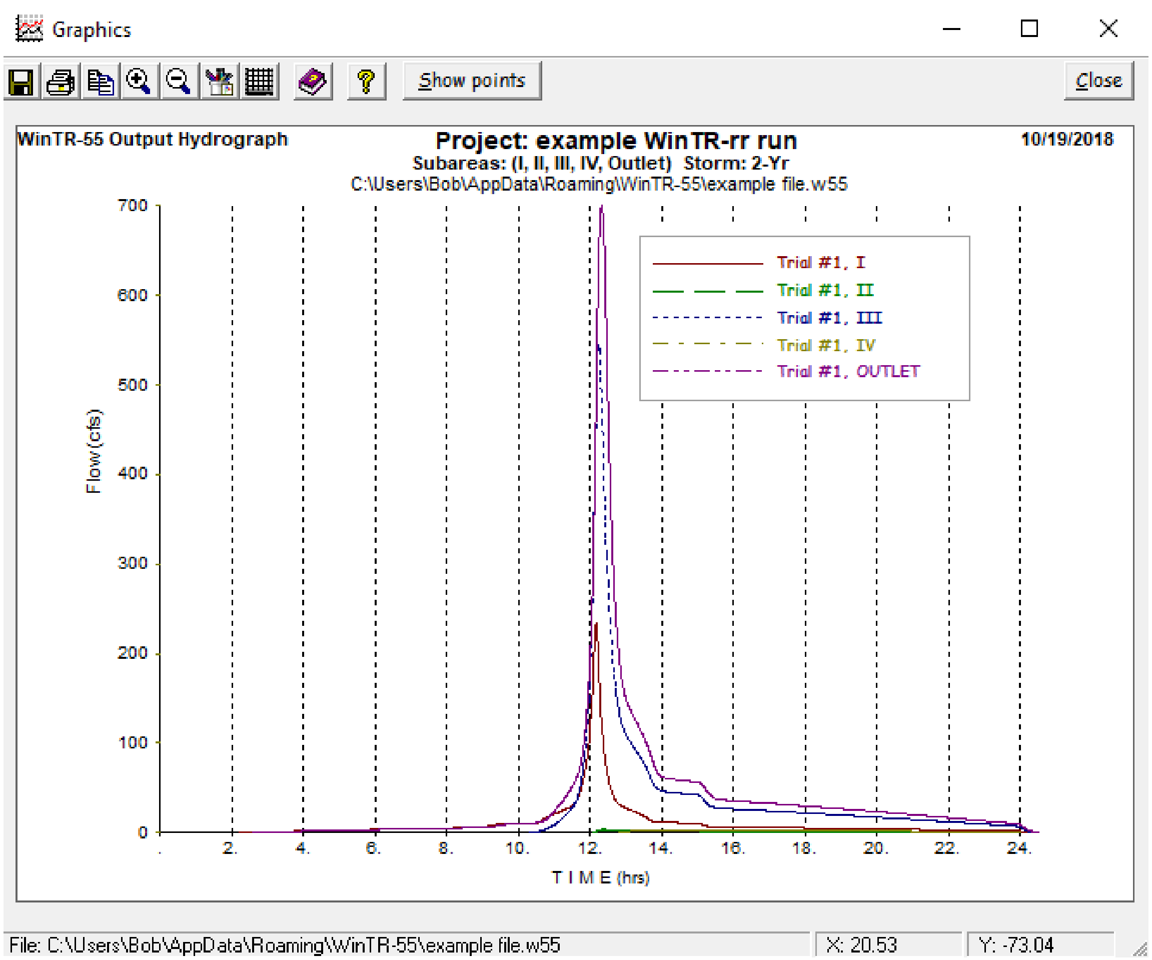


Figure 3-44. WinTR55 hydrograph plot screen.

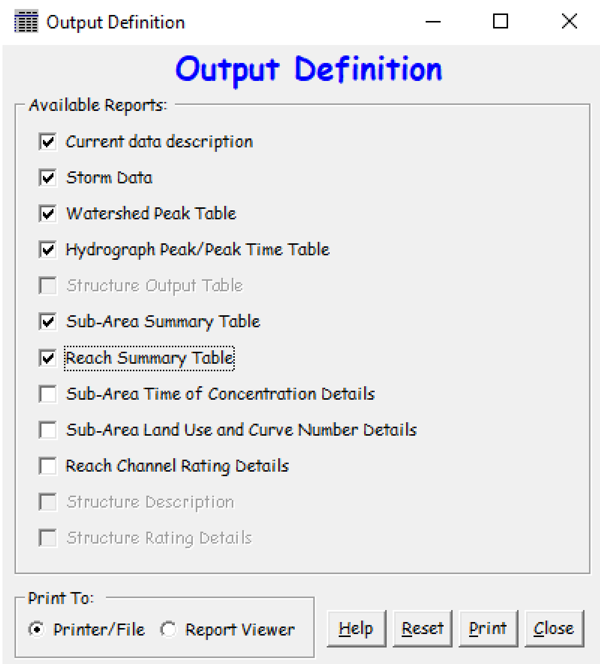


Figure 3-45. WinTR55 report generation screen.

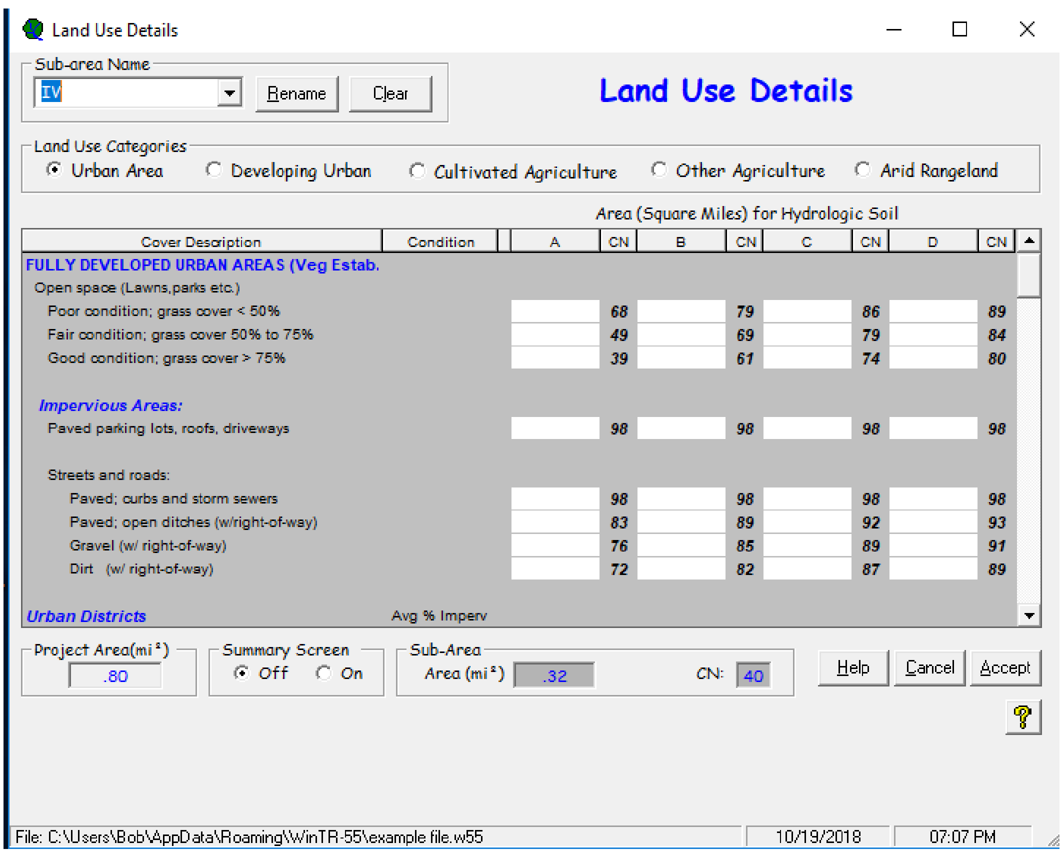


Figure 3-46. WinTR55 land use details screen (used if data not directly entered).

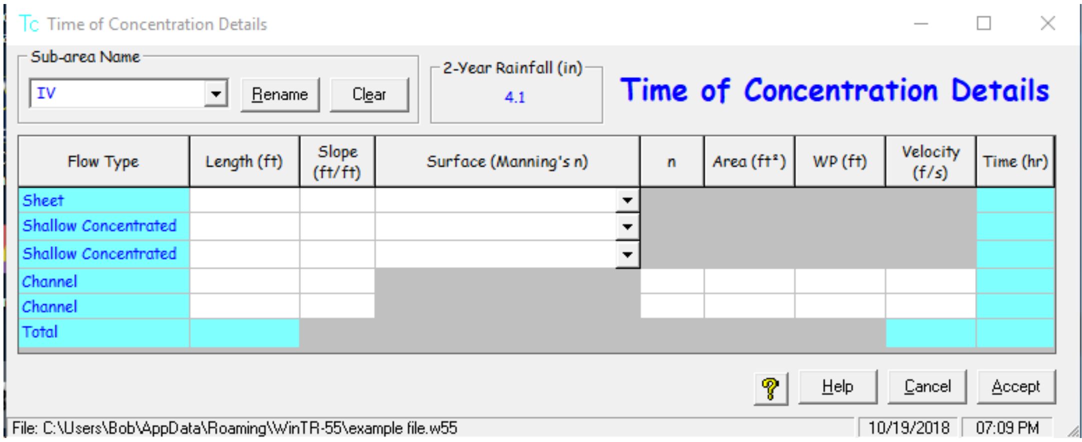


Figure 3-47. WinTR55 time of concentration details screen/calculator (used if data not directly entered).

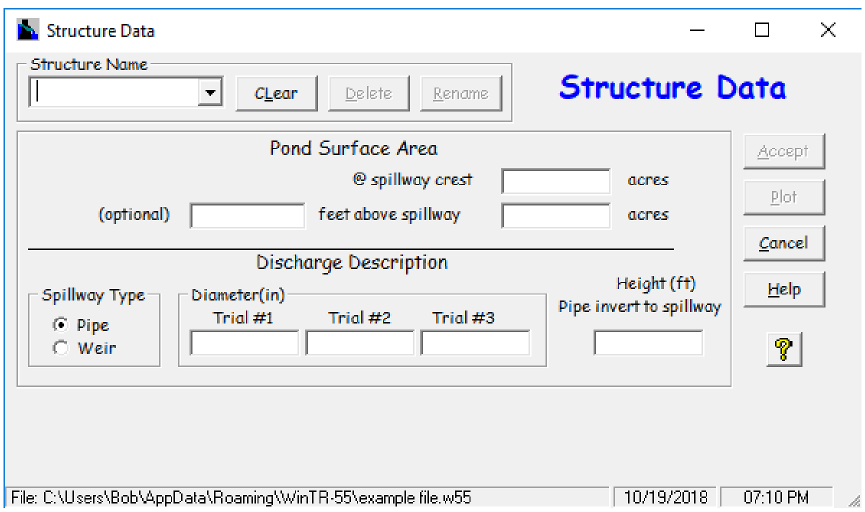


Figure 3-48. WinTR55 structure data screen for detention facilities.

This WinTR55 example resulted in a peak flow for the 2-yr storm of about 700 cfs, compared to the previously calculated value of 910 cfs. This difference is due to the different routing procedure used, the more precise hydrograph development procedure in WinTR55 version compared to the tabular hydrograph method, and the updated local rain depths for the different frequency storms. As noted previously, these smaller events usually result in over-designs of urban infrastructure when the older TR-55 methods are used compared to the updated Atlas 14 rain depths.

Example: WinTR55 Applications to Construction Sites

As indicated previously, there are a number of situations where WinTR55 (or TR55) can be used to advantage when evaluating construction sites, including the design of erosion and sediment controls. These may include:

- Determination of flows leaving the site that may affect downstream areas. Downstream erosion controls may include silt fencing along the project perimeter, or sediment ponds, depending on flow conditions. These controls must be completed before any on-site construction is started.

- Determination of upland flows coming towards the disturbed areas. These flows must be diverted by swales or dikes, or safely carried through the construction sites. Channel design will be based on the expected flow conditions. These controls must be completed after the downstream controls, and before any on-site controls are started.

- Determination of on-site flows on slopes going towards silt fencing, sediment ponds, or other controls. These flows also will be needed to evaluate shear stress on channels and on slopes.

Figure 3-49 is an example map (base map: a portion of a USGS quadrangle sheet with 20 ft contours) showing a construction site, and the associated upland and downslope drainages. This chapter has illustrated how it is possible to easily calculate the runoff characteristics affecting the site and downslope areas for different rain conditions. In addition, detailed site and rainfall conditions for different project phases can be evaluated and incorporated in the design of appropriate erosion and sediment controls.

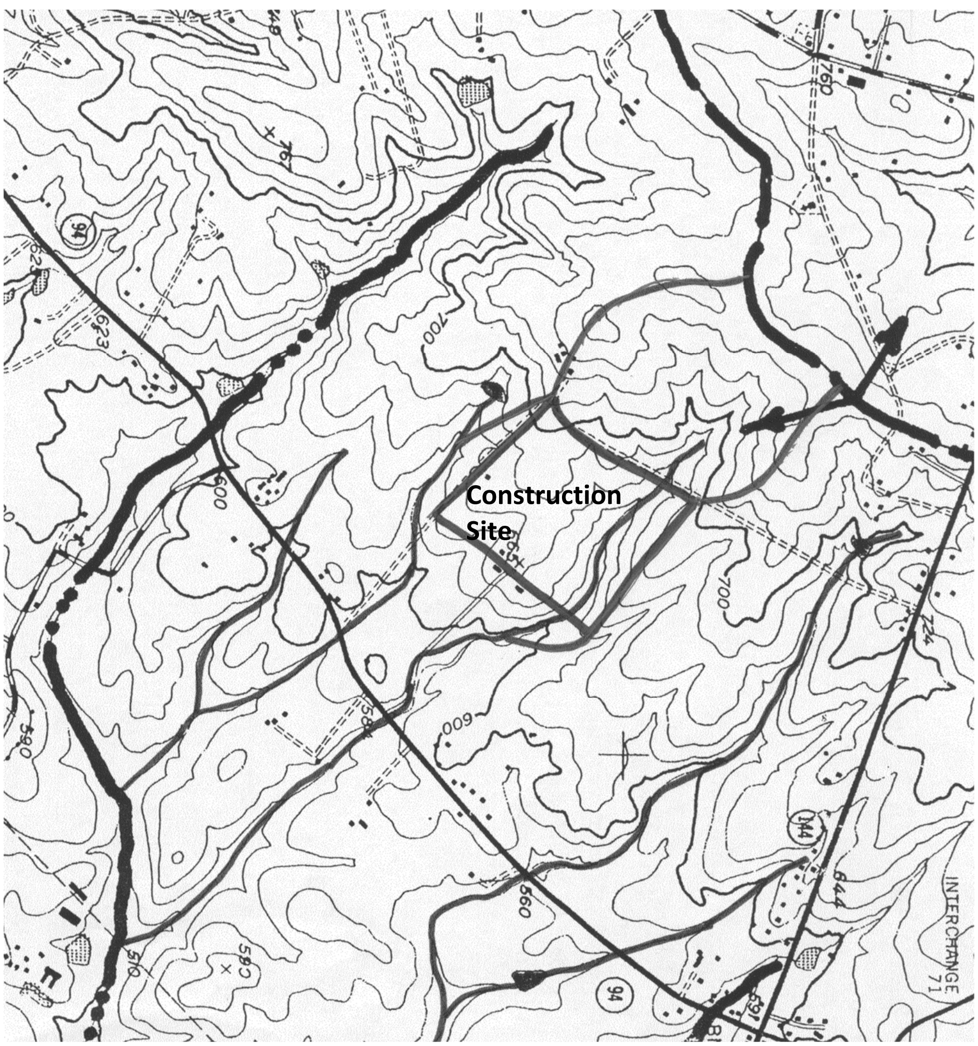


Figure 3-49. Determination of general upslope and downslope drainage areas from construction site.

Figure 3-50 shows subdrainages for the upslope (U1 through U3), downslope (D1 through D3), and on-site areas (O1 through O7) for this example construction site. Table 3-31 summarizes the characteristics of these areas, along with the hydrologic information needs for each area. Most of the site will be cleared and graded, except for the two small areas near the downslope edge. The upslope diversions (for U2 and U3) will carry the upslope water to the main channel. As an example, the diversion length for U2 is 900 ft long and the elevation drop is 70 ft. The channel slope for this diversion is therefore 70/900 = 0.08, or 8%.The runoff from the O1 and O2 on-site areas will be controlled by slope mulches and silt fences, before the runoff drains to the on-site main channel. A sediment pond will be constructed at the downslope property boundary before this main channel leaves the site, receiving runoff from U1, U2, U3, O1, and O2. This table shows 2 different rain depths for some conditions, based on the following discussion and Table 3-33.

Table 3-32 and Figure 3-51 is an example using WinTR55 for this site. This example is for a sediment pond at the downslope boundary. Subareas O3, O4, O5, O6, and O7 are all very small and do not drain to this pond site, but drain towards the perimeter silt fences. The reach data assumed for reach A (the main channel to the outlet) is as follows: 1240 ft. long at 0.04 (4%) slope, n = 0.08, and bottom width = 10 ft. The channel side slopes are 1 to 3. Table 3-32 shows subareas O1 and O2 draining into reach A, but they actually drain directly to the outlet (the pond).

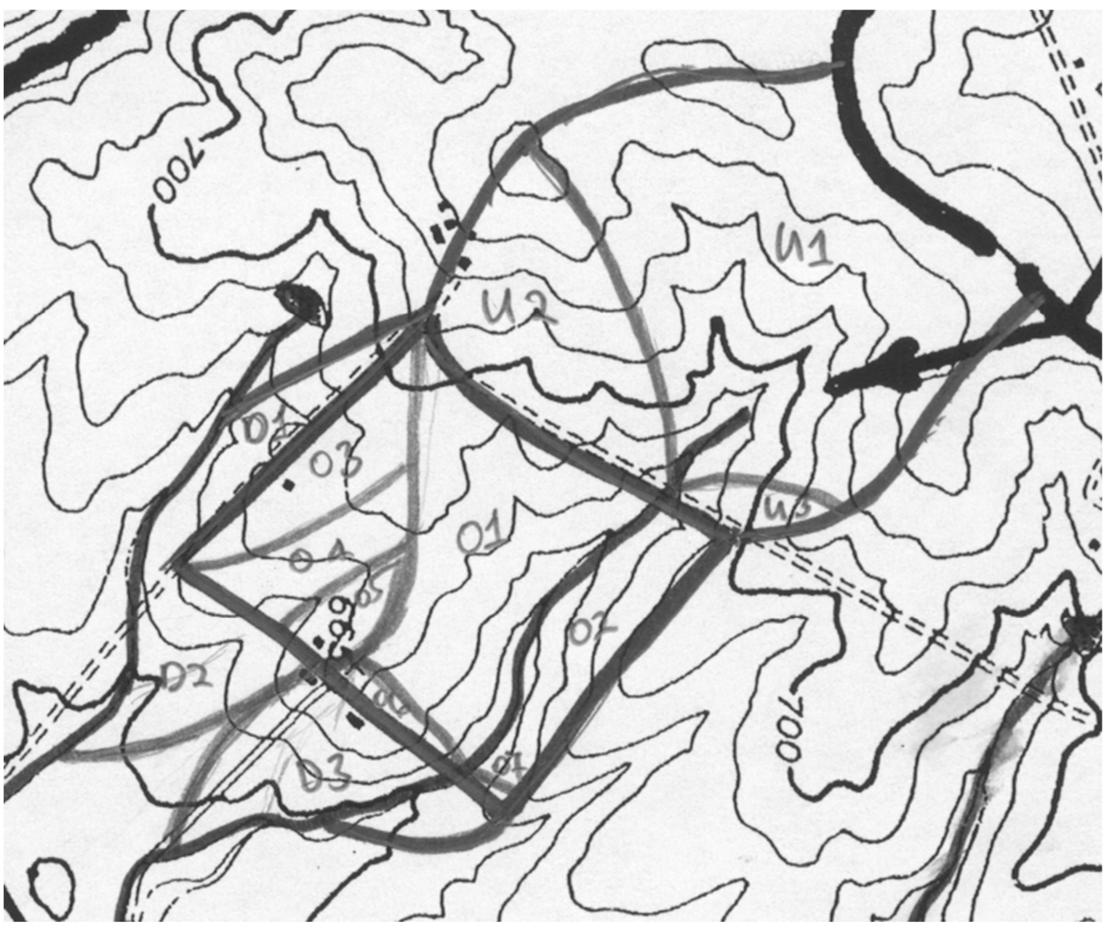


Figure 3-50. Subdrainage areas on and near construction site.

- Silt fences will be located along the side and bottom edges of the site, affected by O3, O4, O5, O6, and O7 subdrainage areas.
- Upslope channel diversions will be located along the upper edge of the site; subdrainage areas U2 and U3 will drain towards the site and drain into the on-site channel.
- All upslope areas, U1, U2, and U3, will be directed to the on-site drainage channel. The O1 and O2 on-site subdrainage areas will also drain to this on-site channel.
- A sediment pond will be located at the downslope edge of the property on the on-site drainage channel and collects the water from U1, U2, U3, O1, and O2.

Table 3-31 summarizes the subarea hydrologic site features, including the T_c values. This table also shows the calculated peak discharge rate for each of these areas. The following WinTR55 example shows the calculations for the hydrograph entering the sediment pond (using Tuscaloosa, AL, rain conditions).

Table 3-31. Upslope and On-Site Subdrainage Area Characteristics for Construction Site and TR55 Calculations

Area Notation	Location	Objective	Area (acres)	Area (Am, mi^2)	Cover n	Average flow path slope	CN (all "C" soils)	Ia (in.)	Rain depth, P (in.)	Ia/P	Tc (min)	Tc (hr)
U1	Upslope – direct to on site stream	Hydrograph (to be combined with U2 and U3)	37.4	0.058	0.4	8%	73	0.74	5.5	0.13	29	0.48
U2	Upslope – diversion to on site stream	Peak flow rate and hydrograph (to be combined with U1 and U3)	14.6	0.023	0.4	11.5	73	0.74	5.5	0.13	25	0.42
U3	Upslope – diversion to on site stream	Peak flow rate and hydrograph (to be combined with U1 and U2)	2.4	0.0038	0.4	12.7	73	0.74	5.5	0.13	20.7	0.35
O1	On site – drainage to sediment pond and main site stream (also slope protection needed)	Peak flow rate and hydrograph	12.6	0.020	0.011	10	91	0.198	6.6 8.4	0.03 0.02	3.5	0.06
O2	On site – drainage to silt fence and main site stream (also slope protection needed)	Peak flow rate and hydrograph	7.1	0.011	0.011	10.5	91	0.198	4.0 6.0	0.05 0.03	1.6	0.03
O3	On site – towards perimeter silt fence (also slope protection needed)	Peak flow rate and hydrograph	6.1	0.0095	0.011	5	91	0.198	4.0 6.0	0.05 0.03	4.1	0.07
O4	On site – towards perimeter silt fence (also slope protection needed)	Peak flow rate and hydrograph	3.1	0.0048	0.011	6.7	91	0.198	4.0 6.0	0.05 0.03	3.3	0.06
O5	On site – towards perimeter silt fence (also slope protection needed)	Peak flow rate and hydrograph	1.8	0.0028	0.011	11.3	91	0.198	4.0 6.0	0.05 0.03	1.5	0.03
O6	On site – nothing (will remain undisturbed)	na	1.3	0.0020	0.24	6.7	na	na	na	na	na	na
O7	On site – nothing (will remain undisturbed)	na	0.3	0.00047	0.24	10	na	na	na	na	na	na

Table 3-31. Upslope and On-Site Subdrainage Area Characteristics for Construction Site and TR55 Calculations (cont.)

Area Notation	Location	Direct Runoff, Q (inches)	area-depth (AmQ), (mi^2-inches)	Peak unit area flow rate (csm/in)	Peak discharge (ft^3/sec)
U1	Upslope – direct to on site stream	2.8	0.16	411	66
U2	Upslope – diversion to on site stream	2.8	0.064	449	29
U3	Upslope – diversion to on site stream	2.8	0.011	449	4.9
O1	On site – drainage to sediment pond and main site stream (also slope protection needed)	5.4 7.3	0.11 0.15	662	73 99
O2	On site – drainage to silt fence and main site stream (also slope protection needed)	3.0 5.0	0.033 0.055	662	22 36
O3	On site – towards perimeter silt fence (also slope protection needed)	3.0 5.0	0.029 0.048	662	19 32
O4	On site – towards perimeter silt fence (also slope protection needed)	3.0 5.0	0.014 0.024	662	9.3 16
O5	On site – towards perimeter silt fence (also slope protection needed)	3.0 5.0	0.0084 0.014	662	5.6 9.3
O6	On site – nothing (will remain undisturbed)	na	na	na	na
O7	On site – nothing (will remain undisturbed)	na	na	na	na

Table 3-32 WinTR55 Example for Sediment Pond (10-year rain event)

File Display

Print Edit WinTR-20 Reports WinTR-55 Reports Help

Current data description

Close

WinTR-55 Current Data Description

--- Identification Data ---

User: Bob Pitt

Date: 10/19/2018

Project:

Units: English

SubTitle: construction site example

Areal Units: Acres

State: Alabama

County: Tuscaloosa MSE5

Filename: C:\Users\Bob\AppData\Roaming\WinTR-55\construction site example.w55

--- Sub-Area Data ---

Name	Description	Reach	Area(ac)	RCN	Tc
U1	upslope to site stream	A	37.4	73	0.480
U2	upslope to diversion	A	14.6	73	0.420
U3	upslope to diversion	A	2.4	73	0.350
O1	on site to pond	A	12.6	91	0.100
O2	on site to pond	A	7.1	91	0.100

Total area: 74.10 (ac)

--- Storm Data --

Rainfall Depth by Rainfall Return Period

2-Yr (in)	5-Yr (in)	10-Yr (in)	25-Yr (in)	50-Yr (in)	100-Yr (in)	1-Yr (in)
4.1	4.98	5.81	7.1	8.22	9.44	3.63

Storm Data Source: Jefferson MSE5 County, AL (NRCS)

Rainfall Distribution Type: Type MSE5

Dimensionless Unit Hydrograph: <standard>

C:\Users\Bob\AppData\Roaming\WinTR-55\tr55rpts.out 10/19/2018 08:23 PM

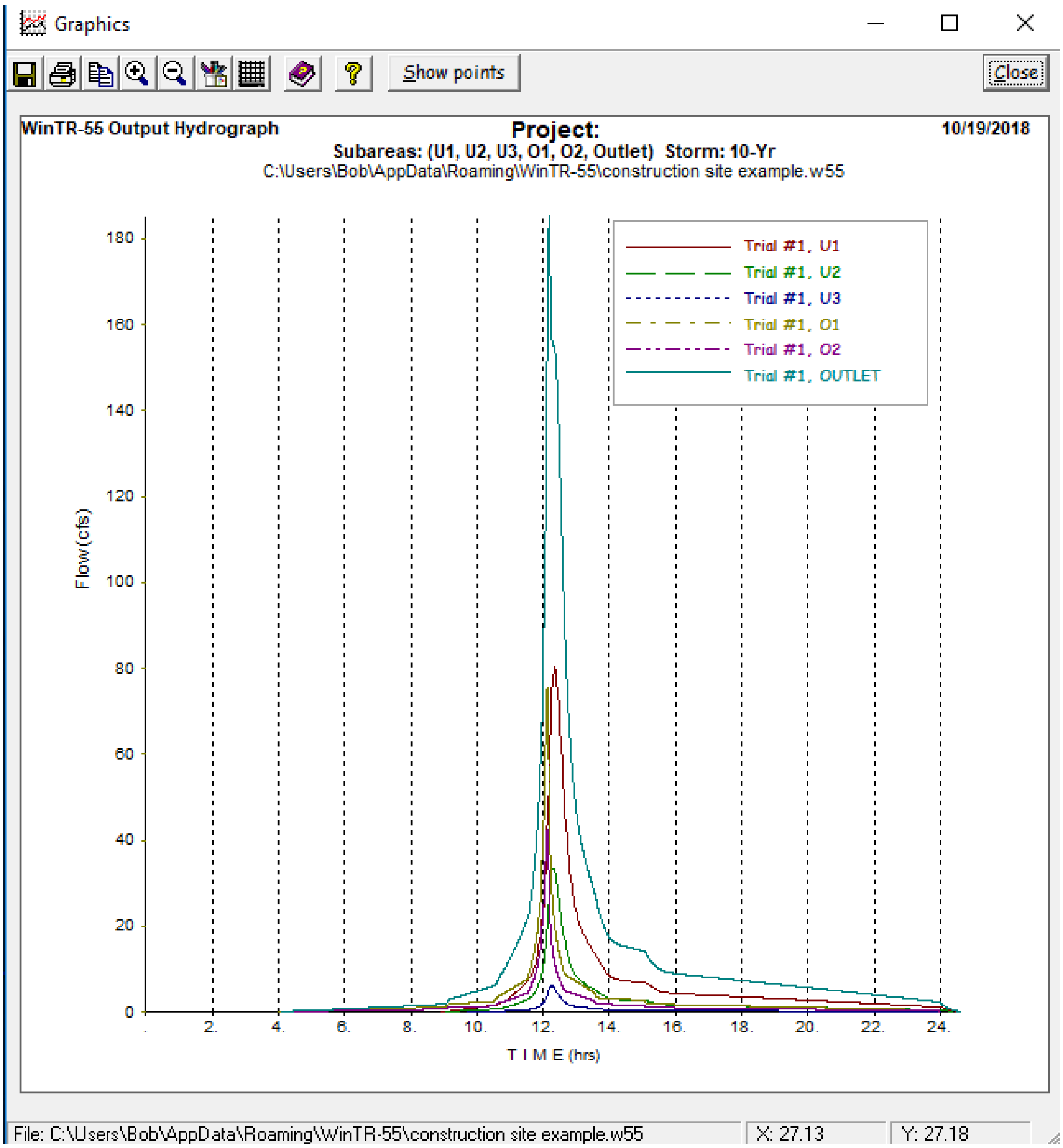


Figure 3-51. Subcatchment and outfall hydrographs for sediment pond location, WinTR55 example (peak outlet flow is 185 CFS).

Design Storms for Different Site Controls

The construction period is assumed to be one year. The different site features will require different design storms due to the different levels of protection that are appropriate for these temporary controls. Table 3-33 lists the features and the example acceptable failure rates during this one-year period, along with the corresponding design storm frequency and associated 24-hr rain total appropriate for the area. The design storms range from 4.0 to 9.4 inches in depth and the times of concentration range from 1.5 to 30 minutes. The design rain intensities could be very large for some of these design elements.

Table 3-33. Acceptable Levels of Protection for Different Site Activities

Site Construction Control	Acceptable Failure Rate during Site Construction Activities	Design Storm Return Period, for a One Year Construction Duration (years)	24-hr Rain Depth Associated with this Design Storm Return Period
Diversion channels	25%	6.5	5.0
Main site channel	5%	20	6.8
Site slopes	10%	10	5.8
Site silt fences	50%	1.9	4.0
Sediment pond	5% and 1%	20 and 100	6.8 and 9.4
Downslope perimeter silt fences	10%	10	5.8

Runoff Water Depth

In some construction erosion control designs (such as those that use the shear stress calculations in Chapter 5), the water depth is needed for sheetflow conditions. The following equation can be used to calculate the estimated water depth for sheetflow, based on the Manning's equation (R, the hydraulic radius is equal to the flow depth for sheetflow):

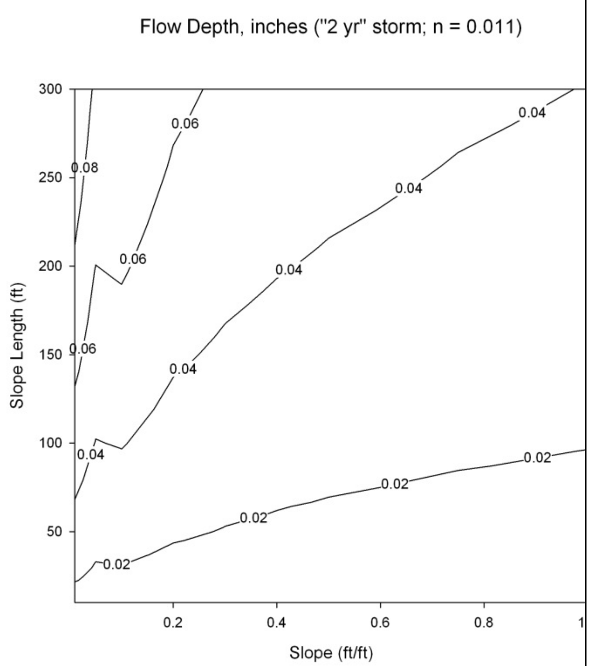
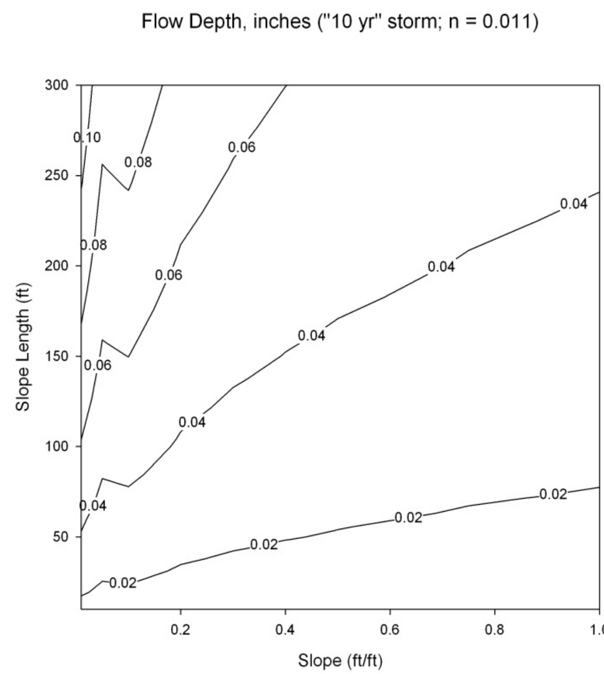
$$y = \left(\frac{qn}{1.49 s^{0.5}} \right)^{\frac{3}{5}}$$

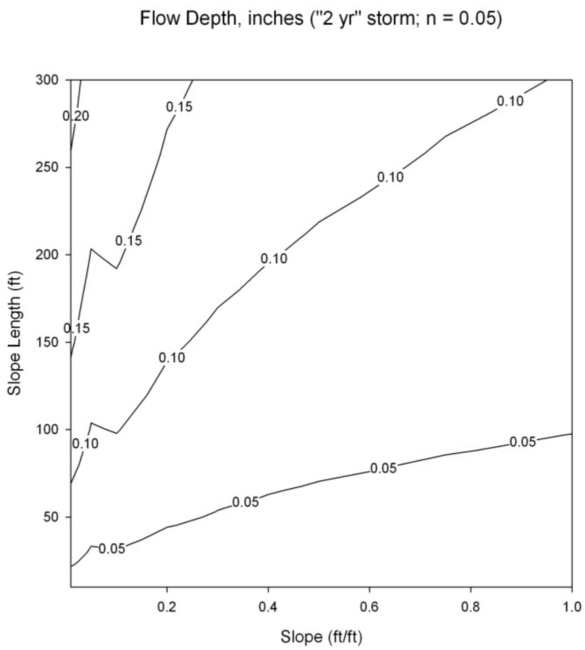
where: y is the sheetflow depth (in feet),
q is the unit width flow rate (Q/W, the total flow rate, in ft^3/sec, divided by the slope width, in ft.)
n is the sheet flow roughness coefficient, and
s is the slope (as a fraction)

Figure 3-52 contains plots of calculated flow depths for different slope conditions, using Birmingham, AL, rain conditions. These data are used later in Chapter 5 for calculating slope stability and needed reinforcements. These calculations used the Rational Method formula for the rain falling directly on the slopes, with the time of concentrations equal to the travel time of runoff down the slopes. The Rational coefficients were varied depending on the slopes, according to typical values given for lawns in good condition: C = 0.11 for slopes < 2%, C = 0.16 for slopes between 2 and 7%, and C = 0.24 for slopes > 7%. These coefficients are averaged for sandy and heavy soil conditions. The calculations were made for several surface roughness conditions representing a range of slope surfaces at construction sites, including smooth surfaces (bare soil), fallow, cultivated soils, dense grass, and light underbrush. The slopes ranged from 1 to 100 percent and the slope lengths were as long as 300 ft, while the maximum accepted slope length for silt fences, or for terrace spacing is now restricted to 100 ft.

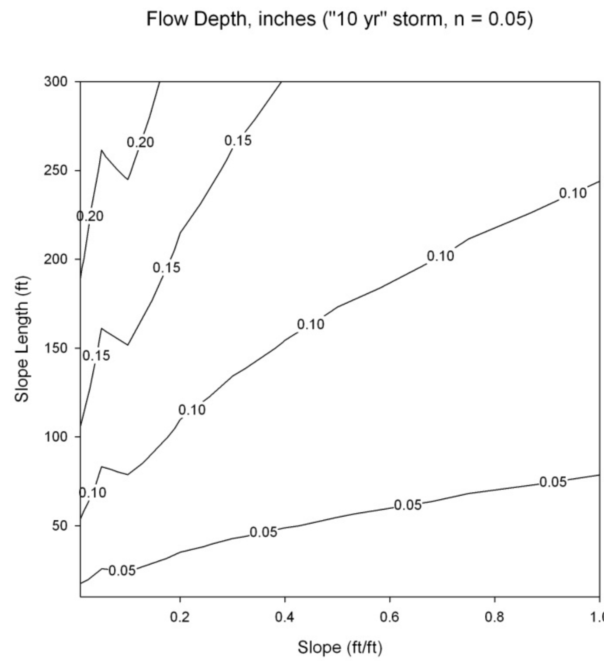
The Birmingham, AL, IDF curves for 2- and 10-year frequency storms (events having a 50 and 10% chance of occurring in any one year), are example design storms for erosion controls on construction site slopes. These IDF curves are for the older NRCS type III rainfall distributions and have 24-hr total rain depths of 6 inches for the 10-yr event and 4.2 inches for the 2-yr event. The IDF curves assume the same rain intensities for all times of concentrations less than 5 minutes. That, plus changes in the Rational runoff coefficient for different slopes, cause the discontinuity on these plots at about 10 percent slopes.

The deepest water depths were for the flattest, but longest slopes, conditions that maximize the catchment area, increase the likelihood of substantial friction effects, and hinder drainage. Typical maximum water depths on the slopes are about 0.25 to 0.5 inches when the slopes have some residue, or growing grasses. If bare, the maximum depths can be much less. The slope length is generally about twice as important as the slope angle in determining the water depth.

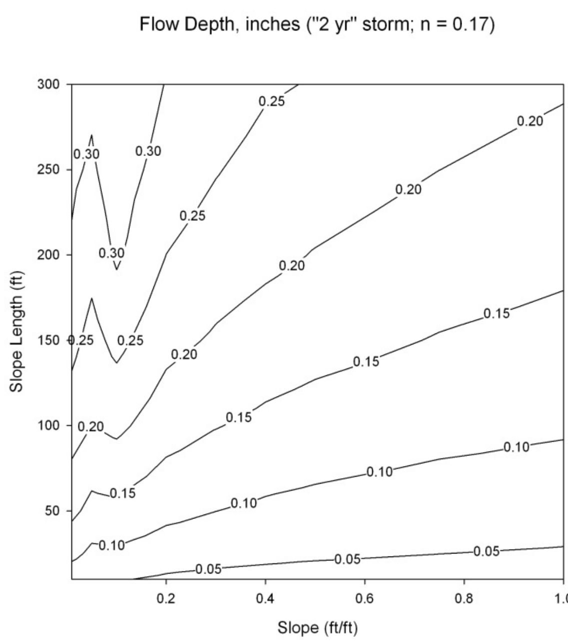
	
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	**Smooth surfaces (concrete, asphalt, gravel, or bare soil)**



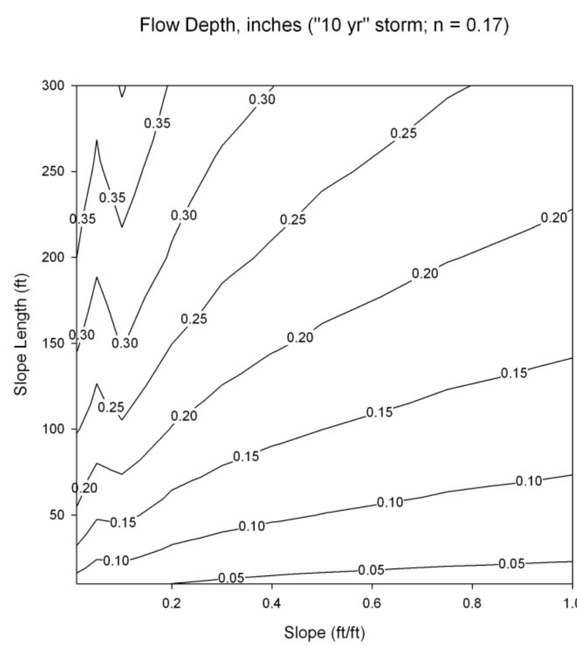
Fallow (no residue)



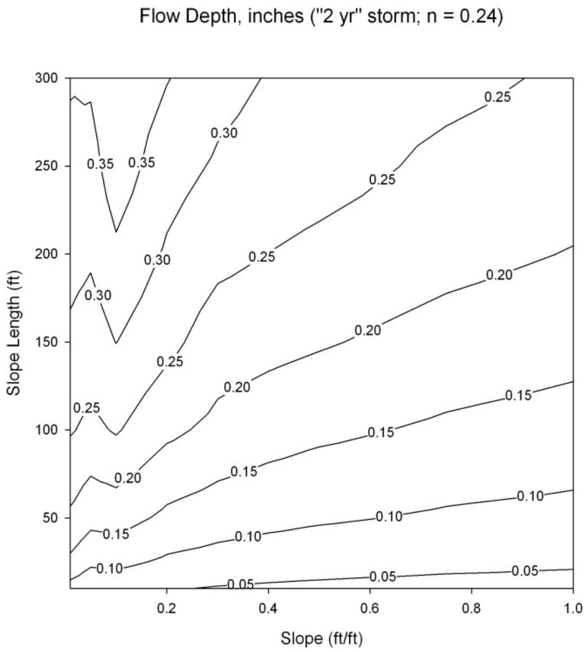
Fallow (no residue)



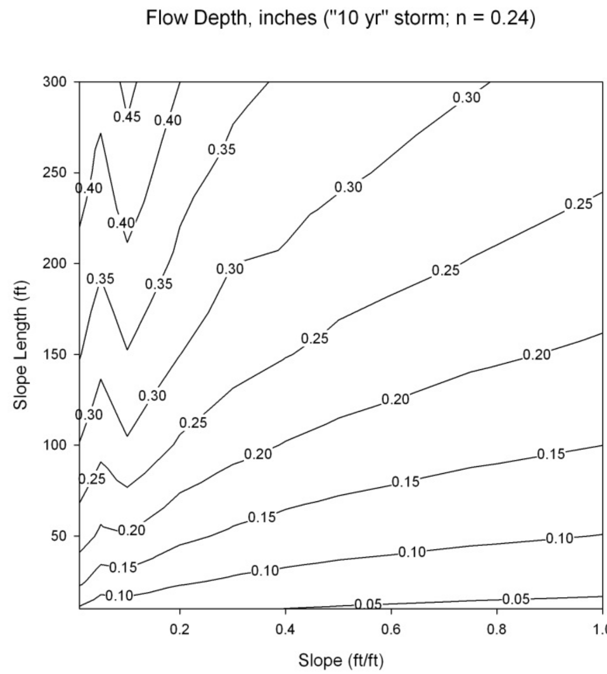
Cultivated soils: residue cover > 20%



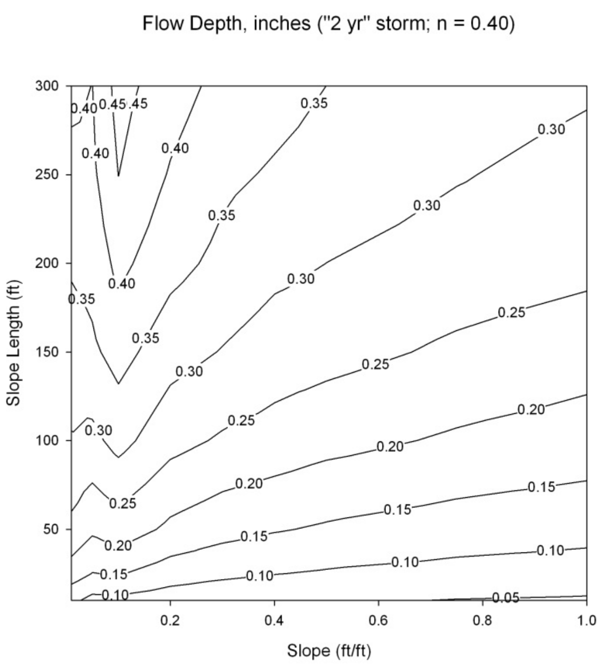
Cultivated soils: residue cover > 20%



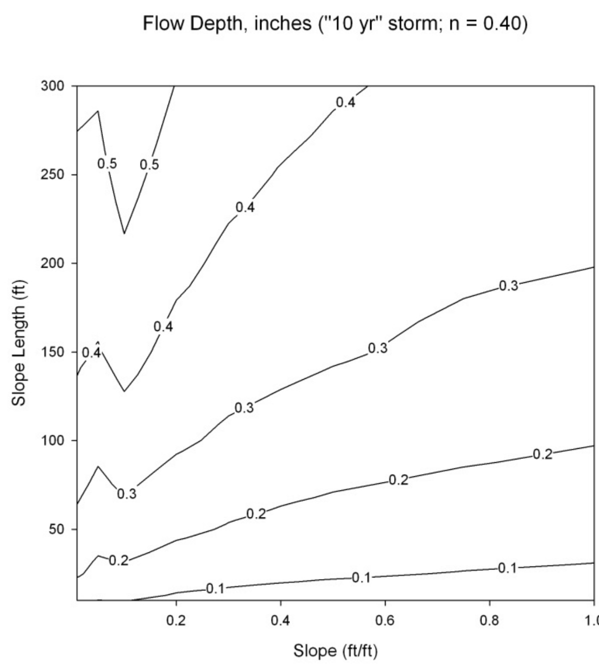
Grass, dense (weeping lovegrass, bluegrass, buffalo grass, blue gama grass, and native grass mixtures



Grass, dense (weeping lovegrass, bluegrass, buffalo grass, blue gama grass, and native grass mixtures



Grass: bermudagrass or woods, light underbrush (considering cover to height of about 0.1 ft)



Grass: bermudagrass or woods, light underbrush (considering cover to height of about 0.1 ft)

Figure 52. Sheetflow depths for different slopes and rains.

Summary

This chapter reviewed rain conditions that affect erosion at construction sites. In many cases, relatively few of the annual rains are responsible for the vast majority of the erosion potential. The much more common small rains likely contribute a very small fraction of the annual erosion losses from construction sites. The larger rains result in the greatest erosion and translate into much more substantial and costly sediment controls than if the focus could be only on the smaller rains. As frequently noted in this book, preventative erosion control strategies are much more cost effective than many of the treatment options.

This chapter also examines several approaches for calculating runoff conditions at construction sites. For some design objectives, peak flow rates are needed, while complete hydrographs may be necessary to meet other objectives. WinTR55 is emphasized as a suitable and simple method for obtaining design flows and hydrographs for construction site erosion control design and for site evaluation. As noted, the NRCS is currently updating the curve number hydrology methods, with numerous changes in the selection and use of the curve numbers and other elements of the process. The hydrology calculation methods need to be approved by any local review agency.

Long-term continuous simulations would be preferred for site evaluations, but a comprehensive model that considers construction site features and potential controls is not readily available, so traditional single design storms are usually applied to construction sites.

The chapter ends with an example for determining site hydrographic and hydrologic conditions at construction sites. This chapter is a fundamental component of a complete approach for evaluating and solving construction site erosion problems. These tools will be referenced frequently in the other book chapters.

Useful Internet Links

The following URLs were correct as of late 2018. However, these can change, especially for government agencies, so if a link is no longer working, please use an Internet search to locate the newest versions (and to eliminate the need to type in complex URLs).

Maps and Aerial Photographs:
http://Virtualearth.msn.com

http://maps.google.com

Web Soil Survey:
https://websoilsurvey.nrcs.usda.gov/app/HomePage.htm

California Department of Transportation Hydrology Design Manual:
http://www.dot.ca.gov/hq/oppd/hdm/pdf/chp0810.pdf

WinTR55 computer program (new windows version, ver. 1.00.10, February 2013 and updated database April 2015):
https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/hydrology/?cid=stelprdb1042901

WinTR55 User Guide (January 2009):
file://synologyds1817/Data/current%20files/pubs%20and%20projects/Construction%20Erosion%20Control%20Book/second%20edition/New%20inserts%20for%202nd%20edition/ch%203%20rain%20and%20runoff/WinTR55/WinTR55UserGuide.pdf

TR55 1986 documentation and early version of TR55 program:
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

WinTR20 computer program (Version 3.20) and training materials:
https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/null/?cid=stelprdb1042793

NOAA Precipitation Atlas 14:
http://nws.noaa.gov/oh/hdsc/currentpf.htm

NOAA Atlas 14 Precipitation Frequency Data Server:
http://hdsc.nws.noaa.gov/hdsc/pfds/

Northeast Regional Climate Center (NRCC) Precipitation Data:
http://precip.eas.cornell.edu/

Precipitation Atlas User Guide:
http://www.nws.noaa.gov/oh/hdsc/PF_documents/NA14_Sec5_PFDS.pdf

HydroCad software:
https://hydrocad.net/

National Engineering Handbook, Part 630 HYDROLOGY
https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/hydrology/?cid=stelprdb1043063

US Army Corps of Engineers, Hydrologic Management System User Guide (replacement for HEC-1) and River Analysis System User Guide for water surface profile calculations (replacement for HEC-2):
http://www.hec.usace.army.mil/software/hec-ras/

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Pitt, R. and S.R. Durrans. *Drainage of Water from Pavement Structures*. Alabama Dept. of Transportation. 253 pgs. September 1995.

Pitt, R., J. Lantrip, R. Harrison, C. Henry, and D. Hue. *Infiltration through Disturbed Urban Soils and Compost-Amended Soil Effects on Runoff Quality and Quantity*. U.S. Environmental Protection Agency, Water Supply and Water Resources Division, National Risk Management Research Laboratory. EPA 600/R-00/016. Cincinnati, Ohio. 231 pgs. December 1999.

Pitt, R., M. Lilburn, S. Nix, S.R. Durrans, S. Burian, J. Voorhees, and J. Martinson *Guidance Manual for Integrated Wet Weather Flow (WWF) Collection and Treatment Systems for Newly Urbanized Areas (New WWF Systems).* U.S. Environmental Protection Agency. 612 pgs. 1999.

Pitt, R, S. Chen, and S. Clark. "Compacted urban soils effects on infiltration and bioretention stormwater control designs." *Global Solutions for Urban Drainage; 9IUCD*. CD-ROM Proceedings of the 9th International Urban Drainage Conference, edited by E.W. Strecker and W.C. Huber., Sept 8-13, 2002, Portland, OR. Sponsored by the ASCE, Reston, VA, and the International Water Association, London. 2002.

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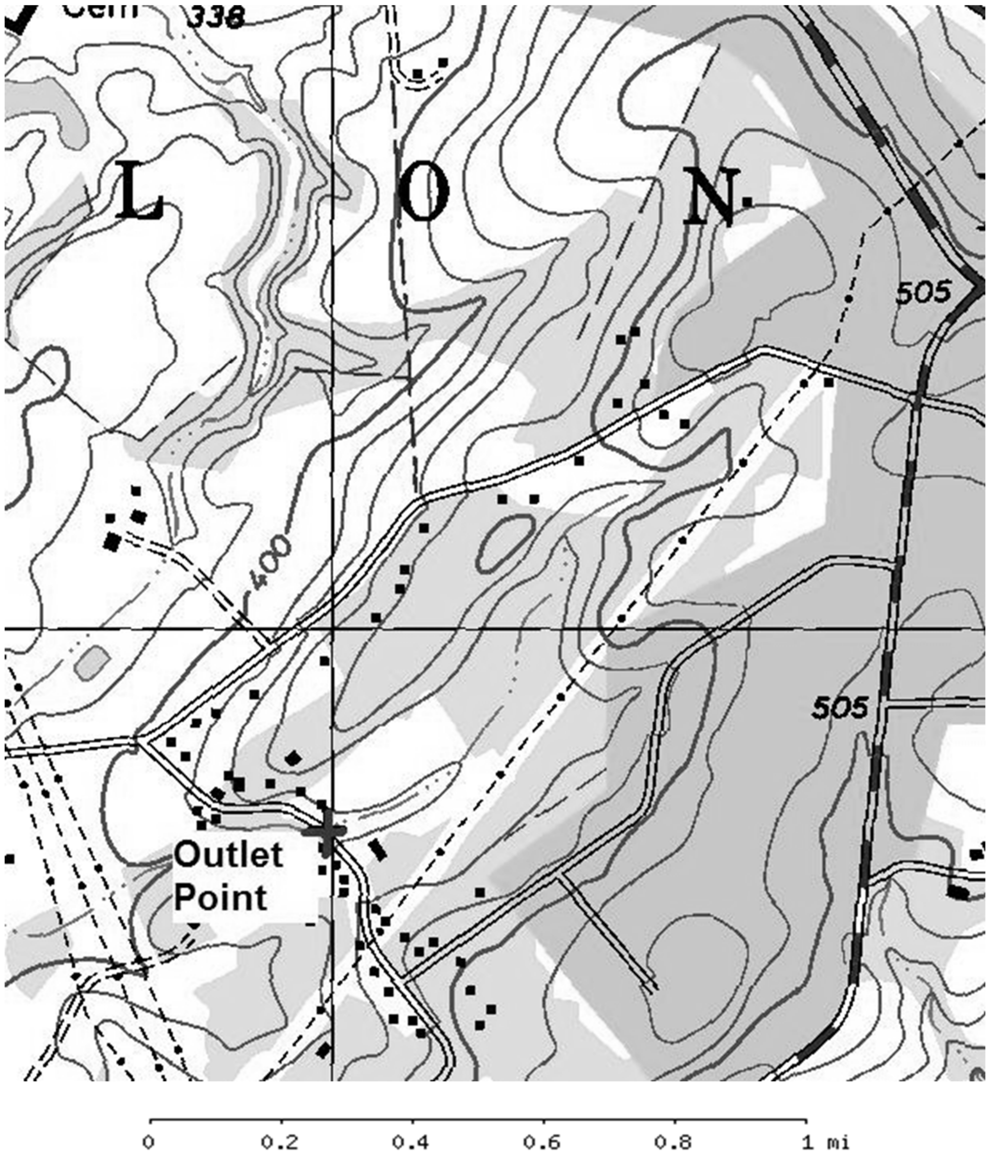
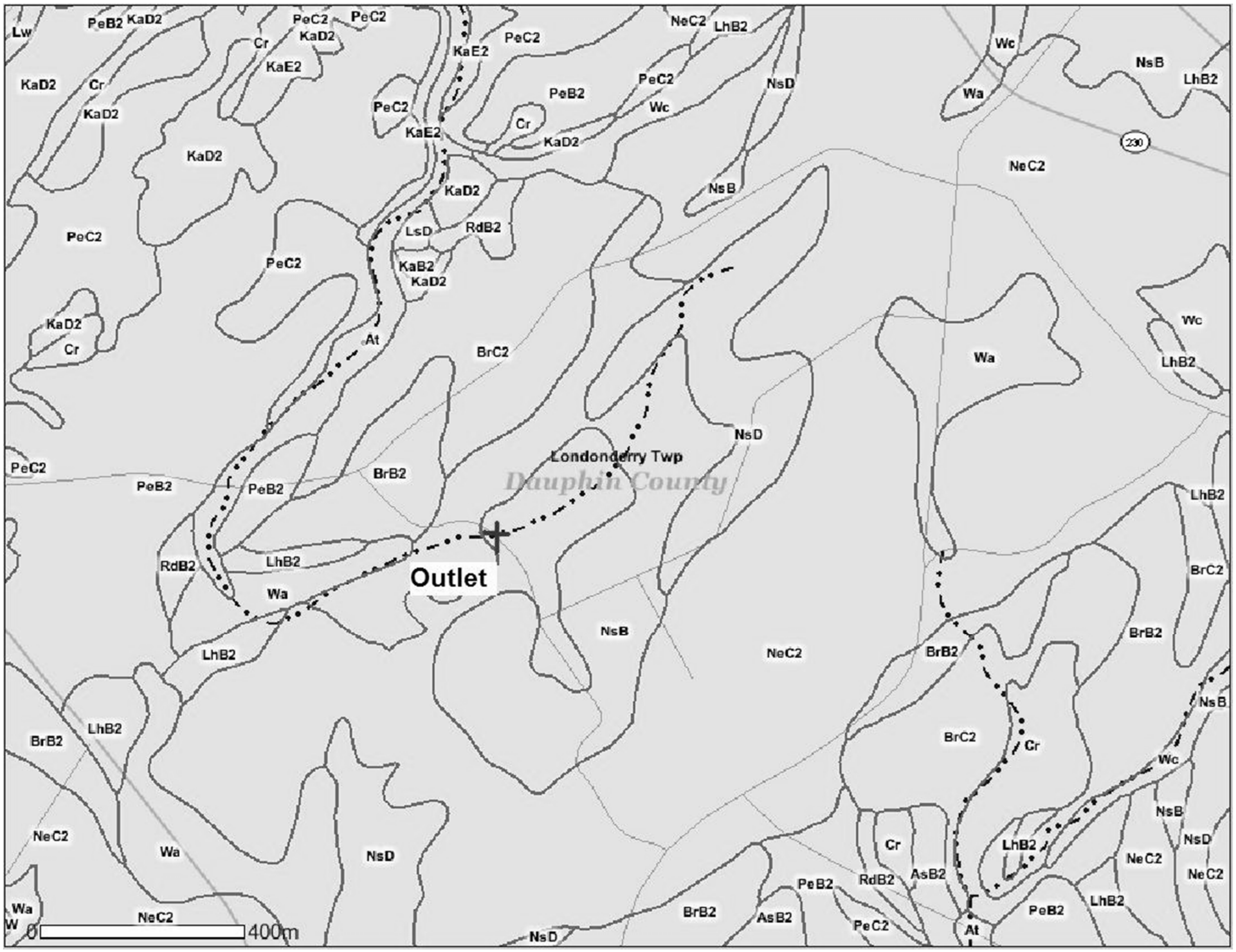
Problems

1. A rectangular, forested 10-acre parcel of property has been purchased by a developer for conversion to a three-shop strip mall. Can this plot of land be considered a watershed? Why or why not? What factors support your decision?

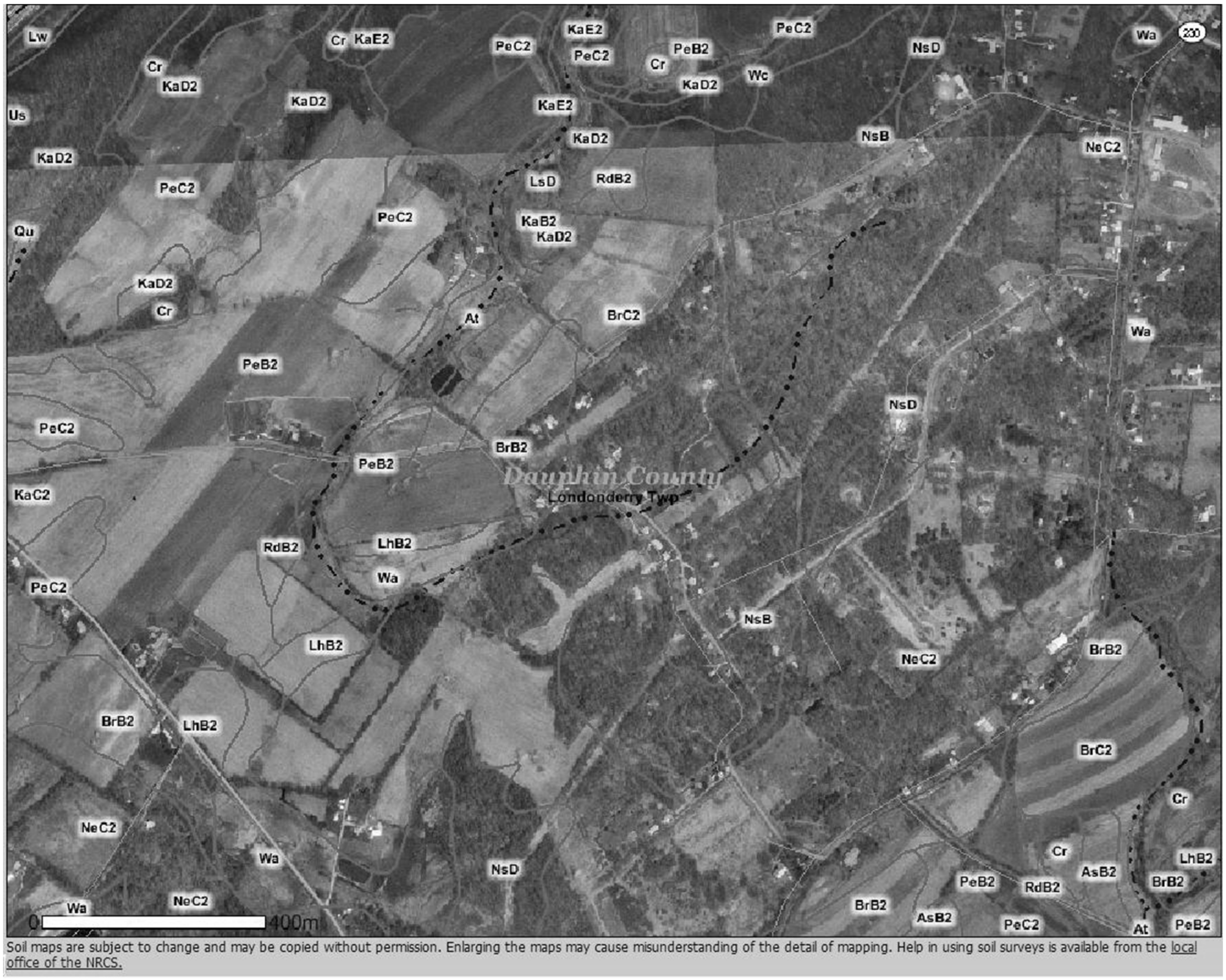
2. Delineate the watershed that is draining to the specified outlet in the map given below. Compute the watershed slope, the channel length and the channel slope. The interval contours are 20 ft. Describe the site soils and determine the areas for each soil type in the watershed.



Note: the above map has 20 ft contour lines



Soil map (source: Dauphin County, PA USDA, obtained from http://soilmap.psu.edu)



Soil map with aerial photograph (source: Dauphin County, PA USDA, obtained from http://soilmap.psu.edu)

3. Sources, and the resultant effects, of uncertainty are always a concern when making hydrologic calculations. Compute the channel slope between sections 1 and 4 and for each of the three reaches. Average the computed slopes for the reaches. Is the slope calculated based on averaging the reach slopes similar to the overall watershed slope? Why or why not? How will this affect design decisions for the site assuming the entire watershed is developed?

Survey Section	Elevation (ft)	Distance from Outlet (ft)
1	82	0
2	92	10,300
3	103	13,600
4	105	15,800

4. For the reaches described in Problem 3, calculate the average velocity in these channels assuming that the channel is concrete lined, has side slopes of 3:1 (h:v), and the depth of

flow is 0.2 ft. The base width is 4 ft. How does the velocity change if the channel is grass-lined? Does slope have a greater effect on the velocity for concrete- or grass-lined channels?

5. On a construction site, it is necessary to construct a grass-lined diversion channel. The cross section has a width of 10 ft, a depth of 1.5 ft, and side slopes of 4:1 (h:v), find the velocity assuming a slope of 0.002 ft/ft and an earthen surface with short grass (<6 inches high).

6. A small forested watershed (light understory brush) has an elevation drop of 15 ft and a principal flow path of 1000 ft. Compute the travel time along this flow path using the SCS Time of Concentration method, assuming that the slope is consistent along this flow path and no channel flow occurs. Compare the results for sheetflow lengths of 100 ft and 300ft. Use the 2-year storm for your local area.

7. A graded, but unpaved, highway section under construction has a concrete gutter, with a longitudinal slope of 4% and a length of 10,800 ft. Determine the travel time using the SCS Time of Concentration method. The sheetflow path will be across the lane section that is 40 ft wide with 0.5 lateral slope. Use the 2-year storm for your local area. Assume the gutter flow is shallow-concentrated flow.

8. The critical flow path for the time of concentration consists of the following sections. Estimate the time of concentration using the SCS Time of Concentration method.

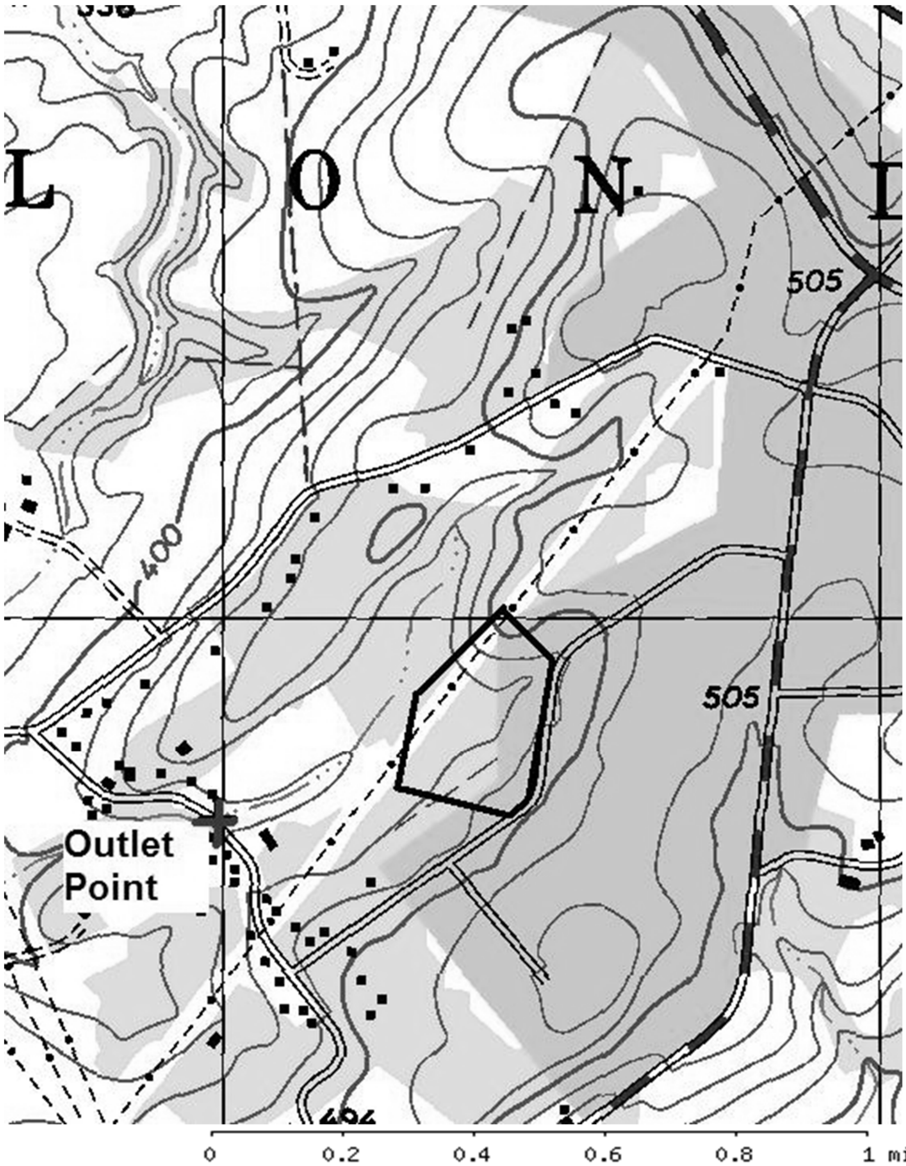
Section	Slope (%)	Length (ft)	Land Use
1	5.5	160	Forest (light underbrush)
2	3.1	690	Short grass
3	2.4	370	Bare ground
4	1.1	520	Riprap-lined waterway

9. Using the T_c from problem 8, estimate the peak flow rate on a 3,280-ft section of asphalt roadway that is 60 ft wide using the SCS tabular hydrograph method. Assume a 10-yr design frequency and your local IDF curve and rain type.

10. Calculate the time of concentration for the watershed shown in Problem 2, assuming the natural channel is 5 ft wide at the bottom and had 5:1 (h:v) side slopes. Assume good wood cover for the watershed and make reasonable assumptions as needed.

11. For the watershed delineated in Problem 2 and the T_c calculated in Problem 10, calculate the peak runoff rate for the 25-year storm (assuming B soils and good wood cover and making other reasonable assumptions as needed) using your local IDF curve.

12. The newest construction site in the watershed shown in Problem 1 has been delineated (the limits are outlined in black on the map copied below). Delineate the watershed that will drain the entire construction site to the creek.



Note: the above map has 20 ft contour lines

13. Conduct a watershed analysis for the area containing your construction site (delineate the area into upstream, on-site, and downstream areas). Calculate the hydrologic information needed for the eventual design of the expected erosion and sediment controls. Select appropriate levels of service (design storms) for each area and device. Obtain local information as needed and make all necessary assumptions.

Chapter 4: Erosion Mechanisms, the Revised Universal Soil Loss Equation (RUSLE), and Vegetation Erosion Controls

Contents

Introduction

Knowledge of the potential erosion problems on a construction site enables the site planner to better manage site development and erosion controls to minimize soil loss off the property. Prevention (erosion control) is much more effective than trying to improve the water quality of the runoff (sediment control). Information in this chapter enables a planner to understand basic erosion mechanisms and how they vary for different site conditions. Characteristics of construction site erosion material are highly dependent on site conditions and the local rainfall. This chapter describes how the Revised Universal Soil Loss Equation (RUSLE) can be used to predict the amount of erosion from a site, and it introduces some preventative practices to minimize site erosion. An introduction to RUSLE2 is also provided, an emerging powerful tool that should provide more useful and accurate insights to construction site erosion problems, and their control, as it becomes more fully developed over the next several years.

Basic Erosion Mechanisms and Rain Energy

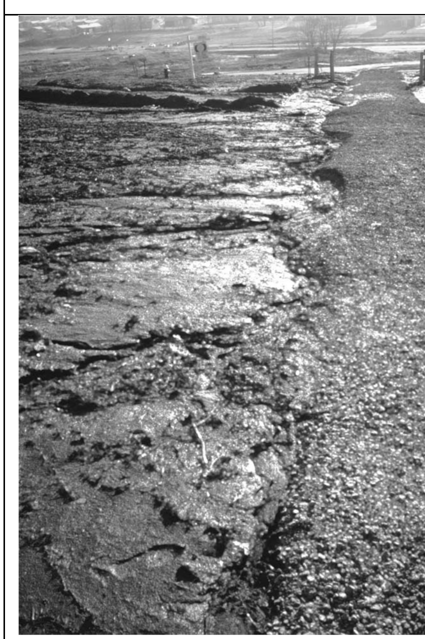
Soil erosion results when soil is exposed to the erosive powers of rainfall energy and flowing water (Barfield, *et al.* 1983). Rain (along with the shearing force of flowing water) acts to detach soil particles, while runoff transports the soil particles downslope. The most significant factor causing sheet erosion is raindrop impact, while the shearing force of flowing water is most important in rill and gully erosion.

Small-scale sheet erosion on tops, rill erosion forms further downslope, and finally deposition zones, on a material stockpile at a construction site.

Sheet flows forming concentrated flows which will eventually form rill and possibly gully erosion.

Large-scale sheet and rill erosion and isolated gully erosion beginning to start at an inadequately protected construction site.

Extensive gully erosion on unprotected steeper slopes of detention pond.



Several inches of material have been eroded by sheetflows at this construction site.	Gully erosion beginning to form where concentrated flows form after sheetflows.
 Large gully from concentrated flow (Bill Morton photo).	 Gully erosion where concentrated flows formed, and down gradient deposition area in seeded construction area.
 Sheet and rill erosion on hillside.	

Figure 4-1. Various erosion mechanisms found at construction sites.

Erosion Mechanisms

Soil detachment has usually been related to raindrop and soil characteristics (Huang, *et al*. 1982). The most important rain parameter is kinetic energy, while the most important soil parameter is shear strength. Soil detachment occurs when rain energy overcomes the soil's shear strength. This is why the use of surface mulches over bare soils can greatly decrease the transfer of energy to the soil, thereby lessening erosion losses.

When a raindrop strikes a surface, pressure acts to destabilize the particles. The raindrop impact loading function is very different from a uniform loading function (Huang, *et al*. 1982). The initial loading magnitudes are very high but diminish very rapidly. These loadings are also not uniform and are concentrated at the edge of the contact area. When the drop strikes a surface, lateral jet streams impinge on adjacent irregular surfaces or dirt particles, as shown on Figure 4-2, further destabilizing the surrounding area (Springer 1976). It is very difficult to model the specific drop impact forces due to these irregularities and simple approximations are usually used.

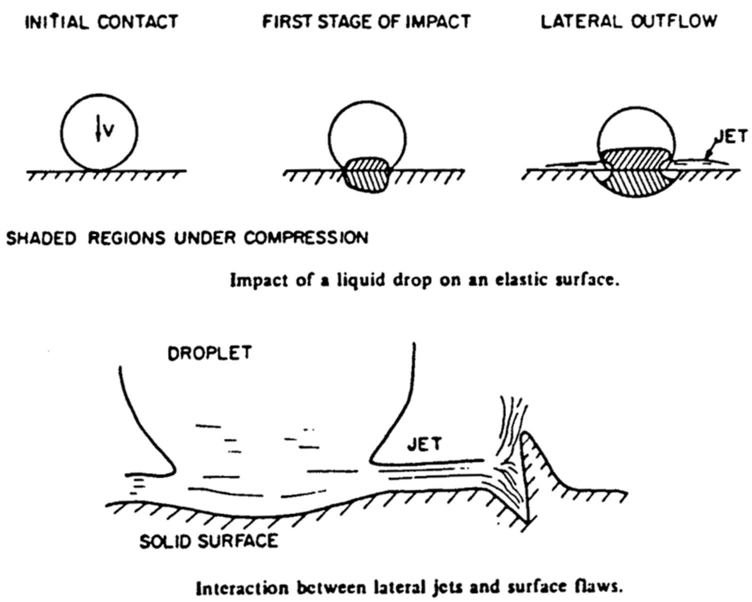


Figure 4-2. Raindrop impact with ground surface (from Springer 1976).

Kinnell (1981) defines two forms of raindrop kinetic energy, the rate of expenditure of energy per unit time (Err, in units of energy per area per time) and the amount of rainfall kinetic energy expended per unit quantity of rain (Era, in units of energy per area per rain depth). Based on typical drop sizes of about 1.5 mm, known drop populations (see Figures 4-3 and 4-4), and a terminal velocity of about 5.5 m/sec, it can be calculated that each drop contains about 3×10^{-4} joules of kinetic energy (Springer 1976). A 3 mm per hour rain delivers about 11 joules per m^2 per minute (Err), while a 12 mm per hour rain delivers about 30 joules per m^2 per minute. Err and Era are related:

$$Era = Err\ (I)^{-1}$$

where I is the rain intensity. The Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1965) uses a similar equation to predict rain energy.

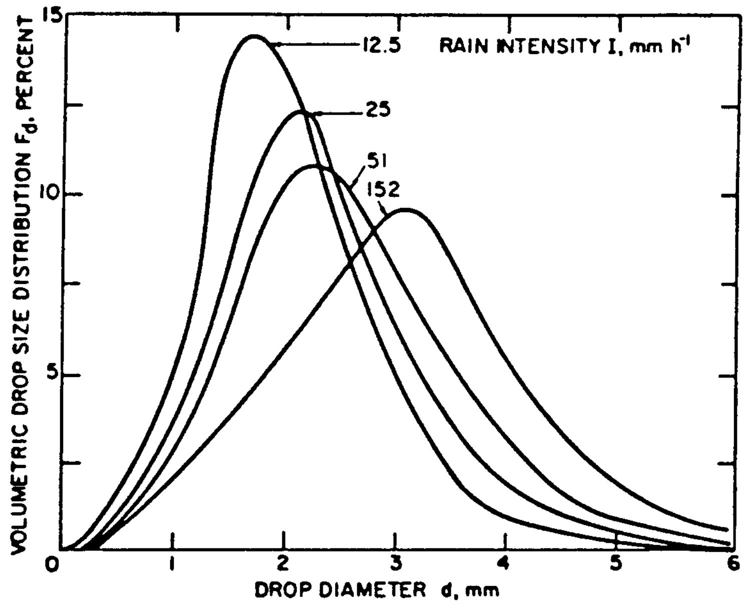


Figure 4-3. Typical rain drop size distribution (from Springer 1976).

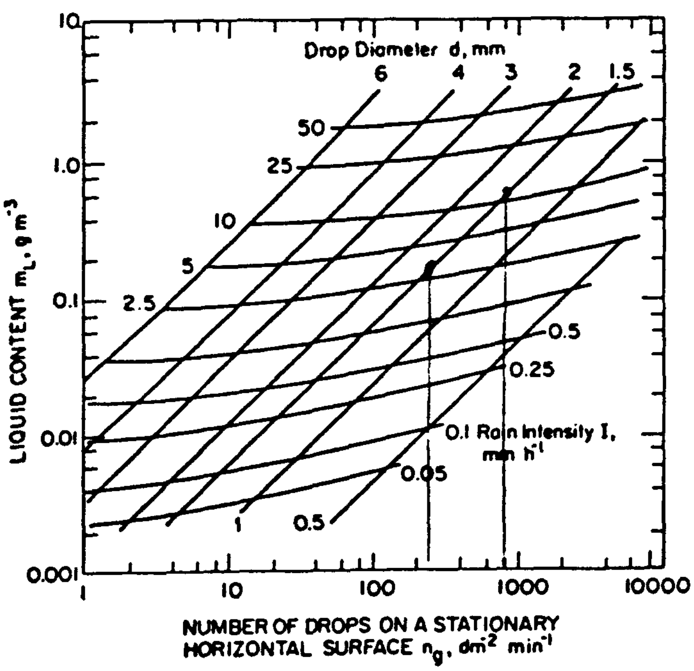


Figure 4-4. Characteristics of an idealized natural rain consisting of constant diameter spherical droplets distributed uniformly in air (from Springer 1976).

The Revised Universal Soil Loss Equation (RUSLE) and Relating Rain Energy to Erosion Yield

The Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1965) was based on many years of data collected at about 10,000 small test plots from throughout the US. Most test plots had approximately

22-m flow lengths at 9% slopes. All were operated in a similar manner, allowing the soil loss measurements to be combined into a predictive tool. The USLE has been extensively used for conservation planning in agricultural operations for decades. Many of the features, and the original database, also allow it to be used to predict erosion losses and the benefits of some erosion controls at construction sites. The RUSLE only predicts sheet and rill erosion; it does not predict the effects of concentrated runoff and gully formations.

The Revised Universal Soil Loss Equation (RUSLE) (Renard, *et al.* 1987) was developed to incorporate new research since the earlier USLE publication in 1978 (Wischmeier and Smith 1978). The basic form of the equation has remained the same, but modifications in several of the factors have been made. There are many sources of information for the RUSLE, including the USDA's National Sedimentation Laboratory where extensive information can be obtained (http://www.sedlab.olemiss.edu/rusle/). The RUSLE document (Renard, *et al.* 1987) and the material on this referenced web site should be consulted for greater detail on RUSLE than can be given in this chapter. This chapter focuses on construction site erosion issues and is greatly simplified compared to the complete RUSLE that stresses agricultural operations, but does periodically refer to construction site issues.

The underlying assumption in the RUSLE is that detachment and deposition are controlled by the sediment content of the flow. The erosion material is not source limited, but the erosion is limited by the carrying capacity of the flow for sediment. When the sediment load reaches the carrying capacity of the flow, no further sediment can be carried along by the flow. Sedimentation must also occur during the receding portion of the hydrograph as the flow rate decreases (Novotny and Chesters 1981).

The RUSLE relates the rate of erosion per unit area (A) to the erosive power of the rain (R), the soil erodibility (K), the land slope and length (LS), the degree of soil cover (C), and conservation practices (P):

$$A = (R)(K)(LS)(C)(P)$$

Where A = rate of erosion per unit area (t/ha)
R = rainfall erosivity (MJ-mm/ha-h-yr)
K = soil erodibility (t-ha-h)/(ha MJ mm)
L = length-slope factor
C = soil cover practice factor (dimensionless)
P = conservation practice factor (dimensionless)

The important aspect of this equation to note is the linear relationship between the equation parameters. As any parameter is changed, the resulting erosion yield is similarly changed. Also, the default values for LS, C, and P are all 1.0. They are changed by the planner as specific site and management conditions change. Many of these factors will change seasonally, especially those corresponding to plant growth and those affected by changes in rain and temperature characteristics. A modified version of RUSLE, the computer model RUSLE2, is now available (http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm), that incorporates many of these seasonal changes (see later description of RUSLE2).

In this chapter, this equation is used to predict the amount of soil that may be eroded from construction sites. Specifically, it enables the most critical source areas to be identified and allows predictions of the benefits of basic mulching and seedbed controls. Also, the erodibility of different slope and timing options can be compared for better preventive design. In addition, RUSLE can be used to predict the amount of sediment that may enter a sediment pond. Table 4-1 includes conversion factors that can be used to predict the volume of sediment given the weight of sediment generated, according to the RUSLE calculations. As an example, if a site is predicted to erode about 450 tons of silty-clay soil, the associated volume in cubic yards is about 1.02 times this amount, or about 460 cubic yards of material.

Table 4-1. Conversion Factors to Estimate Volume of Eroded Material

Soil Texture Class	Conversion Factor to Convert tons to cubic yards
Sands, loamy sands, sand loam	0.70
Sand clay loam, silt loams, loams, and silty clay	0.87
Clay loams, sandy clays, and silty clays	1.02

Rainfall Energy (R)

The RUSLE implies that rain energy is directly related to erosion yield. Originally, the USLE was used with an annual R value to predict annual erosion yields, but Barfield, *et al.* (1983) summarizes several procedures and studies that have demonstrated relationships between individual storm energies and erosion yields. Therefore, the example rain energy calculations in the following subsections are used to directly relate the probabilities of individual rain events to approximate erosion yields.

Wischmeier (1959) found that the best predictor of R was:

$$R = \frac{1}{n}\sum_{j=1}^{n}\left[\sum_{k=1}^{m}(E)(I_{30})_k\right]$$

where E is the total storm kinetic energy in hundreds of ft-tons per acre, I_{30} is the maximum 30-minute rainfall intensity, j is the counter for each year used to produce the average, k is the counter for the number of storms in a year, m is the number of storms each year, and n is the number of years used to obtain the average R.

The calculated erosion potential for an individual storm is usually designated EI. The total annual R is therefore the sum of the individual EI values for each rain in the year.

Wischmeier also found that the rain kinetic energy (E) could be predicted by:

$E = 916 + (331)\log_{10}(I)$, in ft-tons/acre per inch of rain

where I is the average rain intensity. E is given in ft-tons per acre per inch of rain, if intensities in inches per hour are used (for up to 3 in/hr). Hence, the rain energy (and R parameter) is dependent only on rain intensities. Table 4-2 shows the calculated kinetic energy per inch of rain for different rain intensities (calculated using this equation). As an example, a rain having an average intensity of 0.37 in/hr would have a calculated kinetic energy of 773 ft-tons per acre of land per inch of rain. The maximum calculated kinetic energy using this equation is 1,074 ft-tons/acre/in. It would be applied to rain intensities of 3.0 inches/hr and greater. This equation has been used to calculate the R values for the maps in RUSLE (Renard, *et al.* 1987). However, Renard, *et al.* (1987) recommend the following equation for all future R calculations:

$E = 1099\ [1-0.72\ \exp(-1.27I)]$, also in ft-tons/acre per inch of rain

They found less than a 1% difference in EI for example storms calculated using the two methods. The largest difference is for less intense events where little erosion occurs.

Table 4-2. Kinetic Energy of Rainfall (ft-tons per acre per inch of rain) (Wischmeier and Smith 1978)

Intensity (in/hr)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0	254	354	412	453	485	512	534	553	570
0.1	585	599	611	623	633	643	653	661	669	677
0.2	685	692	698	705	711	717	722	728	733	738
0.3	743	748	752	757	761	765	769	773	777	781
0.4	784	788	791	795	798	801	804	807	810	814
0.5	816	819	822	825	827	830	833	835	838	840
0.6	843	845	847	850	852	854	856	858	861	863
0.7	865	867	869	871	873	875	877	878	880	882
0.8	884	886	887	889	891	893	894	896	898	899
0.9	901	902	904	906	907	909	910	912	913	915
1.0	916	930	942	954	964	974	984	992	1000	1008
2.0	1016	1023	1029	1036	1042	1048	1053	1059	1064	1069
3.0	1074[1]	1074	1074	1074	1074	1074	1074	1074	1074	1074

[1] 1074 ft-lbs/acre/inch is the maximum value and is applied for all intensities greater than 3.0 inches per hour of rain.

Wischmeier and Smith (1978) present an example for calculating the rainfall kinetic energy from a rain gauge record, as illustrated in Table 4-3. In this example, the total kinetic energy of the storm equals 1,284 ft-tons per acre. The maximum 30-minute rainfall during this 90-minute storm was 1.08 inches, occurring from 4:27 to 4:57. The corresponding I_{30} was therefore 2.16 inches per hour. The EI for this storm is calculated as (2.16)(12.84) = 27.7. (Note: If the storm duration is less than 30 minutes, the I_{30} used is twice the total rain depth, with a maximum used I_{30} value of 2.5 in/hr.).

Table 4-3. Procedure for Calculating Kinetic Energy using a Rain Gage Record (Wischmeier and Smith 1978)

Rain Gage Chart Readings		Storm Increments			Kinetic energy	
Time	**Accumulative depth (inches)**	**Duration (minutes)**	**Amount (inches)**	**Intensity (in/hr)**	**Per inch (ft-tons per acre per inch of rain)**	**For increment (ft-tons per acre)**
4:00	0					
4:20	0.05	20	0.05	0.15	643	32
4:27	0.12	7	0.07	0.60	843	59
4:36	0.35	9	0.23	1.53	977	225
4:50	1.05	14	0.70	3.00	1074	752
4:57	1.20	7	0.15	1.29	953	143
5:05	1.25	8	0.05	0.38	777	39
5:15	1.25	10	0	0	0	0
5:30	1.30	15	0.05	0.20	685	34
Totals:	1.30	90	1.30			1284

Figures 4-5 through 4-8 (isoerodent maps) present values of R for the eastern US and the western states. The USDA's National Sedimentation Laboratory (at http://www.sedlab.olemiss.edu/rusle/) contains extensive information on RUSLE and rainfall erosivity. The values shown in this figure were averaged from 20 to 25 years of data. The break between individual rains was defined as 6 or more hours, having less than 0.5 inches of rain. Rains of less than 0.5 inches, separated from other showers by 6 or more hours, were omitted from the calculation, unless the maximum 15-minute intensity was greater than 0.95 in/hr. Also, the maximum I_{30} value used in the calculations was 2.5 in/hr.

Locations in the southeast experience very high values of R, compared to other US locations. As an example, the lowest values in Alabama are found in the northern part of the state, with R values of about 300. Most of the state has R values between 300 and 400, while values greater than 600 are shown for Mobile and Baldwin counties. Only the southern tip of Louisiana has a larger value of R in the continental US (slightly more than 700).

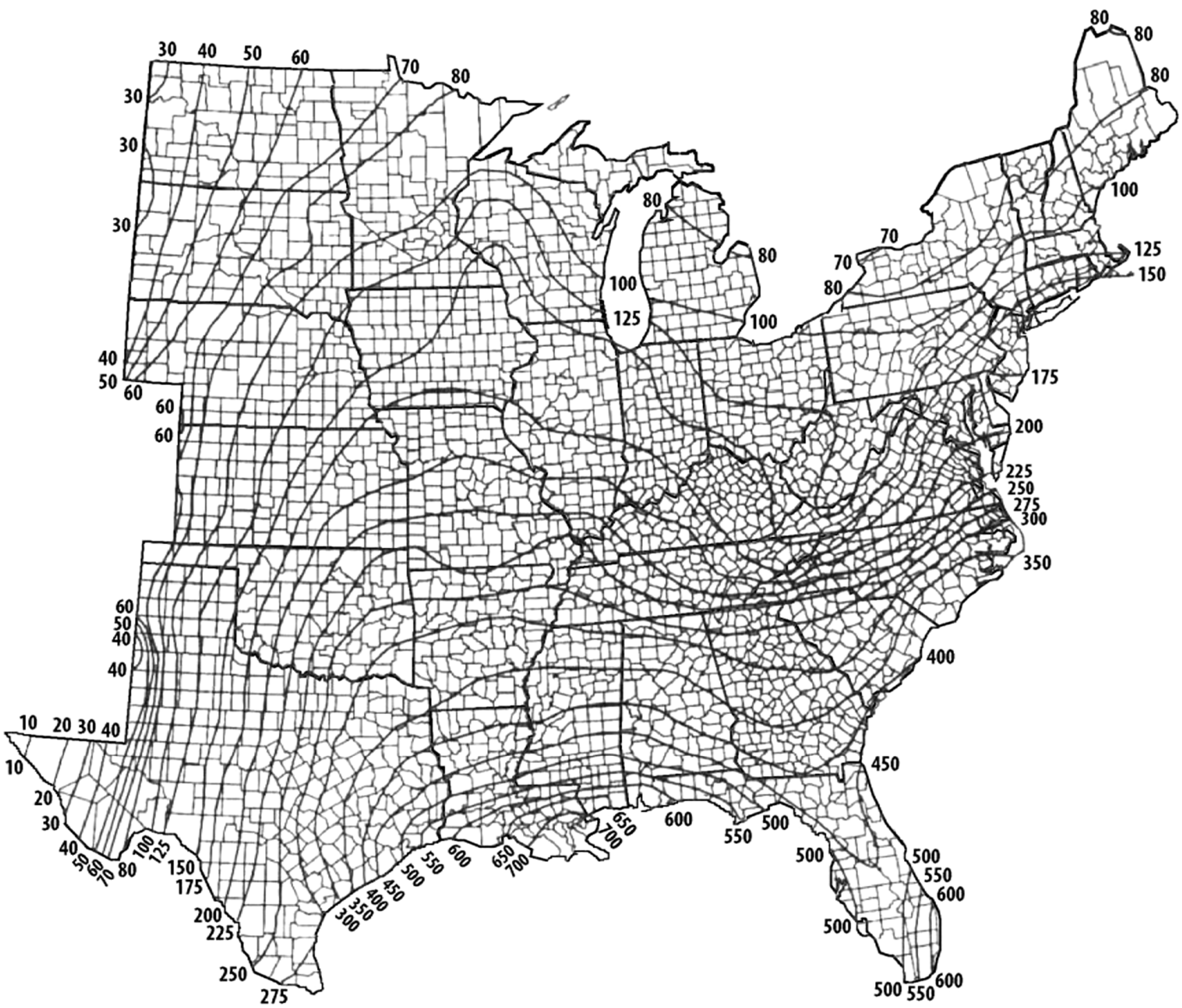


Figure 4-5. Isoerodent map of the Eastern U.S. (EPA 2001).

Figure 4-6. Isoerodent map of the Western U.S. (EPA 2001).

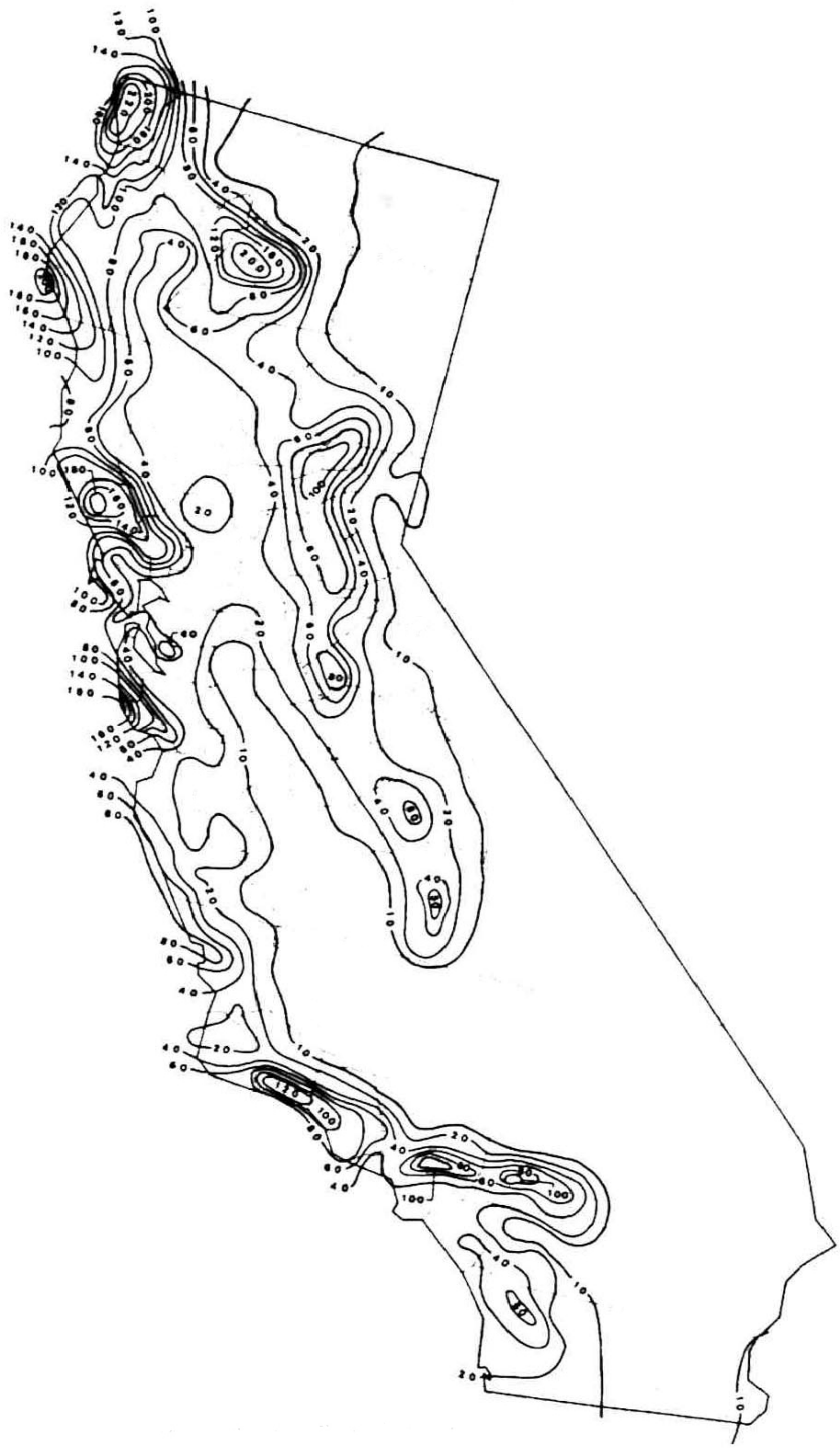


Figure 4-7. Isoerodent map of California (EPA 2001).

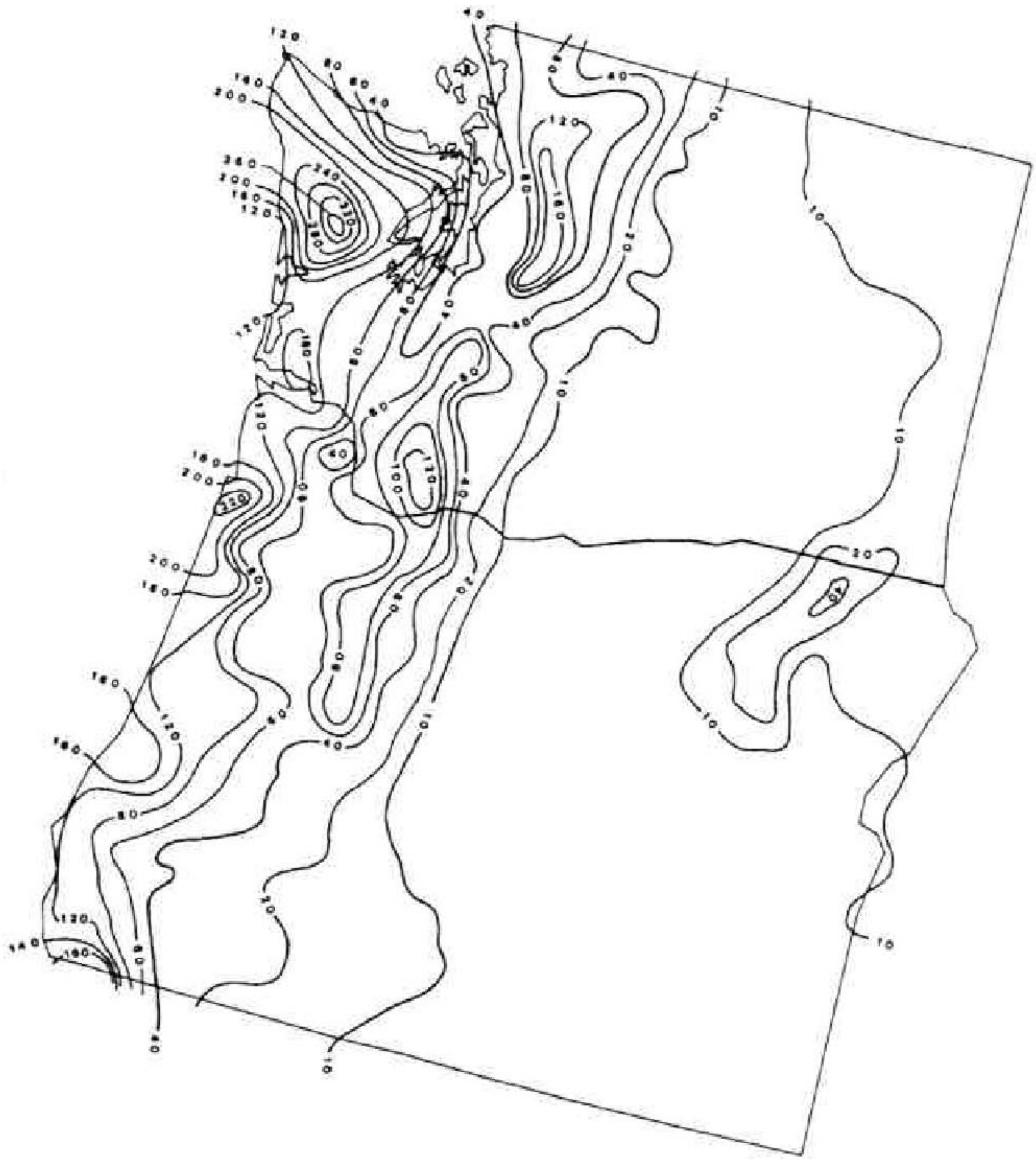


Figure 4-8. Isoerodent map of Oregon and Washington U.S. (EPA 2001).

Example: How do the rainfall patterns affect erosion control strategies?

There can be large year-to-year variations in the annual R values and individual storms may be responsible for large fractions of the annual rain energy. Table 4-4 presents measured probabilities of the annual R values for three Alabama locations (Wischmeier and Smith 1978). The 50 percent probability values are the values plotted on the RUSLE maps. Table 4-5 shows the frequency of expected magnitudes of the calculated single-storm erosion index (EI) values. For example, there is a 5% chance that a single storm in any year could cause about half of the total annual erosion in the Birmingham and Montgomery areas (annual R values between 350 and 400), and about 30% of the total annual erosion in Mobile (annual R values between 600 and 650). The typical worst storm in any one year may cause about 15 to 20% of the total annual erosion in any of these cities.

Table 4-4. Probabilities of Annual R Values for the Calculation Period for Alabama Locations (Wischmeier and Smith 1978)

	Observed 22-year range	50 percent probability	20 percent probability	5 percent probability
Birmingham	179-601	354	461	592
Mobile	279-925	673	799	940
Montgomery	164-780	359	482	638

Table 4-5. Probabilities of Individual Storm Erosion Index (EI) Values for Alabama Locations (Wischmeier and Smith 1978)

	Probability of Single Storm Exceeding EI Value in Any One Year:				
	100%	50%	20%	10%	5%
Birmingham	54	77	110	140	170
Mobile	97	122	151	172	194
Montgomery	62	86	118	145	172

As was discussed in Chapter 3, rainfall is distributed unevenly throughout the year at a single location, resulting in an uneven distribution of the rainfall energy. For that reason, the US has been divided into rainfall erosion index zones. In each zone, the distribution of R in a year (i.e., the percentage of R that can be associated with any specific range of dates) is similar. Figure 4-9 shows the rainfall erosion index values for the southeast. Appendix 4A includes the erosion index map and associated tables for the entire country. In Alabama, there are five regions, although most of the state is in regions 107 or 108. In contrast, North Dakota has one region. These regions are used to predict the fraction of the annual R that occurs in 2-week increments throughout the year. Incremental R information is useful for planning relatively rapid, but sensitive, construction practices, and to see if a potential project may be eligible for the Construction Rainfall Erosivity Waiver (https://www.epa.gov/npdes/construction-rainfall-erosivity-waiver-fact-sheet), which may allow sites where the project period R value is ≤ 5). Table 4-6 lists these distribution values for R for these areas in the state, while Appendix 4A includes the values for all regions of the US.

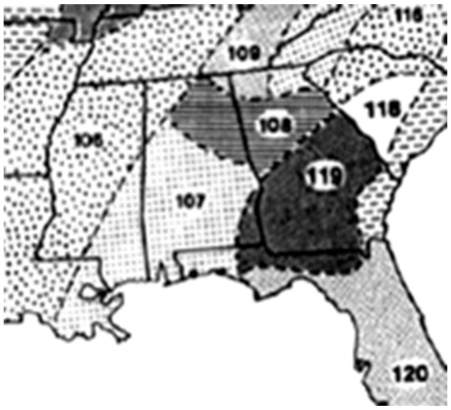


Figure 4-9. Rainfall erosion index zones for southeastern US (Renard, *et al.* 1987).

The values in Table 4-5 are the percentage of the total annual R values that occur in each 2-week period. To meet the R ≤ 5 waiver in Alabama, and much of the southeast US, only very short construction periods may be eligible. Only small portions of region 119 may possibly qualify (if the annual R<500) and if the construction activity could be completed within a 2-week period during November, December, or January. The erosivity index values range from lows of 1% to a high of 11% per two-week period. Periods greater than the average of 4.1% indicate periods when higher amounts of erosion than the overall average may occur. Depending on location, these periods are generally from the first of April through August, or September. Periods with the lowest erosion potentials are in the fall, winter and early spring. In contrast, construction in North Dakota could feasibly last for two-to-three months and still meet the "R ≤ 5" waiver, depending on the selected construction period. The same construction plan would not meet the waiver requirement if construction occurred during the times when North Dakota typically receives its largest and most intense rains.

To determine the R value for USLE/RUSLE calculations, the EPA has an online calculator for small construction sites (https://www.epa.gov/npdes/rainfall-erosivity-factor-calculator-small-construction-sites). The inputs to the online calculator are the start of land disturbance and the end date where the soil has undergone final stabilization and the latitude and longitude of the project site. An R value will be calculated. If the R value meets the criteria for the waiver, the site engineer is directed to the appropriate permitting authority to determine if the waiver rule is applicable for their site. For example, in certain states, when the construction is in a high-value watershed, there is no small-site, R-value-based waiver.

As indicated above, a relatively few number of intense rains can contribute much more of the annual rainfall energy than most rains, with the more intense rains contributing greater erosion losses per inch of runoff than the less intense rains. As an example, the most important single rain in the Birmingham area that may occur in any one year has an R value of about 54, and therefore contributes about 15 percent of the annual erosion losses. The most important single rain that may occur once every ten years has an R value of about 140 and may therefore contribute about 40 percent of the annual erosion losses for that year. This ten-year rain would only contribute about four percent of the average ten-year total erosion losses in any one year, however.

An analysis was conducted using the recorded 1977 Birmingham rains (a typical rain year) to determine the distributions of erosion factors for individual rains and their recurrence intervals. This year was selected due to its similarity to the long-term average rain conditions (based on total annual rain depth and the distribution of the rains throughout the year). Most of the erosion is produced by a relatively few highly-erosive rains that may occur during any month. About 50 percent of the annual erosion yield is associated with only 11 individual rains (out of 96 that occurred in 1977). Approximately 40 percent of the individual rains were responsible for more than 90 percent of the annual erosion yield, and about 25 percent of the rains were responsible for about 75 percent of the annual erosion yield.

Table 4-6. Distribution of the Erosivity Index Values for Different Time Periods throughout the Year for Index Zones in the Southeast

Period	106	107	108	109	119
Jan 1-15	3	3	3	3	1
Jan 16-31	3	2	3	3	1
Feb 1-15	3	2	3	4	2
Feb 16-29	4	3	3	3	2
Mar 1-15	4	4	4	3	1
Mar 16-31	4	4	4	3	2
Apr 1-15	**6**	**5**	4	4	3
Apr 16-30	**6**	4	4	3	3
May 1-15	**5**	4	**5**	3	3
May 16-31	**6**	4	**5**	4	**5**
Jun 1-15	**5**	4	**5**	**6**	**8**
Jun 16-30	**6**	**6**	**7**	**8**	**9**
Jul 1-15	**6**	**8**	**9**	**11**	**5**
Jul 16-31	**6**	**7**	**10**	**10**	**9**
Aug 1-15	4	**7**	**6**	**7**	**6**
Aug 16-31	4	**7**	**5**	**5**	**9**
Sep 1-15	3	**6**	4	3	**6**
Sep 16-31	3	4	3	3	**10**
Oct 1-15	3	2	3	2	4
Oct 16-31	2	2	2	2	4
Nov 1-15	4	2	2	2	1
Nov 16-31	4	3	2	3	1
Dec 1-15	3	2	2	2	1
Dec 16-31	3	**5**	2	3	1

Source: EPA's *Construction Rainfall Erosivity Waiver,* Fact Sheet 3.1. EPA 833-F-00-014. Jan, 2001.

The probabilities of different highly erosive rains occurring during 7-, 14-, and 30-day periods for Birmingham 1977 conditions were calculated. Table 4-7 indicates these probabilities and the expected erosion yields for these time periods. Most erosion-protection regulations require disturbed areas inactive for more than 14 days to have suitable site erosion controls. During a 14-day period of time, more than a ton of sediment could be washed from each disturbed acre during four separate rain events. There is a 30 percent chance that the same amount of sediment could be washed from the site during a single event during this time period. If this time period was lengthened, the amount of sediment that could be lost and the probability of highly-erosive rains occurring would increase proportionately. Because of these potentially large sediment losses, most regulations also require appropriate downslope controls to capture any sediment that may move from uncontrolled disturbed areas on the site. However, downslope controls are not adequate by themselves in controlling all sediment during highly erosive rains. The on-site protection offered by mulching inactive disturbed areas, in addition to the diversion of waters from upslope off-site areas, greatly lessens the burden on the downslope controls and allows them to remain useful during all rains.

Table 4-7. Probabilities of Highly Erosive Rains Occurring During Different Time Periods (Birmingham 1977 data)

Percentage of Annual Erosion Yield During Event	Estimated Erosion Yield During Single Event (with some site controls) (lb/acre)	Probability of Event Occurring at Least Once per:		
		7 days	14 days	30 days
7%	3,500	3%	6%	12%
5	3,000	8	16	31
3	1,800	17	31	55
2	1,200	29	50	77
1	600	45	70	92
Probable number of events per time period (out of 96):		2	4	8
Probable total erosion yield per time period (lb/acre):		1,200	2,300	5,000

Comparison of Rainfall Energy Calculation Methods

Clark, *et al.* (2009) investigated the discrepancies between the original R calculations and the EPA approximation shown in the prior section. R was based on primarily agricultural-research field test sites (Wischmeier 1959; Wischmeier and Smith 1958). The results showed that, on cultivated land, soil losses were proportional to the E (total storm energy) multiplied by the 30-minute maximum rainfall intensity (Imax). This allowed for the inclusion of the effects of the raindrop impact on the soil and the transportability of the soil particle in runoff. Because the erosional effects were cumulative and primarily associated with both moderate and large storms, the calculated R was an average annual rainfall erosivity.

To address the variability year-to-year in rainfall patterns in any given area, a minimum of twenty-two years of rainfall records, considered a rainfall cycle, was used at each of approximately 2,000 sites in the Eastern U.S. to calculate annual R values for those sites. Importantly, rains less than 12.5 mm in total depth were not included in the original calculations, unless at least 6.13 mm fell in 15 minutes. As noted with the Birmingham analysis, storm events were separated by a 6-hour or greater time period on either side of the storm with less than 1.25 mm of rain (Wischmeier 1962).

Based on this past research, isoerodent (lines of equal erosivity) maps were published for the eastern United States by the USDA based on the calculated R values assisted by published rainfall-intensity and topographic maps for those areas where R values had not been calculated (Wischmeier 1962). Linear interpolation was recommended for sites not on an isoerodent line.

The U.S. EPA, based on data and rainfall pattern interpretations from the USDA Soil Conservation Service (SCS – now the Natural Resources Conservation Service or NRCS), published equations for the isoerodent lines based on the equation above (Thronson 1973; USEPA 1973). Individual storm R values were added up for the rainfall record and then divided by the number of years of data.

Clark, *et al*. (2009) addressed the question of the impact of very localized topographic and rainfall influences on R and whether calculation of individual R values, versus using the maps, was justified. The first assumption under Wischmeier was to ignore rainfalls less than 12.5 mm (0.5 inches). Figure 4-10 highlights that excluding rains less than 12.5 mm did not result in substantial changes in the median annual R value. Figure 4-11 demonstrates the impacts of incorporating additional rainfall energy information into the mapping procedure for Pennsylvania. Both the original and the US EPA R maps better represented the locally-calculated R values for western PA. However, nearer the eastern edge of Pennsylvania, estimated R values were substantially higher than predicted.

One concern is the impacts of climate change and increases in precipitation intensity over the eastern United States and Canada on R values (Wilkes and Sawada, 2005).

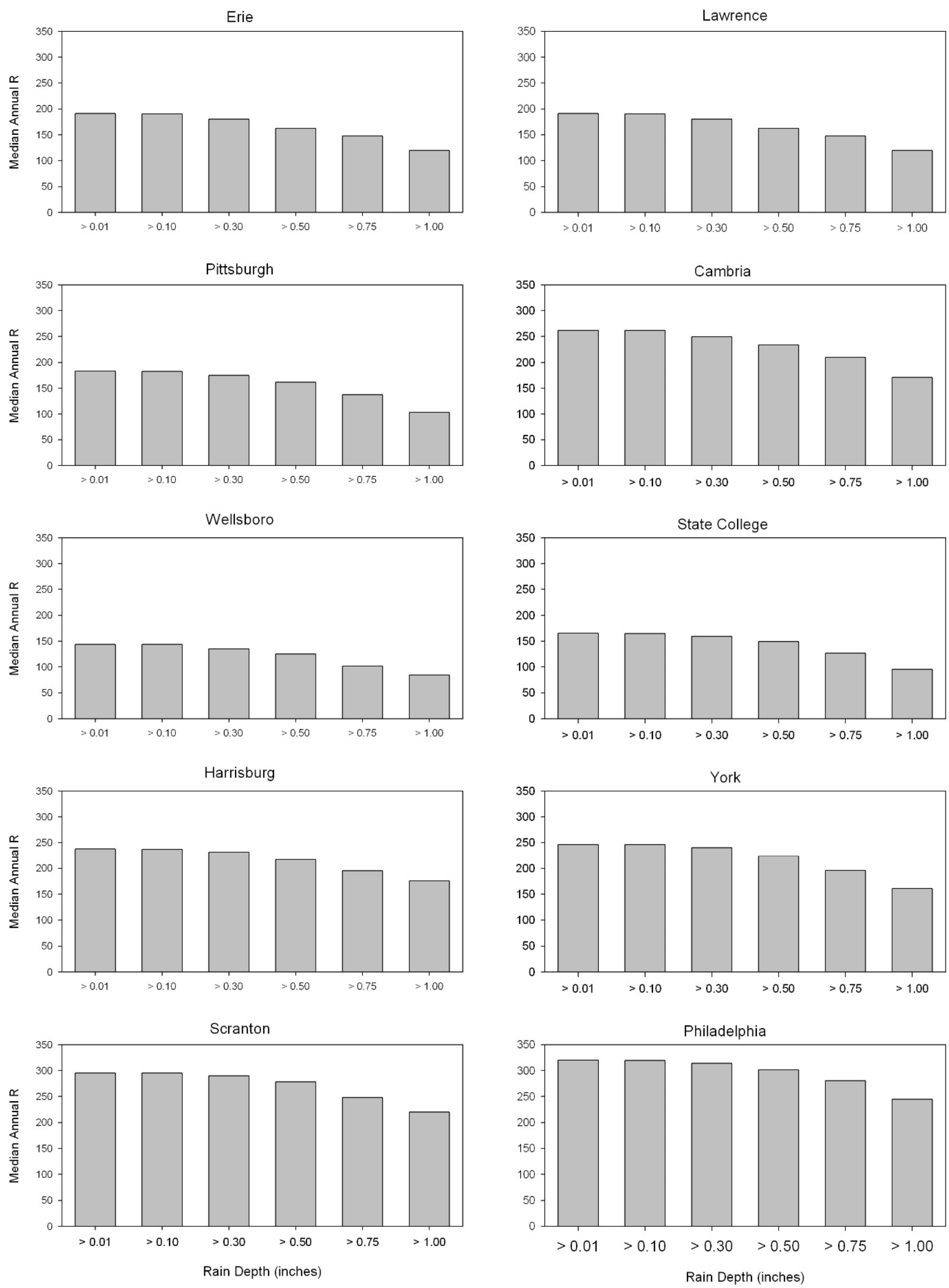


Figure 4-10. Median Annual R values for 10 cities in Pennsylvania as a function of total rain depth using US EPA 1973 equation.

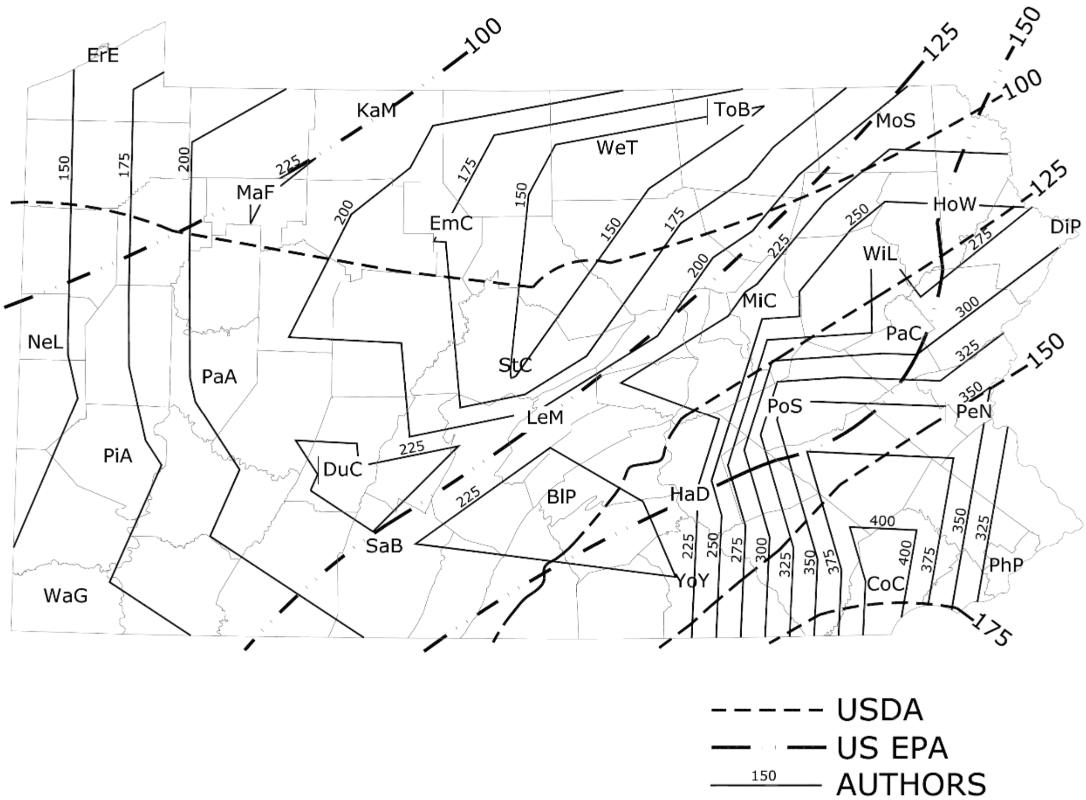


Figure 4-11. Comparison of the USDA/Wischmeier (1958), US EPA/Thronson (1973), and locally calculated annual R values. (Source: Clark, *et al*. 2009)

Example Equations Used to Calculate R in China

In China, as with many places in the world, 30-minute rainfall intensity values may not be available. In order to use the Universal Soil Loss Equation in China, researchers such as Yin, *et al.* (2015) have developed equations to predict both the rainfall kinetic energy (EI_{30}) and the annual R value. Table 4-8 highlights the equations developed by Yin, *et al*. (2015) to predict EI and R.

Table 4-8. Predicting EI_{30} and R values from rainfall data in eastern China (Yin, *et al.* 2015).

Model based on Type of Available Rainfall Data	Equation
Event I (event rainfall and maximum 10-minute intensity)	$EI_{30} = \lambda_1 P_{event} I_{10}$
Event II (storm rainfall and maximum 30-minute intensity)	$EI_{30} = \lambda_2 P_{event} I_{30}$
Event III (storm rainfall and maximum 60-minute intensity)	$EI_{30} = \lambda_3 P_{event} I_{60}$
Event IV (storm rainfall and 30 minute intensity)	$EI_{30} = \lambda_4 P_{event} I_{30}$ where $I_{30} < 15$ mm/h $EI_{30} = \lambda_5 P_{event} I_{30}$ where $I_{30} \geq 15$ mm/h
Daily I (daily rainfall and maximum daily 10-minute intensity	$R_{day} = \lambda_6 P_{day} (I_{10})_{day}$

Month I (monthly rainfall)	$R_{month} = \alpha_1(P_{month})^{\beta 1}$
Month II (monthly rainfall and maximum 60-minute rainfall in the month)	$R_{month} = \lambda_7 P_{month}(P_{60})_{month}$
Month III (monthly rainfall and maximum 1440-minute rainfall in the month)	$R_{month} = \lambda_8 P_{month}(P_{1440})_{month}$
Average Month I (average monthly rainfall)	$R_{ave\_month} = \alpha_3(P_{ave\_month})^{\beta 3}$
Average Month II (average monthly rainfall and maximum 60-minute rainfall in the maximum month)	$R_{ave\_month} = \lambda_{11} P_{ave\_month}(P_{60})_{month\_max}$

Where these types of equations exist, R values for the USLE equation can be estimated in order to predict rainfall erosivity.

Soil Erodibility Factor (K)

Soil texture, and other soil characteristics, affect the soil's susceptibility to erosion. The soil K factors were determined experimentally in early test plots that were 73-ft (22-m) long and had uniform slopes of 9% (Wischmeier 1959; Wischmeier and Smith 1958). Normally, more than 10 years of runoff plot data was used to determine these values in order to eliminate any effects from prior organic material and mulch, as well as effects associated with mechanical disturbance from constructing the plots. Figure 4-12 is the nomograph used to determine the K factor for a soil, based on its texture (% silt plus very fine sand, % sand, % organic matter), structure, and permeability. The NRCS county soil maps list the K factors for all soils in each county. However, significant disturbances and modifications of the soil obviously occur at construction sites and care needs to be taken to ensure that the K factor used in the calculations is based on the actual surface soil conditions. As an example, the organic matter (decreases as the top soils are removed), permeability (decreases with compaction with heavy equipment), and soil structure (subsurface soils more massive than surface soils) could all likely change, causing the K factor to change for a soil undergoing modification at a construction site.

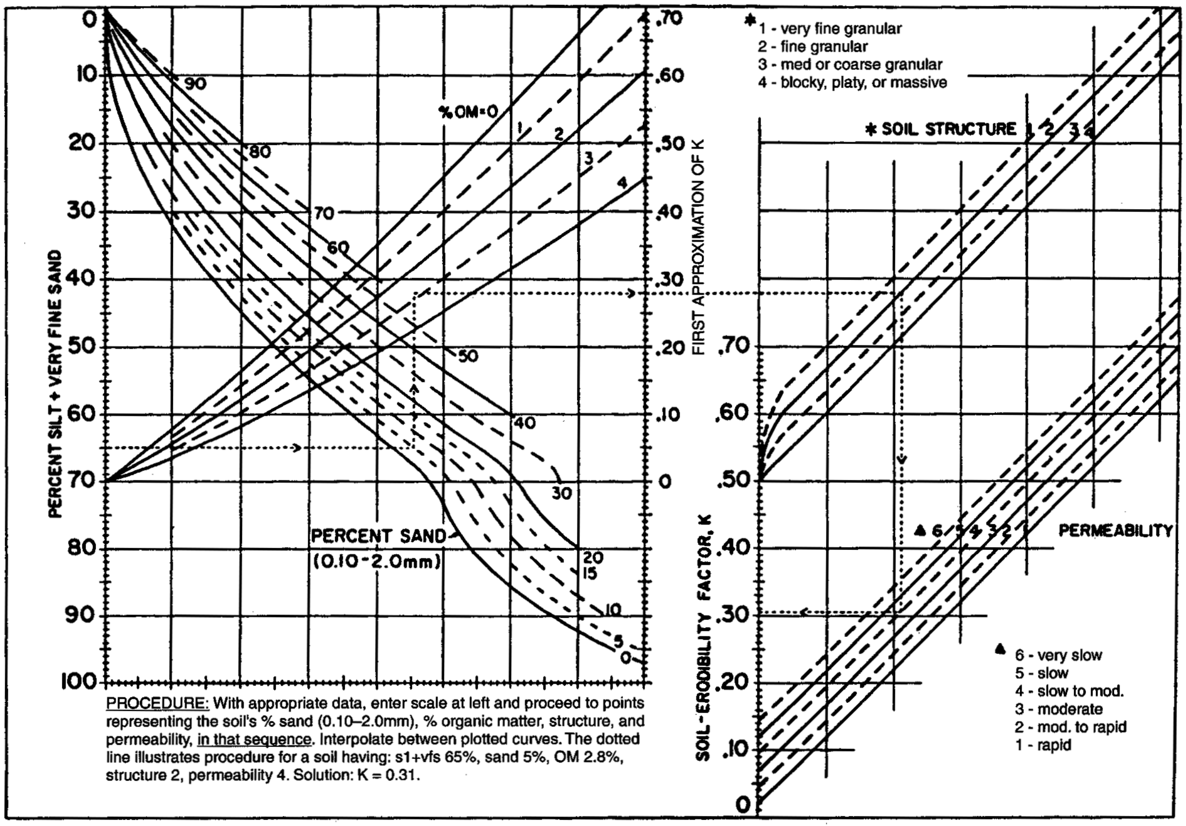


Figure 4-12. USDA nomograph used to calculate soil erodibility (K) factor.

Dion (2002) provided estimates of the K factor for soils based on textural class. These are approximations and are useful for preliminary calculations in areas where no additional information is available.

Table 4-9. K values based on soil textural class. (Source: Dion 2002)

Textural Class	General K value
Sandy, fine sand, loamy sand	0.10
Loamy sand, loamy fine sand, sandy loam, loamy, silty loam	0.15
Loamy, silty loam, sandy clay loam, fine sandy loam	0.24
Silty clay loam, silty clay, clay, clay loam, loamy	0.28

Estimating the K Factor from Soil Analyses

Wischmeier (1971) proposed the following equation to calculate the soil erodibility factor K using the following equation. The equation is applicable when the silt and fine sand content is < 70% of particle size distribution.

$$K = \frac{0.00021M^{1.14}(12 - OM) + 3.25(c_{soilstr} - 2) + 2.5\left(C_{perm} - 3\right)}{100}$$

Where OM = percent organic matter (%) = 1.72(percent organic carbon content)
$C_{soilstr}$ = soil structure code used in soil classification
C_{perm} = profile permeability class
M = particle-size parameter

$$M=(m_{silt}+m_{vfs})(100-m_c)$$

m_{silt} = percent silt content (0.002 – 0.05 mm particles)
m_{vfs} = percent very fine sand (0.05 – 0.10 mm particles)
m_c = percent clay (< 0.002 mm particles

According to the Soil and Water Assessment Tool (SWAT) Input Manual, the following four primary types of soil structures are used in the K factor equation:

- Platy – particles arranged around a plane, mostly horizontal
- Prismlike – particles arranged around vertical line and founded by relatively flat vertical surfaces
    - Prismatic: without rounded upper ends
    - Columnar: with rounded caps
- Blocklike or polyhedral – particles arranged around a point and bounded by flat or rounded surfaces
- Spheroidal or polyhedral – particles arranged around a point and bounded by curved or very irregular surfaces
    - Granular – relatively non-porous
    - Crumb – very porous

The $C_{soilstr}$ term is assigned a value from 1 to 4 based on the following characteristics of the soil (Table 4-10).

Table 4-10. Soil structure classification according to the SWAT model.

Shape of Structure				
Size Classes	Platy	Prismatic and Columnar	Blocky	Granular
Very fine	< 1 mm	< 10 mm	< 5 mm	< 1 mm
Fine	1 – 2 mm	10 – 20 mm	5 – 10 mm	1 – 2 mm
Medium	2 – 5 mm	20 – 50 mm	10 – 20 mm	2 – 5 mm
Coarse	5 – 10 mm	50 -100 mm	20 – 50 mm	5 – 10 mm
Very Coarse	> 10 mm	> 100 mm	> 50 mm	> 10 mm

Codes assigned to $C_{soilstr}$ are:

1 Very fine granular
2 Fine granular
3 Medium or coarse granular

4 Blocky, platy, prismlike, or massive

The soil permeability factor, C_{perm}, is selected based on the following permeability scale (SWAT Input Documentation), using the lowest reported saturated hydraulic conductivity in the profile at the site: The codes assigned to C_{perm} are:

1 Rapid (> 150 mm/h)
2 Moderate to Rapid (50 – 100 mm/h)
3 Moderate (15 – 50 mm/h)
4 Slow to Moderate (5 – 15 mm/h)
5 Slow (1 – 5 mm/h)
6 Very slow (< 1 mm/h)

Williams (1995) developed the following relationship for the soil erodibility factor:

$$K_{USLE}=f_{csand}*f_{(cl-si)}*f_{orgC}*f_{hisand}$$

Where f_{csand} – factor that gives low soil erodibility for soils with high coarse-sand contents
f_{cl-si} = factor that gives low soil erodibility factors for soils with high clay to silt ratios
f_{orgC} = factor that reduces soil erodibility for soils with high organic carbon content
f_{hisand} = factor that reduces soil erodibility for soils with extremely high sand contents

The factors are calculated using the following equations:

$$f_{csand} = \left(0.2 + 0.3exp\left[-0.256 * m_s * \left(1 - \frac{m_{silt}}{100}\right)\right]\right)$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0.3}$$

$$f_{orgC} = \left(1 - \frac{0.0256 * orgC}{orgC + exp[3.72 - 2.95 * orgC]}\right)$$

$$f_{hisand} = \left(1 - \frac{0.7 * \left(1 - \frac{m_s}{100}\right)}{\left(1 - \frac{m_s}{100}\right) + exp\left[-5.51 + 22.9 * \left(1 - \frac{m_s}{100}\right)\right]}\right)$$

Where: m_s = percent sand content (0.05 – 2.00 mm)
m_{silt} = percent silt content (0.002 – 0.05 mm)
m_c = percent clay content (<0.002mm)
orgC = percent organic carbon content of layer

These equations generally were developed and calibrated in the United States. Many of them have been recalibrated or have been modified by others to address erosion in non-US locations. For example, Wang, *et al.* (2016) found that the Dg-SOM model was best able to predict K factors for use in the USLE model in eastern China. The Dg-SOM model is given below.

$$K = 0.0667 - 0.0013\left[ln\left({}^{SOM}/_{Dg}\right) - 5.6706\right]^2 - 0.015exp[-28.9589(log(Dg) + 1.827)^2]$$

$$Dg = exp\left(0.01 * \sum_{i=1}^{n} f_i ln(m_i)\right)$$

Where Dg = geometric mean diameter;
f_i = weight percent of particle size fraction;
m_i = arithmetic mean of particle size limits (mm);
n = number of particle size fractions;
SOM = soil organic matter

Soil Classifications

The designation for a sand or clay is given in the *Unified Soil Classification System*, ASTM D 2487. Sandy soils, by definition, must have more than half of the material larger than the No. 200 sieve, and more than half of that fraction must be smaller than the No. 4 sieve. Similarly, for clayey soils, more than half of the material is required to be smaller than the No. 200 sieve. Silt soils are intermediate between sands and clays in their size. Figure 4-13 is the standard soil texture triangle defining the different soil texture categories and Table 4-11 shows the standard USDA particle size ranges for the different soil texture categories.

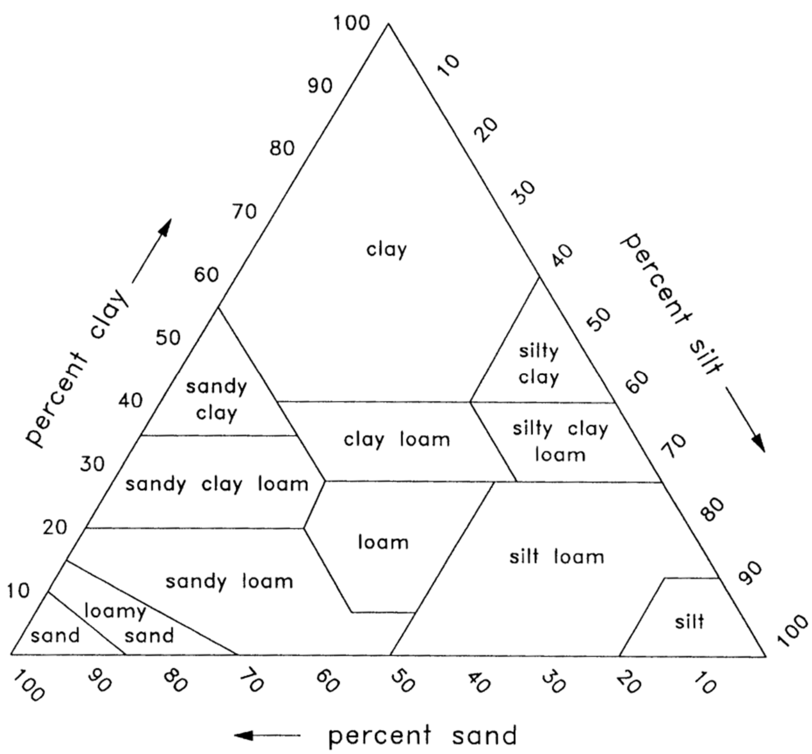


Figure 4-13. Standard USDA soil texture triangle.

Table 4-11. USDA Particle Size Ranges for Different Soil Texture Categories

	Size Range		
Soil Particle	**micrometers**	**millimeters**	**inches**
Cobble	150,000 to 300,000	150 to 300 mm	6 to 12 in.
Gravel	2,000 to 150,000	2 to 150	0.08 to 6
Sand[1]	50 to 2,000	0.05 to 2.00	0.002 to 0.08
Silt	2 to 50	0.002 to 0.05	0.00008 to 0.002
Clay	<2	<0.002	<0.00008

[1] "very fine sand" is in the 50 to 100 μm range

Silt particles are barely visible to the naked eye and have many properties that fall between the values for sand and clay. Silt is characterized by its plasticity and stickiness. According to the USDA (1993), the silt content is an important characteristic for determining erodibility because silt-sized particles are easily detached and transported in runoff. The small particle size also makes silt difficult to capture in sediment controls. There are two major types of clays found in the natural environment – kaolinite and montmorillonite. Kaolinite is relatively inactive and fairly stable. Montmorillonite is a very active clay that shrinks when dry and swells when wet. These characteristics affect the permeability of soils and are very important to their use and management. Clayey soils retain water that should be available for plant growth, but these soils are often very susceptible to compaction, dense, hard, wet, airtight, acidic, and infertile. They can restrict root growth even though their water retention is favorable.

The AASHTO system classifies soils according to the properties that affect roadway construction and maintenance. The fraction of a mineral soil that is less than 3 inches in diameter is classified in one of seven groups from A-1 through A-7 on the basis of grain-size distribution, liquid limit, and plasticity index. Soils in group A-1 are coarse grained and low in silt and clay. Soils in group A-7 are fine grained. Highly organic soils are in Group A-8 and are classified on the basis of visual inspection.

Problem: An Evaluation of Soil Conditions Affecting Construction Site Erosion Problems
The Alabama Soil and Water Conservation Committee produced the *Alabama Handbook for Erosion Control, Sediment Control, and Stormwater Management on Construction Sites and Urban Areas* in 1993 (ASWCC 1993), which was revised in 2003 for use with the Phase II stormwater regulations, and most recently updated in 2018. Some of this discussion is summarized from that manual, as an example of evaluating the erodibility of soils and the information available in soil surveys.

Soil formation in Alabama has been influenced primarily by parent materials and relief. The Appalachian Plateau, Limestone Valleys and Uplands, and Piedmont Plateau of Northern Alabama are all products of uplift and extended geologic erosion. The Coastal Plain and Blackland Prairie sections of the state represent the sedimentation and deposition products from millions of years of geologic erosion. As a result, soils differ among the major soil areas throughout the state.

Many characteristics of soils, including texture, organic matter, fertility, acidity, moisture retention, drainage, and slope, have an influence on the soils' vulnerability to erosion. Except for most of the Prairie area, most disturbed sites after grading end up with a surface layer of acid infertile subsoil materials. The soils of these sites can be toxic to many plants and may not be capable of supporting growth sufficient to prevent erosion. Construction activities further restrict plant growth by increasing compaction and altering the slopes and drainage patterns. To offset these problems, the original site topsoil should be removed, stockpiled, and reapplied to the disturbed area. Soil amendments (limestone and fertilizer) should also be applied based on a soil test of the area. In some areas, special seedbed preparation will also be necessary.

County soil surveys typically have been available from local Natural Resources Conservation Service (NRCS) offices. Many counties no longer have current printed soil surveys. The NRCS provides updated soil surveys through their Web Soil Survey website (https://websoilsurvey.nrcs.usda.gov/app/). The type of graphical information provided by Web Soil Survey is shown in Figure 4-14.

Figure 4-14. Web Soil Survey soil map for Middletown, PA and the Penn State Harrisburg campus. Orange lines denote boundaries of specific soil types.

Soil surveys include a tremendous amount of information about local soils, including special concerns about different land uses in those areas. The following information is summarized from the Jefferson County, AL, soil survey prepared by the SCS in 1981, and is presented as an example of the type of information available from the county soil surveys.

Soil information for the 10 most common Jefferson County, AL, soils are listed in Tables 4-12 and 4-13. These ten soils cover about 75% of the county. The urban soils currently comprise much more than the amounts shown on this table due to the urban development that has occurred during the past 40 years since these soil surveys were last updated.

For this Jefferson County example, the K values range from 0.17 to 0.37. No K values are available for the urban soils, as they have been dramatically disturbed, and no generic values could be assigned. For "urban soils," soil samples should be collected and analyzed. Then, the nomograph in Figure 4-12, or the equations, should be used to estimate appropriate K values. It is interesting to note that almost all of these most common soils are on moderately-steep to steep slopes. Also, the soil erodibility factors are given for several soil horizons for most soils. The K values may increase or decrease with depth for the different soils. The K factors for different soil horizons can be used to determine the erosion rates for a site for different stages of excavation as these lower soil horizons are exposed. In areas of fill, the characteristics of the “new” exposed soil must be considered, and Figure 4-12 must be used to determine an estimated K value based on the measured properties.

Table 4-12. Ten Most Common Soils in Jefferson County, AL, in 1980

		Area in Jefferson County:		
Soil name	**Map symbol**	**Acres**	**%**	**Soil type**
Montevallo-Nauvoo association, steep	29	260,930	36.3	Montevallo Nauvoo
Nauvoo fine sandy loam, 8 to 15% slope	31	51,440	7.2	Nauvoo
Nauvoo-Montevallo association, steep	34	44,010	6.2	Nauvoo Montevallo
Palmerdale complex, steep	35	29,390	4.1	Palmerdale
Urban land	44	27,080	3.8	Urban land
Townley-Nauvoo complex, 8 to 15% slope	40	25,870	3.6	Townley Nauvoo
Bodine-Birmingham association, steep	8	25,560	3.6	Bodine Birmingham
Fullerton-urban land complex, 8 to 15% slopes	18	21,990	3.1	Fullerton Urban land
Bodine-Fullerton association, steep	9	20,720	2.9	Bodine Fullerton
Sullivan-State complex, 0 to 2% slopes	39	19,600	2.7	Sullivan State

Table 4-13. Erodibility Factors, K, for the Most Common Soils in Jefferson County, AL

Soil name	**Soil horizon depth and soil erodibility K factor**		
Birmingham	0 to 5 inches (0.24)	5 to 29 inches (0.28)	
Bodine	0 to 72 inches (0.28)		
Fullerton	0 to 6 inches (0.28)	6 to 35 inches (0.24)	35 to 65 inches (0.20)
Montevallo	0 to 6 inches (0.37)	6 to 16 inches (0.32)	
Nauvoo	0 to 12 inches (0.28)	12 to 46 inches (0.32)	
Palmerdale	0 to 60 inches (0.24)		
State	0 to 40 inches (0.28)	40 to 60 inches (0.17)	
Sullivan	0 to 66 inches (0.32)		
Townley	0 to 4 inches (0.37)		
Urban land	No specific information		

These generally clayey soils in northern Alabama have surface horizon K factors of 0.24 to 0.37, with the most common Jefferson County soils (Montevallo and Nauvoo) having 0.37 and 0.28 K values. Sandy soils with low organic content and with high permeability (similar to Gulf Coast soils) may have K values that are less than half of these values and could conceivably be as low as 0.05, although 0.10 is the more commonly seen minimum K value for Alabama soils. Another example of K values for soils having different textures are listed below (Dion 2002):

Sandy, fine sand, loamy sand	0.10
Loamy sand, loamy fine sand, sandy loam, loamy, silty loam	0.15
Loamy, silty loam, sandy clay loam, fine sandy loam	0.24
Silty clay loam, silty clay, clay, clay loam, loamy	0.28

There is substantial overlap for the different soil textures, as there are other factors besides texture that are used to determine the K value, but this list does illustrate that K values generally increase as the soil particle sizes decrease. Soil surveys need to be consulted to determine the RUSLE K factors for the construction-site soils of interest. This information can be found in Web Soil Survey under the Soil Data Explorer tab after the Area of Interest (AOI) has been selected. Under the Soil Properties and Qualities tab, the user can select Soil Erosion Factors to determine the K values for the AOI. An example of K factor for rock-free soils for the AOI outlined in Figure 4-12 is given in Table 4-14 (note that about 60% of this area is designated as urban land with no K values given).

Table 4-14. Rock-Free K Factor for the Dominant Condition.

Map Unit Symbol	Map Unit Name	Rating (K)	Acres in AOI	Percent of AOI
At	Atkins silt loam	0.28	18.6	0.8%
Bc	Basher silt loam	0.37	10.5	0.4%
CnA	Chavies fine sandy loam, 0 to 3 percent slopes	0.17	93.0	3.9%
CnB2	Chavies, fine sandy loam, 3 to 8 percent slopes, moderately eroded	0.17	308.4	12.9%
CnC2	Chavies fine sandy loam, 8 to 15 percent slopes, moderately eroded	0.17	65.5	2.7%
DvA	Duncannon very fine sandy loam, 0 to 3 percent slops	0.32	9.6	0.4%
DvB2	Duncannon very fine sandy loam, 3 to 8 percent slopes, moderately eroded	0.32	2.9	0.1%
LeB2	Lawrenceville very fine sandy loam, 2 to 8 percent slopes, moderately eroded	0.37	12.6	0.5%
LrB2	Lewisberry gravelly sandy loam, 3 to 8 percent slopes, moderately eroded	0.15	134.1	5.6%
LrC2	Lewisberry gravelly sandy loam, 8 to 15 percent slopes, moderately eroded	0.15	72.9	3.0%
LrD2	Lewisberry gravelly sandy loam, 15 to 25 percent slopes, moderately eroded	0.15	68.7	2.9%
Lt	Lindside silt loam	0.37	8.6	0.4%
Lw	Lindside silt loam, coal overwash	0.37	3.7	0.2%
MW	Miscellaneous water		4.0	0.2%
PeB2	Penn channery silt loam, 3 to 8 percent slopes	0.37	1.9	0.1%
PeC2	Penn channery silt loam, 8 to 15 percent slopes	0.37	1.3	0.1%
RdB	Readington silt loam, 3 to 8 percent slopes	0.37	4.0	0.2%
Ta	Tioga fine sandy loam	0.20	4.1	0.2%
Tg	Tioga fine sandy loam, high bottom	0.02	28.2	1.2%
Ua	Urban land, alluvial materials		717.3	29.9%
Ub	Urban land, limestone materials		478.6	20.0%
Us	Urban land, shale materials		270.7	11.3%
W	Water		77.2	3.2%

Length-Slope Factor (LS)

The erosion of soil from a slope increases as the slope increases and lengthens. RUSLE defines a parameter called the length-slope (LS) factor that is used to calculate the impact of the interaction between these two parameters on erosion losses. This factor is not a simple multiplied length times slope value, but is used with a look-up table to determine the factor associated with the combined interaction of the length and slope values. The slope length, λ, is the horizontal distance, or flat map distance, from the start of the erosion area (typically a ridge, but not in all cases) to the start of the area where deposition of eroded sediment occurs. The slope length is used in RUSLE for calculating interrill (sheet) and rill erosion. Several example slope lengths are shown on Figures 4-15 and 4-16 (Renard, *et al.* 1987):

- Slope A: If undisturbed forest soil above the slope does not yield surface runoff, the top of the slope starts with the edge of the undisturbed forest soil and extends down slope to the windrow, if runoff is concentrated by the windrow.
- Slope B: Point of origin of runoff to the windrow, if the runoff is concentrated by the windrow.
- Slope C: From windrow to flow concentration point.
- Slope D: Point of origin of runoff to road that concentrates runoff.
- Slope E: From road to flood plain where deposition would occur.
- Slope F: On nose of hill, from point of origin of runoff to flood plain where deposition would occur.
- Slope G: Point of origin of runoff to slight depression where runoff would concentrate

Once the slope length has been measured (such as from a detailed topographic map), the slope of the eroded area is calculated based on the elevations at the start of the erosion and the end of the erosion/start of deposition. RUSLE includes a table (Table 4-15) for selecting the length-slope factor, LS, according to these site characteristics. Values of 1.0 (the base condition) correspond to the standard condition of 9% slope and about 73 ft slope length (the dimensions and slopes of the erosion test plots). If the length of the slope is 300 ft., or less, the LS factor would be less than 0.10 for all slopes of 0.5%, or less. Roadway side cuts of 1:2 (50%) would have LS factors greater than 1.0 for all slope lengths of about 6 ft, or longer. Long and steep slopes, frequently occurring along roadway cuts in hilly terrain, can have extremely large LS factors. It is interesting to note that more than 80% of Jefferson County, AL, lands have slopes greater than 8% (1981 USDA Jefferson County Soil Survey). Land slopes are much less steep in Alabama below the fall line (ancient coast) and approaching the gulf coast. Figure 4-17 highlights both the slope length and the uniform slope used in the LS factor table.

The RUSLE LS factors have been significantly changed compared to the original USLE LS values. There are now four separate LS tables, although Table 4-15 is the only one appropriate for construction sites because it characterizes freshly prepared sites that are highly disturbed. The LS values have also been generally reduced compared to the original values, sometimes by as much as 50% for the largest values. LS values for slopes less than 20% are similar in both versions. Also, steepness and length are now more evenly sensitive to the LS factor, while previously, slope steepness was much more critical.

Table 4-15. LS Values for Freshly Prepared Construction and other Highly Disturbed Soil, with Little, or no Cover (Renard, *et al.* 1987)

	Slope length in feet																
Slope	<3	6	9	12	15	25	50	75	100	150	200	250	300	400	600	800	1000
%																	
0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06
0.5	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.09	0.09	0.10	0.10	0.10	0.11	0.12	0.12	0.13
1.0	0.09	0.09	0.09	0.09	0.09	0.10	0.13	0.14	0.15	0.17	0.18	0.19	0.20	0.22	0.24	0.26	0.27
2.0	0.13	0.13	0.13	0.13	0.13	0.16	0.21	0.25	0.28	0.33	0.37	0.40	0.43	0.48	0.56	0.63	0.69
3.0	0.17	0.17	0.17	0.17	0.17	0.21	0.30	0.36	0.41	0.50	0.57	0.64	0.69	0.80	0.96	1.10	1.23
4.0	0.20	0.20	0.20	0.20	0.20	0.26	0.38	0.47	0.55	0.68	0.79	0.89	0.98	1.14	1.42	1.65	1.86
5.0	0.23	0.23	0.23	0.23	0.23	0.31	0.46	0.58	0.68	0.86	1.02	1.16	1.28	1.51	1.91	2.25	2.55
6.0	0.26	0.26	0.26	0.26	0.26	0.36	0.54	0.69	0.82	1.05	1.25	1.43	1.60	1.90	2.43	2.89	3.30
8.0	0.32	0.32	0.32	0.32	0.32	0.45	0.70	0.91	1.10	1.43	1.72	1.99	2.24	2.70	3.52	4.24	4.91
10.0	0.35	0.37	0.38	0.39	0.40	0.57	0.91	1.20	1.46	1.92	2.34	2.72	3.09	3.75	4.95	6.03	7.02
12.0	0.36	0.41	0.45	0.47	0.49	0.71	1.15	1.54	1.88	2.51	3.07	3.60	4.09	5.01	6.67	8.17	9.57
14.0	0.38	0.45	0.51	0.55	0.58	0.85	1.40	1.87	2.31	3.09	3.81	4.48	5.11	6.30	8.45	10.40	12.23
16.0	0.39	0.49	0.56	0.62	0.67	0.98	1.64	2.21	2.73	3.68	4.56	5.37	6.15	7.60	10.26	12.69	14.96
20.0	0.41	0.56	0.67	0.76	0.84	1.24	2.10	2.86	3.57	4.85	6.04	7.16	8.23	10.24	13.94	17.35	20.57
25.0	0.45	0.64	0.80	0.93	1.04	1.56	2.67	3.67	4.59	6.30	7.88	9.38	10.81	13.53	18.57	23.24	27.66
30.0	0.48	0.72	0.91	1.08	1.24	1.86	3.22	4.44	5.58	7.70	9.67	11.55	13.35	16.77	23.14	29.07	34.71
40.0	0.53	0.85	1.13	1.37	1.59	2.41	4.24	5.89	7.44	10.35	13.07	15.67	18.17	22.95	31.89	40.29	48.29
50.0	0.58	0.97	1.31	1.62	1.91	2.91	5.16	7.20	9.13	12.75	16.16	19.42	22.57	28.60	39.95	50.63	60.84
60.0	0.63	1.07	1.47	1.84	2.19	3.36	5.97	8.37	10.63	14.89	18.92	22.78	26.51	33.67	47.18	59.93	72.15

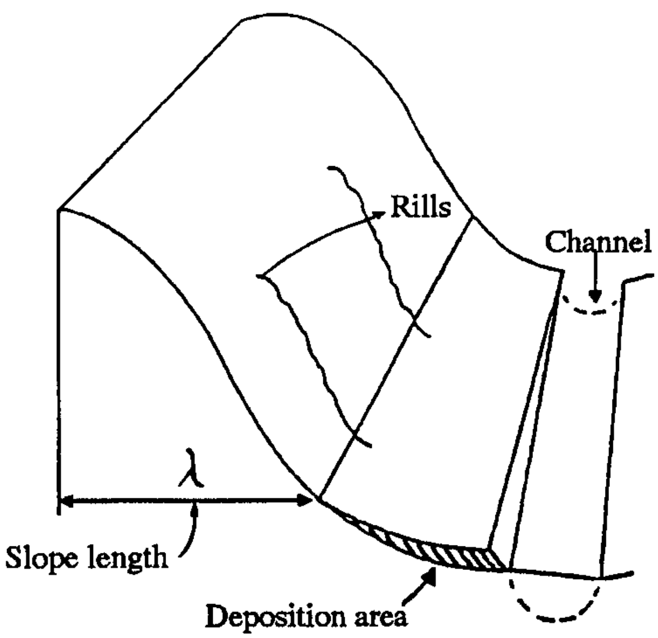


Figure 4-15. Definition of slope length as used in RUSLE (Renard, *et al.* 1987).

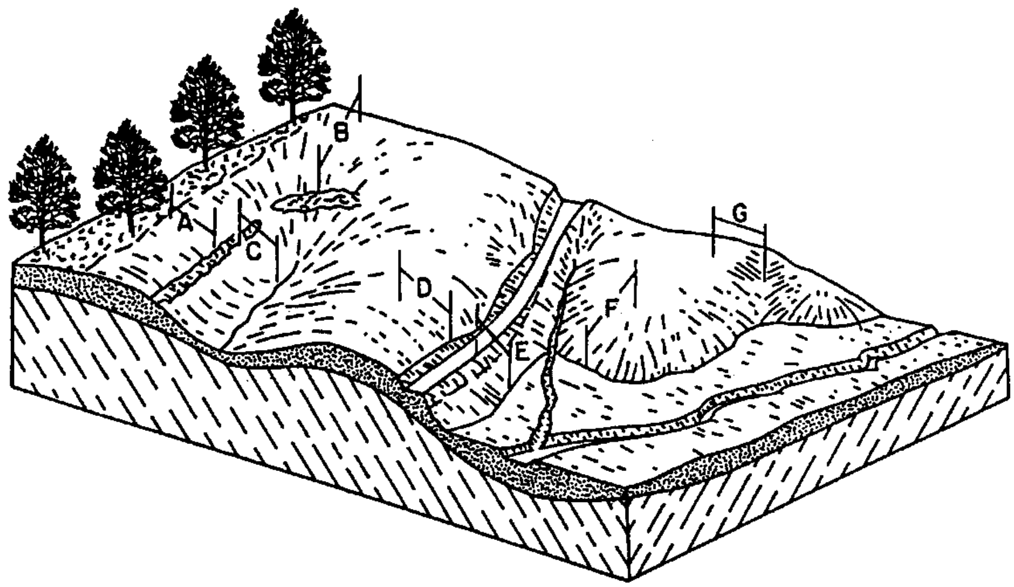


Figure 4-16. Examples of different slope length measurements (Renard, *et al.* 1987).

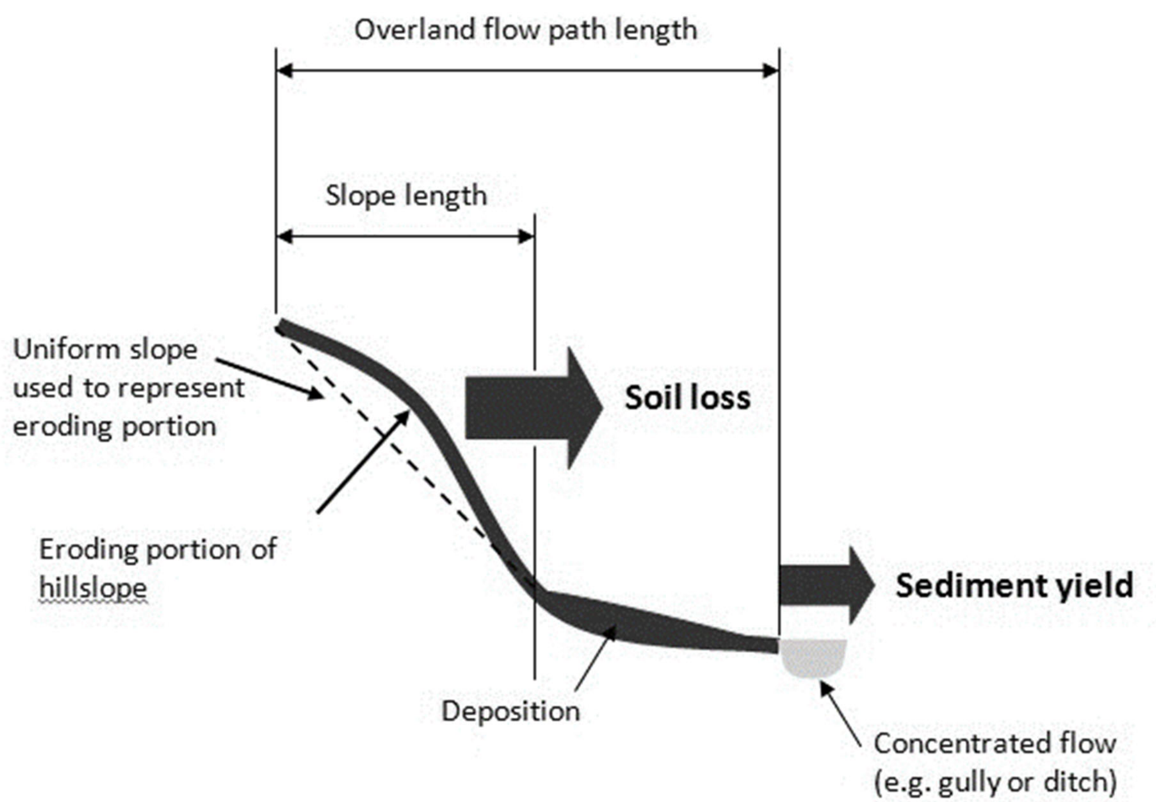


Figure 4-17. Illustration of erosion and deposition areas and the segments used to calculate slope length and slope. (Source: http://www.omafra.gov.on.ca/english/engineer/rusle2/fieldslope.htm)

If ponding occurs on a site due to heavy rain intensities, low infiltration rates, and small slopes, the erosion loss will be substantially less than predicted using the above LS factors. The basic method to correct for this over-prediction is to estimate the land area subject to ponding (assumed to have no erosion due to the ponding which absorbs the rain energy and having no flow to carry away sediment) and reduce the site area accordingly.

Calculating the LS Factor
In the USLE, historically, the LS factor could be calculated at the product of L*S. The slope-length factor, L, was calculated using the following formulas:

$$L = \left(\frac{\lambda}{22.13}\right)^m$$

$$m = \frac{\beta}{1+\beta}$$

$$\beta = \frac{sin\theta}{[3(sin\theta)^{0.8} + 0.56]}$$

Where λ = slope length (m)
m = length-slope exponent (function slope angle)
β = factor that varies with slope gradient
θ = slope angle (radians)

The slope factor S was calculated using the following equations, depending on the slope of the eroded section of land:

$S = 10.8sin\theta + 0.03$ $\quad\theta < 9\%$
$S = 16.8sin\theta - 0.5$ $\quad\theta \geq 9\%$

Where θ = slope angle (radians)

These equations were developed for gently-sloping cropland with one-dimensional flow.

However, when calculating sheet and rill erosion on larger scale, the flow often is not 1-dimensional. Many people use delineation and flow features in GIS to estimate these parameters as hydrologic features incorporated into GIS. If GIS data not readily available for larger watersheds, Moore and Wilson (1992) proposed an estimator of LS:

$$LS = \left(\frac{A_s}{22.13}\right)^m \left(\frac{sin\theta}{0.0896}\right)^n$$

Where A_s = λ (m)
θ = slope (radians)
m & n = exponents (m = 0.4 – 0.56; n = 1.2 – 1.3)

The above equations were developed for use in the U.S. Researchers have used the US equations as a basis to develop similar equations that are applicable in other areas of the world. For example, given the

steep slopes and soil erodibility of the Loess Plateau in China, the LS factor can be calculated as the product of L*S, but using the following equations (Zhang, *et al.* 2017):
:

$$L = \left(\frac{\lambda}{22.1}\right)^{m}$$

Where	m = 0.2	$\theta \le 1.7\%$
	m = 0.3	$1.7\% < \theta \le 5.2\%$
	m = 0.4	$5.2\% < \theta \le 9\%$
	m = 0.5	$\theta > 9\%$

$S = 10.8\, sin\theta + 0.03$	$\theta < 9\%$
$S = 16.8 sin\theta - 0.05$	$9\% \le \theta < 17.6\%$
$S = 21.9 sin\theta - 0.96$	$\theta > 17.6\%$

Where θ = slope angle in radians

Cover Management Factor (C)

The methods used to protect the soil surface will affect the amount of soil erosion that may occur. Chapter 5 on channel and slope stability contain additional information pertaining to this factor, and to mulches in general. Wischmeier and Smith (1978) commented in their original USLE report regarding the model's applicability and use for construction sites. The following paragraphs are summarized from their prior discussion.

Site preparations that remove all vegetation and also the root zone of the soil not only leave the surface completely without protection, but also remove the residual effects of prior vegetation. This condition is comparable to the standard continuous fallow condition, and C = 1. Roots and residual effects of prior vegetation, and partial covers of mulch or vegetation, substantially reduce soil erosion. These reductions are reflected in the soil loss prediction by C values of less than 1.0.

Mechanical Mulches

Applied mulches immediately restore protective cover on denuded areas and drastically reduce the C values, and hence erosion. Where mulch effects are insignificant, these C values equal 1.0, the standard value. Straw or hay mulches applied on steep construction slopes and not tied to the soil by anchoring and tacking equipment are usually much less effective than equivalent mulch rates on relatively flat land.

Table 4-16 presents approximate C values for straw, crushed stone, and woodchip mulches on construction site slopes where no canopy cover exists. This table also shows the maximum slope lengths for which these values may be assumed to be applicable. These values are from the original (1978 USLE) guidance and can now be better determined by making calculations based on specific site and rainfall conditions, as described in the chapters on hydrology (Chapter 3) and slope stability (Chapter 5). Also, currently available mulching products and erosion control blankets offer a much greater range of options for controlling erosion on construction site slopes. However, the values given here are suitable for calculating the effects of a basic mulch.

Table 4-16. Construction Site Mulching C Factors and Length Limits for Different Slopes (Wischmeier and Smith 1978)

Type of Mulch	Mulch Rate (tons per acre)	Land Slope (%)	Mulching C Factor	Length Limit (ft)[1]
None	0	all	1.0	n/a
Straw or hay, tied down by anchoring and tacking equipment	1.0	1-5	0.20	200
	1.0	6-10	0.20	100
	1.5	1-5	0.12	300
	1.5	6-10	0.12	150
	2.0	1-5	0.06	400
	2.0	6-10	0.06	200
	2.0	11-15	0.07	150
	2.0	16-20	0.11	100
	2.0	21-25	0.14	75
	2.0	26-33	0.17	50
	2.0	34-50	0.20	35
Crushed stone, ¼ to 1-1/2 inch	135	<16	0.05	200
	135	16-20	0.05	150
	135	21-33	0.05	100
	135	34-50	0.05	75
	240	<21	0.02	300
	240	21-33	0.02	200
	240	34-50	0.02	150
Wood chips	7	<16	0.08	75
	7	16-20	0.08	50
	12	<16	0.05	150
	12	16-20	0.05	100
	12	21-33	0.05	75
	25	<16	0.02	200
	25	16-20	0.02	150
	25	21-33	0.02	100
	25	34-50	0.02	75

[1] Maximum slope lengths for which the specified mulch rate is considered effective. If these limits are exceeded, either a higher application rate or mechanical shortening of the effective slope length is required (such as with terracing).

The percentage mulch covering the bare ground is what generally determines the effectiveness of the mulch. This is the percentage of the soil surface that is covered by pieces of mulch laying on the surface. According to Wischmeier and Smith (1978), a simple method of estimating mulch cover is with a line at least 50 ft long that has 100 equally spaced markings. The line is stretched over the mulched surface and the marks that contact a piece of mulch are counted. The number of counted marks indicates the percentage coverage of mulch on the site. This is repeated randomly on the site to obtain an average value along with an indication of the variation. Table 4-17 shows the approximate percentage coverage for different mulching rates for straw, along with the range of erosion control (Wischmeier and Smith 1978).

Table 4-17. Straw Mulching Rates, Approximate Coverage and Corresponding Erosion Control (data from Wischmeier and Smith 1978)

Straw mulch rate (tons per acre)	Percent coverage	Erosion control for selected coverages
0.10	10%	
0.25	30	
0.5	50	
1.0	70	80%
1.5	84	88%
2.0	92	80 to 94%

2.5	96
3.0	97

Vegetative Covers

It is very important to establish vegetation on denuded areas as quickly as possible. A good sod has a C value of 0.01 or less, but such a low C value can be obtained quickly only by laying sod on the area at a substantial cost. When grass or small grain is started from seed, the probable soil loss for the period while cover is developing can be computed by the standard procedure for estimating crop stage-period soil losses. If the seeding is on topsoil without a mulch, the soil loss ratios given in Table 4-18 are appropriate for crop stage C values.

Table 4-18. Cover Factor C Values for Different Growth Periods for Planted Cover Crops for Erosion Control at Construction Sites (data from Wischmeier and Smith 1978)

	SB (seedbed preparation)	Period 1 (establishment)	Period 2 (development)	Period 3a (maturing crop)	Period 3b (maturing crop)	Period 3c (maturing crop)
Crop canopy[1]	0 to 10%	10 to 50%	50 to 75%	75 to 80%	75 to 90%	75 to 96%
Seeding is on topsoil, without a mulch	0.79	0.62	0.42	0.17	0.11	0.06
Seeding is on a desurfaced area, where residual effects of prior vegetation are no longer significant	1.0	0.75	0.50	0.17	0.11	0.06

[1] Percent canopy cover is the percentage of the land surface that would not be hit by directly falling rain drops because the drops would be intercepted by the plant. It is the portion of the soil surface that would be covered by shadows if the sun were directly overhead.

When the seedbed is protected by a mulch covering, the pertinent mulch factor from Table 4-18 is applicable until good canopy cover is attained. When grass is established in small grain as a nurse crop, it can usually be evaluated as “established meadow” about 2 months after the grain is harvested after which values in the following discussion can be used.

Table 4-19 (from the NRCS’s current *National Engineering Handbook*) lists cover management C factors for land covers with no trees. This table can be applied to construction sites having temporary or permanent vegetative covers, or mulches. It indicates the improved erosion control as the ground coverage increases. With good coverage (more than 80% ground cover), the erosion control could be 95%, or greater. These values assume that the vegetation or mulch is randomly distributed over the entire area. In areas with canopies where the rain drops have much less effective drop heights, and correspondingly less energy, the C factors are further decreased. A mechanically prepared site with no topsoil and no forest residue mixed in would have a C close to 1.0 if no cover was applied. With an 80% cover of mulch, this type of site (indicative of most construction sites) would have about 90% erosion control. In comparison, the C factor for a woodland with 100 percent thick duff cover (partly decayed organic matter on the forest floor) would be a low 0.0001 (99.99% erosion control), the lowest reported value.

Table 4-19. Cover Factor C Values for Established Plants (data from NEH chapter 3 and Wischmeier and Smith 1978)

			Percentage of surface covered by residue in contact with the soil:					
	Percent cover[1]	Plant type	0 %	20	40	60	80	95+
C factor for grass, grasslike plants, or decaying compacted plant litter.	0	Grass	0.45	0.20	0.10	0.042	0.013	0.003
C factor for broadleaf herbaceous plants (including most weeds with little lateral root networks), or undecayed residues.	0	Weeds	0.45	0.24	0.15	0.091	0.043	0.011
Tall weeds or short brush with average drop height[2] of ≥20 inches	25	Grass	0.36	0.17	0.09	0.038	0.013	0.003
		Weeds	0.36	0.20	0.13	0.083	0.041	0.011
	50	Grass	0.26	0.13	0.07	0.035	0.012	0.003
		Weeds	0.26	0.16	0.11	0.076	0.039	0.011
	75	Grass	0.17	0.10	0.06	0.032	0.011	0.003
		Weeds	0.17	0.12	0.09	0.068	0.038	0.011
Mechanically prepared sites, with no live vegetation and no topsoil, and no litter mixed in.	0	None	0.94	0.44	0.30	0.20	0.10	Not given

[1] percent cover is the portion of the total area surface that would be hidden from view by canopy if looking straight downward.
[2] drop height is the average fall height of water drops falling from the canopy to the ground.

The C-factor can be calculated using the following formula:

$$C = \frac{\sum_{i=1}^{n} SLR_i EI_i}{EI_t}$$

Where Soil Loss Ratio (SLR) = ratio of soil loss under actual conditions to losses experienced under reference conditions.
EI = rainfall erosivity

C represents the effects of plants, soil cover, soil biomass, and soil disturbing activities on erosion. SLR vary with time as canopy, ground cover, roughness, soil biomass and consolidation change. To be considered an adequate surface cover, the material must be of sufficient size or attached to the surface such that is not removed by runoff. Roughness indicates the degree of clodiness and the likelihood that the surface will seal, producing increased runoff and soil erodibility.

In non-US locations, especially in areas with steep slopes and erodible soils, many researchers are developing equations and tables to predict the SLR in order predict C for use in RUSLE.

Supporting Practices Factor (P)

The method of tillage and crop rotations all affect the soil erosion rate for an agricultural operation. This factor is rarely applicable for construction sites and is therefore given a value of 1.0 for this application, although some construction site erosion decision support models use the P factor when considering the effects of on-site controls (Dion 2002). Other chapters in this book describe specific hydrologic and sediment transport functions that enable these effects to be directly calculated for specific site and design conditions.

RUSLE2 Information

The following description of RUSLE2 is based on information provided by the USDA. RUSLE2 is an upgrade of the text-based RUSLE DOS version 1 model. It is a computer model containing both empirical and process-based processes in a Windows environment. It predicts rill and interrill (sheet) erosion by rainfall and runoff on a daily basis (in contrast to the longer period analyses for RUSLE). The USDA-Agricultural Research Service (ARS) is the lead agency for developing the RUSLE2 model, including developing the technical processes in the model and the model interface. The NRCS RUSLE2 Internet site is at: https://www.ars.usda.gov/southeast-area/oxford-ms/national-sedimentation-laboratory/watershed-physical-processes-research/research/rusle2/revised-universal-soil-loss-equation-2-overview-of-rusle2/. The model can be downloaded from this site, along with supporting documents and other materials.

RUSLE2 has evolved from a series of previous erosion prediction methods. The USLE was entirely an empirically-based equation and was limited in its application to conditions where experimental data were available for deriving factor values. While RUSLE2 uses the USLE basic formulation of the unit plot, the calculations of RUSLE2 are based on daily predictions. The major visible change in RUSLE2 is its graphical user interface.

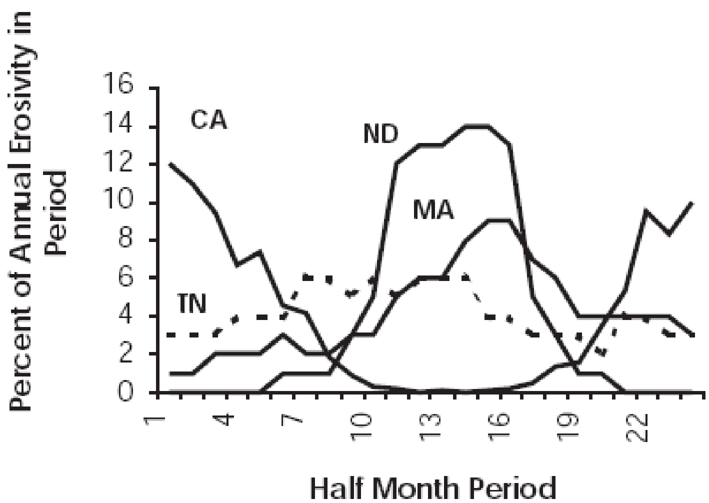
Development of RUSLE2 and its support is on-going. The 2008 version of the User's Reference Guide is available at: https://www.ars.usda.gov/ARSUserFiles/60600505/RUSLE/RUSLE2_User_Ref_Guide.pdf. Descriptions made to RUSLE2 since then are available at: https://www.ars.usda.gov/southeast-area/oxford-ms/national-sedimentation-laboratory/watershed-physical-processes-research/research/rusle2/revised-universal-soil-loss-equation-2-rusle2-documentation/.

The following overview is based on information on RUSLE2 provided by the USDA from the above listed web sites.

Although mostly intended for agricultural erosion prevention and farm operation planning, RUSLE2 can be applied to other erosion problems including construction sites. Earlier sections of this chapter discussed the major components of RUSLE, which are generally applicable to RUSLE2. RUSLE2 is very easy to use; with the exception of the site topography, the RUSLE2 model user describes the site-specific field conditions by selecting the appropriate values and control practices from menus. When a menu selection is made, RUSLE2 uses values stored in the RUSLE2 database and uses them as input values to compute the expected erosion rates. The user enters site-specific values for slope length and steepness to represent site topography.

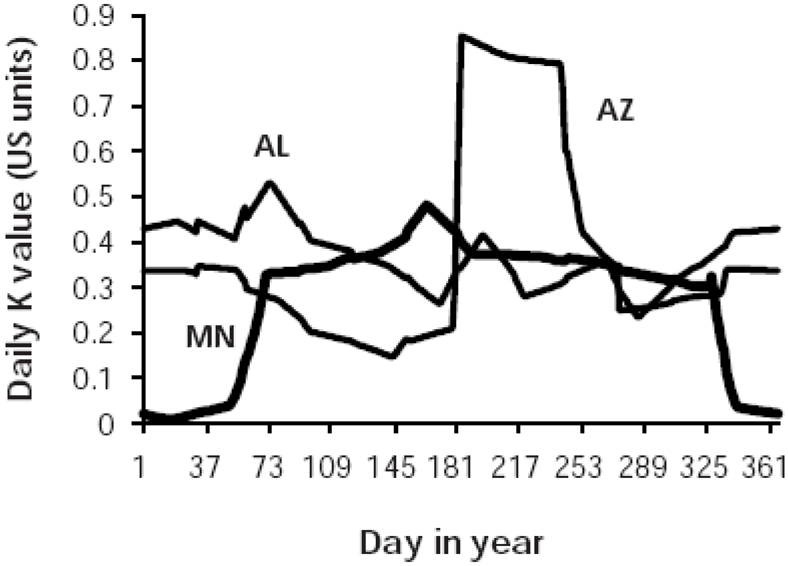
With the development of expanded User Guides, model enhancements, and model templates, RUSLE2 is expected to become the preferred tool to predict erosion rates for construction sites. A number of states and private companies have developed training programs for the use of RUSLE2 at construction sites. One example from the California Department of Transportation is at: http://www.dot.ca.gov/hq/oppd/stormwtr/rusle2.htm. The following are several important enhancements available in RUSLE2 that aid the erosion control planner.

- Although RUSLE can calculate erosion rates for 2-week increments (through the use of the detailed seasonal rainfall erosivity values for all parts of the U.S.), RUSLE2 extends the resolution to daily erosion predictions. RUSLE2 also uses seasonal temperature information, along with rainfall, to predict the longevity of applied mulches for erosion control. Simply selecting the location of the study site automatically uses the correct daily erosivity, precipitation, and temperature values in the model. The following figure shows plots of the erosivity variations throughout the year for sites in California, Tennessee, North Dakota, and Maryland (USDA 2003):



In the above example, erosivity is nearly uniform at Memphis, Tennessee, while 80 percent of the erosivity occurs in the months of May, June and July in North Dakota (the months having most of the annual rainfall). Soil erodibility also varies during the year. Erosion is greatest when peak soil erodibility, rain erosivity, and vulnerability of cover-management all occur simultaneously.

- Another important enhancement of RUSLE2 is its ability to vary the soil erodibility by season. The RUSLE2 user typically selects a soil by soil-map unit name from a list of soils in the RUSLE2 database. Soil erodibility, K, varies by season. It tends to be high early in the spring during and immediately following thawing and other periods when the soil is wet. The value entered for K is a base value. RUSLE2 uses monthly precipitation and temperature to compute monthly K values that vary about the base K value. The monthly values are then disaggregated into daily values. Example variations of K computed by RUSLE2 for St. Paul, MN, Birmingham, AL, and Tombstone, AZ, are shown below (USDA 2003).

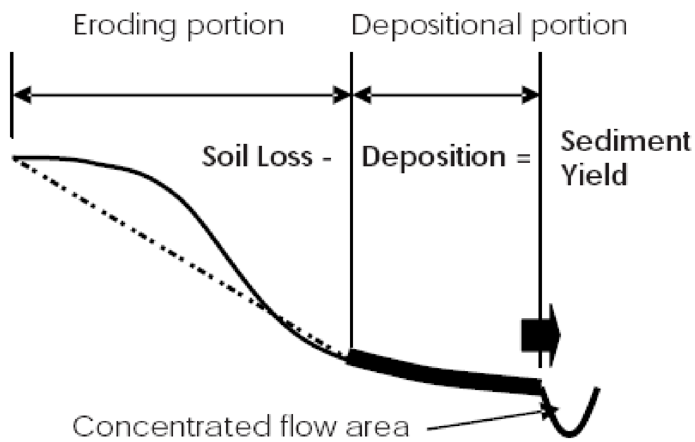


The low values for St. Paul during the winter months represent frozen soil that is nonerodible. RUSLE2 does not fully represent the thawing period in early spring in St. Paul, primarily because observed data are too few to determine a relationship for this period. The peak for Birmingham in March results from rainfall rather than from temperature. The main influence of temperature on temporally varying K values is in late summer when increased temperature increases soil evaporation and reduces runoff and erosion. The peak erodibility during the summer for Tombstone is because most of the annual rainfall at the location occurs during this period.

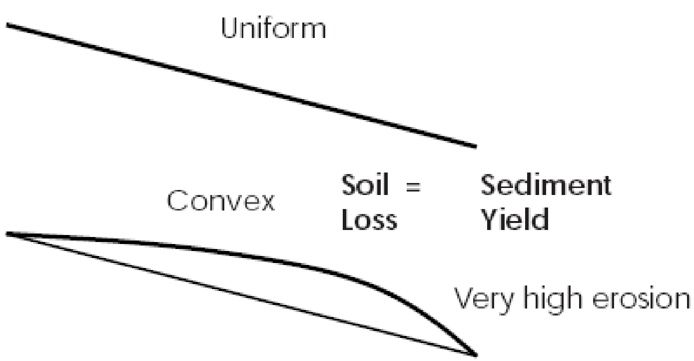
RUSLE2 assumes that soil erodibility is 2.2 times as erodible immediately after a mechanical disturbance than after the soil has become fully consolidated. Therefore, erosion decreases with time as the soil becomes more consolidated. This factor is critical and highly dependent on soil characteristics associated with construction sites, where soil compaction (and associated soil density) increases during construction operations is very common. RUSLE assumes a decrease in soil density – contrary to what actually occurs on a site during construction.

- Topography: Slope length, steepness, and shape are the topographic characteristics that most affect rill and interrill erosion. Site-specific values are entered for these variables. The following examples are from the Technology User's Guide (USDA 2003) and describe some important RUSLE2 topographic features for construction sites.

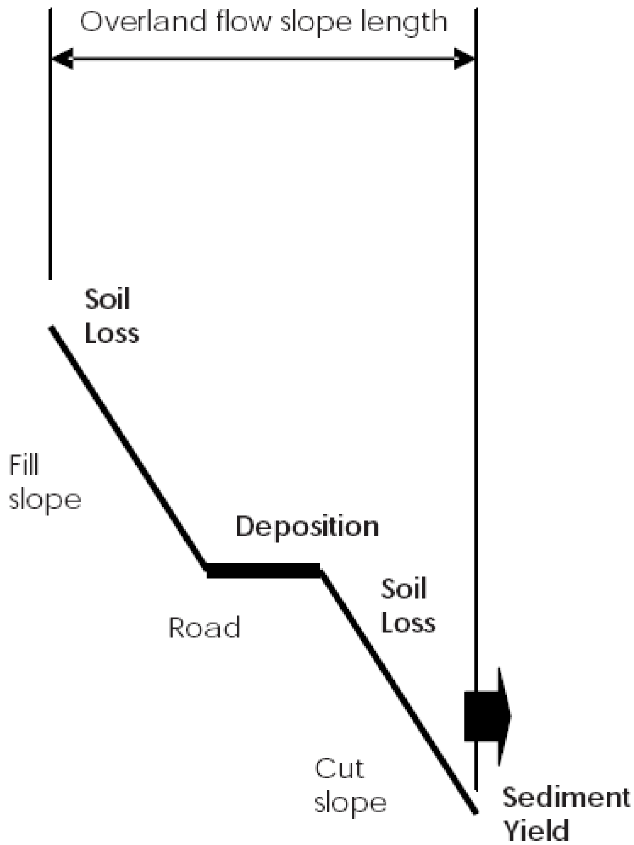
On a complex slope, the sediment yield is reduced by deposition on a downslope concave slope section:



On uniform or convex slopes, the sediment yield is equal to the soil loss, because there is no depositional area:



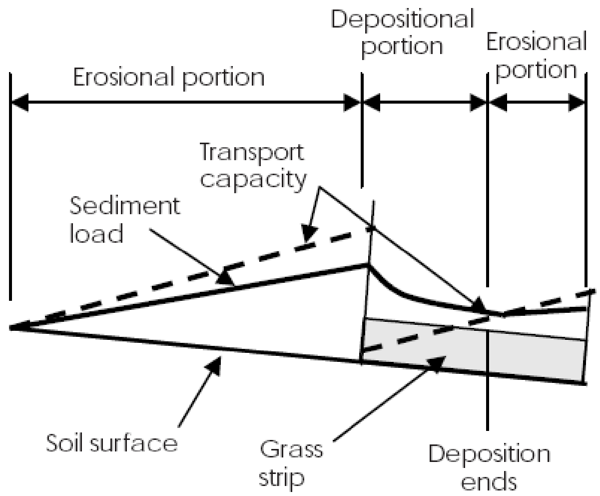
A complex hillslope shape is shown below where a concave section occurs in the middle of the hillslope. This example is for a cut slope (e.g., road-fill) slope that is common in hilly terrain. Deposition can occur on the mid-section of the hillslope where the road is located. Soil loss occurs on the cut slope and on the fill slope where overland flow continues across the road onto the cut slope. Although the steepness and length of the fill slope is the same as that for the upper cut slope, soil loss is likely to be much greater on the cut slope than on the fill slope because of the increased amounts of overland flow of water. Although USLE and RUSLE1 cannot easily describe this hillslope, it can be easily described in RUSLE2, which also determines the appropriate overland flow slope lengths, and computes soil loss on the two eroding portions of the hillslope, deposition on the depositional portion of the hillslope, and final sediment yield from the hillslope. Note that the slope-length used in RUSLE2 does not end where deposition begins for the hillslope profile, as it does in earlier model versions.



- Cover Management Practice: Important features on a construction site include whether or not the land is bare, the soil material is a cut or fill, mulch is applied, or the slope is recently reseeded. The description of any cover-management practice is created, named, and stored in the RUSLE2 database. When RUSLE2 is run, the cover-management practice that fits the site-specific field condition is selected from the menu of choices.

- Support practices, include contouring, vegetative strips and buffer strips, silt fences, terraces, diversions, and sediment basins, all reduce eroded soil discharges primarily by reducing the erosivity of surface runoff and by causing deposition. Support practices are selected from a list of these practices in the RUSLE2 database. Site-specific information, such as the location of a diversion on the hillslope, is entered as required for each practice.

If the control segment is sufficiently long (the grass strip is sufficiently wide) and the increase in transport capacity with distance is less than the detachment quantity, deposition ends within the segment, as illustrated below (USDA 2003). Erosion may occur further downgradient where transport capacity is available. In this case, the sediment load exceeds the transport capacity at the upper end of the grass strip, while both sediment and transport capacity increase within the strip segment. RUSLE2 computes the location where deposition ends and sediment load equals transport capacity, as well as the additional erosion.



The following list (USDA 2003) shows the various RUSLE2 database components that comprise the different parts of the model. The input information is organized using these components, allowing excellent organization and sensitivity analyses:

Worksheet. Computes soil loss for alternative management practices, alternative profiles, and average soil loss for an area.
Profile. Computes soil loss for a single hillslope profile, the basic computational unit in RUSLE2.
Climate. Contains data on average annual erosivity, EI_{30}, rainfall amount and temperature.
Storm erosivity. Contains data on the distribution of erosivity during the year.
Soil. Contains soil data, including erodibility, texture, hydrologic soil group, time to consolidation, sediment characteristics, and soil erodibility nomographs.
Management. Contains descriptions of cover-management systems. Includes dates, operations, vegetation, type and amount of applied materials.
Operation. Contains data on operations (events that affect soil), vegetation and residue. Includes the sequence of processes used to describe each operation, such as for an operation placing residue in the soil: values for flattening, burial and resurfacing ratios; ridge heights; and initial soil roughness.
Vegetation. Contains data on vegetation, like values for residue type, yield, above-ground biomass at maximum canopy, senescence, flow retardance, root biomass, canopy cover, fall height, and live ground cover.
Residue. Contains data that describes the residue assigned to each vegetation. Includes values for decomposition, mass-cover relationship, and how residue responds to tillage.
Contouring. Contains values for row grade used to describe degree of contouring.
Strips/barriers. Contains data that describes filter strips, buffer strips and rotational strip cropping. Includes cover-management in strips, width of strips, number of strips across slope length, whether or not a strip is at the end of the slope, and offset of rotation by strip.
Hydraulic system. Identifies the hydraulic elements and their sequence (e.g., describing the hydraulic systems of diversions, terraces and impoundments). Includes numbers across slope length, and whether or not a system is at the end of the slope or specific locations on the slope length.
Hydraulic element. Contains data on the grade of the named channel for terraces and diversions.
Subsurface drainage system. Contains data on the percent of the area covered by optimum drainage.

For complex constructions sites with multiple drainage paths, computer software such as AnnAGNPS (AGricultural Non-Point Source Pollution Model) could be used. AGNPS was developed primarily for agricultural erosion applications. However, with the inclusion of RUSLE2 into the software and the ability to specify non-crop data, it can be used for complex construction sites. It currently includes information in the database on roads and residential areas, but not construction areas.

Erosion Predictions for Individual Rain Events

As indicated above, the USLE was originally developed for annual and seasonal erosion loss calculation, mainly for agricultural operation phases. RUSLE, and later modifications, included tools to predict erosion losses at 2-week increments as a tool to calculate erosion losses during shorter construction periods. RUSLE2 summarized above enables daily erosion loss calculations. Other modifications of RUSLE for short-term erosion losses are summarized below. This is important due to varying site conditions throughout the year and varying receiving water issues that respond differently to sediment.

The Modified Universal Soil Loss Equation (MUSLE) was developed by Williams (1975), and further discussed by USDA (1981), Smith, *et al*. (1984), and Jackson, *et al*. (1986) for estimating sediment yield for individual runoff events. The MUSLE equation is given as:

$$T = 95*(V*Q_p)^{0.56}*K*LS*C*P$$

Where:

T = Sediment yield per storm event (tons)
V = Volume of runoff per storm even (acre-feet)
Q_p = Peak flow per storm event (cubic feet per second, cfs)
K, LS, C, and P are the same parameters used in RUSLE

The values for V and Q_p are determined by hydrologic analysis of the drainage area to the design point or location of interest. The following example illustrates the use of the MUSLE equation:

Compute the sediment yield to a proposed sediment pond whose drainage area is 5.0 acres which will be all disturbed for construction activities. The sandy loam soil has a soil erodibility factor K = 0.43, whose dry density is 105 pounds per cubic foot. The soil is categorized as a hydrologic soil group “B”. The topographic factor, LS = 2.34. The sediment volume to be captured is that from a 2.5-inch rainfall event.

The Curve Number for “B” soil for newly graded areas is 86, and the amount of runoff from a 2.5-inch rainfall event for this curve number is 1.3 inches. Therefore, the runoff volume is:

$$V = (1.3 \text{ in}*5 \text{ ac.})/(12 \text{ in/ft}) = 0.54 \text{ ac-ft}$$

Utilizing USDA TR55 hydrologic methods, the peak discharge, Q_p, from the drainage area for this rainfall event is calculated to be 8.6 cfs. Solving for sediment yield:

$$T = 95*(0.54*8.6)^{0.56} *(0.43)*(2.34)*(1)*(1) = 226 \text{ tons}$$

Converting the weight to the estimated sediment volume, based on an air-dry unit weight of 105 lbs/cu ft:

Sediment Volume = [(226 tons)*(2,000 lbs/ton)] / [(105 lbs/cu ft)*(27 cu ft/cu yd)]
Thus, the sediment volume in this example is 160 cu yds

Trenouth and Gharabaghi (2015a) examined the benefits of event-based erosion loss estimates at construction sites. They reviewed several methods that have been used to disaggregate the annual loss estimates using individual rain factors (mainly energy). Monitored construction site erosion data were compared to the predicted event losses with good success. The general form of the event model they developed is:

$$A = 120 * EI_{30}^{0.25} * RO^{0.25} * Q_p^{0.5} * K * LS * C * P$$

where A = soil loss (kg ha-1),
EI_{30} = energy-intensity term for rainfall event (MJ mm ha^{-1} h^{-1}) for a 30-minute period,
RO = normalized event runoff volume from each (mm),
Q_p = normalized peak runoff rate for each event (L s ha^{-1}),
K = soil erosivity factor (T ha^{-1}), and
LS, C, P = as defined in the USLE.

The most accurate application of the model relied on artificial neural network calculations to calibrate the coefficients for many of the events for a specific site and then applied to the other events. The event-based calculations are expected to more accurately predict sediment losses by season and phased development (instead of just applying short-term R factors as used in the RUSLE), leading to better placement and designs of erosion and sediment control practices.

One of the reasons for developing this equation form was earlier reported research that indicated that sediment loss calculations can be improved by using a sediment delivery ratio (SDR). The SDR was found to vary greatly by watershed area but was not important (no delivery losses) when the drainage area was less than about 2.5 km^2 (1 mi^2) (SCS 1971; Atkinson 1995). Very few urban construction sites are that large, so SDR was not further investigated for use in these predictive equations.

Trenouth and Gharabaghi (2015b) further showed how this equation can be used to better describe the performance of erosion control practices during different construction phases. They also recognized that particle size distribution information of the eroded material is needed for more effective design of erosion controls.

Zhang, *et al.* (2015) found that sediment concentrations associated with erosion at steep embankment slopes associated with expressway construction were greatly influenced by gravitational erosion at critical flow rates. The statistical-based empirical models used in China that are based on the USLE were found to have limited success in soil loss predictions associated with these steep slopes. These problems were thought due to model conceptualization issues and arbitrary selection of model parameters. They concluded that the use of the USLE for construction sites needs further investigations due to the complicated and varied characteristics of soil erosion processes on construction sites, compared to the uniform conditions used to develop the USLE and RUSLE.

Zhang, *et al.* (2015) conducted pilot-scale tests on steep plots to simulate erosion mechanisms from typical steep spoil deposit slopes (60 to 100% slopes) that are common in China roadway construction. A test plot of 2.5 by 12 m was placed on a 73% slope for these tests. The hydraulic parameters investigated included the Reynolds Number, the Froude Number, Darcy-Weisbach roughness coefficient, shear stress, runoff kinetic energy, stream power, and unit energy of water carrying section. Figure 4-18 illustrates the successful relationships between shear stress (related to product of water depth and slope), and stream power (related to product of discharge rate and slope), with the soil detachment rate observed during these tests. The developed equations that use these observed relationships are unique for the test area soils and slopes, and while not universally applicable, they do indicate the importance of these factors on erosion rate calculations.

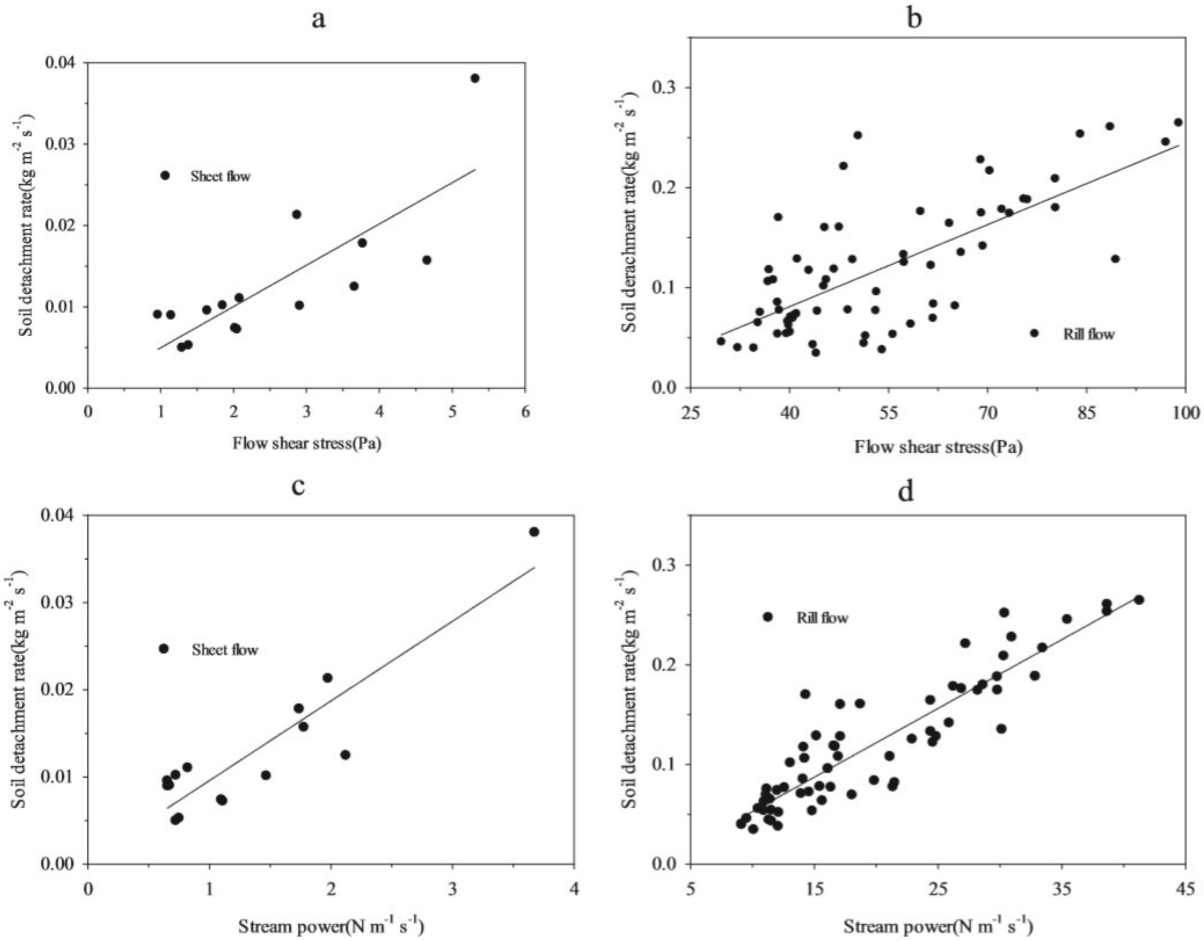


Figure 4-18. Relationships between shear stress or stream power with soil detachment rate for sheet and rill erosion (Zhang, *et al.* 2015).

Figure 4-19 is a plot showing shear stress effects on particle detachment and rill transport (initial motion) and suspension in sheet flows (Cheng and Chiew 1999 as discussed by Avila 2008). A much lower shear stress is need for detachment than for sustained transport of particles. This figure also indicates a rapid increase in required shear stress when particles are larger than about 400 µm in diameter.

Figure 4-19. Initial motion and suspension of particles (specific gravity of 2.5) in flowing water as a function of shear stress (Avila 2008).

Basic Predictions of Soil Losses from a Construction Site

Construction site evaluations have several dimensions: different construction phases lasting for different time periods, different soils on different locations and at different times reflecting cut and fill operations, changes in the gradients and lengths of slopes, and varying cover conditions. Therefore, in order to conduct a site evaluation, these different dimensions need to be clearly organized.

Construction Phases

The most basic dimension is understanding the construction phasing, beginning with site clearing and grubbing to final contouring. The basic time phases of interest for erosion evaluation and control may include the following activities on the site:

1. Install downslope sediment controls (silt fencing and sediment ponds)
2. Install upslope diversions and protect on-site channels that will remain (diversion berms and swales, channel lining, establish buffers, and silt fencing)
3. Clear and grub first area (minimize area used, then minimize area exposed and phase-completion time)
4. Do final contouring of first area (stabilize exposed areas before moving on to next area)

5. Repeat above 2 steps for all other areas, dividing the whole planned disturbed construction site into areas as small as possible
6. Establish roadways and parking areas and install utilities (leaving road bed base, or preliminary pavement, protect inlets, etc.)
7. Erect buildings (provide adequate storage for materials and for construction vehicle parking, practice good housekeeping, etc.)
8. Do final landscaping (remove temporary controls, replace with permanent stormwater facilities, irrigate vegetation until established)

Site Information

Site layouts and erosion control plans are needed for each major phase that alters the construction site contours and soil cover. Specifically, RUSLE should be applied for (1) the initial clearing and grubbing operation, (2) the site reflecting the final contouring, and (3) the final phases during roadway and utility construction and building erection. As indicated above, it is hoped that the site can be divided into smaller units where the clearing to final contouring operations can be completed as rapidly as possible, and temporary soil protection can then be applied before moving to the next area. Obviously, small areas or sites where massive grading is needed simultaneously over most of the site, will prevent this type of phasing. In these situations, the objective will be to complete the grading quickly, and, hopefully, to schedule it during periods when the erosion potential is reduced.

During each phase, the following site information will be needed to use RUSLE:

1. Expected start and finish dates, and corresponding "partial" R based on monthly rain variations
2. Surface soil K values
3. Various slopes and slope lengths over the site for calculating the LS factor
4. Type of mulch or vegetated cover

The LS factor may be the most confusing for a developing site. Basically, the site will need to be divided into separate sections for each slope, from the ridges to the toe of the slopes. The R factor will be uniformly applied to the whole site for each phase period, and the soil maps will help indicate the appropriate K factors. Therefore, RUSLE erosion yields will need to be computed for each separate slope, with the results summed to create a total-site erosion yield. The complete site will need to be represented, even for undisturbed areas (using natural cover conditions). However, the greater the area of the site that is never disturbed, the amounts of runoff and soil loss are reduced.

Example: Quantifying Site Erosion for Different Construction Phases

An example site is represented by the conditions shown in Tables 4-20 through 4-22. Once the conditions for each site area are fully described and a map prepared showing the site areas, the resulting factors can be determined, and calculated soil losses can be displayed in tables such as these. This type of analysis also has the advantage of highlighting areas responsible for most of the site erosion, possibly leading to further modifications in the erosion control plan.

The following example construction area in Birmingham, AL, is on a moderately-sloped site, with most slopes of 10 and 12%. About 22 of the 27 site acres will be graded, with about 5 acres left undisturbed. Approximately 18 acres will be used as parking, on-site roads, and commercial buildings, with about 4.5 acres used for relatively-steep embankments and road cuts.

Table 4-20 shows the erosion predictions for the first construction phase, the initial grubbing of existing vegetation. The erosion control plan calls for temporary mulching on the newly cleared land and limiting the active construction area to 5 acres. The 5 acres is being graded to the final site contours. When completed, that area will be stabilized with appropriate erosion controls and then another area will be graded. During this 3-month period, about 1,600 tons of sediment may be eroded from the site, the vast majority from the active area that has no preventative erosion control measures. Sediment control measures (as described later in Chapter 6) will be used to provide further reductions in sediment losses from the site.

The new site contours will result in milder slopes so the calculations for this phase likely represent worst case conditions. The next phase represents the end of the grading operations when more established controls are in place, but still there will be areas of active construction.

Table 4-20. Example RUSLE Calculations for Initial Grubbing Phase (same site contours as pre-development, but stripped cover and with temporary mulch)

Site areas	Area description	Land area (acres)	R for phase period (June 16 to Sept 15)[1]	K soil factor[2]	LS slope length factor	C cover factor[3]	Calculated unit area soil loss (tons/acre/period)	Calculated total area soil loss (tons/period)
A	Undisturbed area (L=50 ft; S=3%)	5.23	144	0.15	0.30	0.001	0.01	0.03
B	Future development, temp. mulch (L=350 ft; S=10%)	5.81	144	0.37	1.46	0.2	15.6	90
C	Future development, temp. mulch (L=600 ft; S=12%)	11.03	144	0.28	1.88	0.2	13.5	150
D	Future development, active construction (L=600 ft; S=12%)	5.0	144	0.28	6.67	1.0	269	1300
Total site		27.07						1600 tons over 3 months

[1] 41% of annual R; annual R is 350, so final project phase partial R is: (0.41)(350) = 144
[2] from county soil map and anticipated surface soils during this phase
[3] C factors based on native good cover for undisturbed areas, grubbing debris and 1 ton/ac of straw tacked on newly denuded areas having temporary berms to limit slope length to 100 ft., and nothing on active construction area (5 acres maximum is allowed to be under active construction at any time)

Table 4-21 represents site conditions at the end of the rough grading operations. All site contours are in place, and erosion controls have been newly established. There is still the last 5 acres of active construction that is unprotected, but it is at a much less severe slope. It is seen that once re-graded and properly protected, the site's sediment losses are significantly reduced. However, failure of erosion controls on any of the steep slopes could have important consequences.

Table 4-21. Example RUSLE Calculations for Rough Grading Phase (final site contours, but still working on final grades)

Site areas	Area description	Land area (acres)	R for phase period (Sept 16 to Feb 28)[1]	K soil factor[2]	LS slope length factor	C cover factor[3]	Calculated unit area soil loss (tons/acre/period)	Calculated total area soil loss (tons/period)
1a	Undisturbed area (L=50 ft; S=3%)	1.51	105	0.15	0.30	0.001	0.01	0.01
1b	Undisturbed area (L=100 ft; S=5%)	3.72	105	0.17	0.68	0.005	0.06	0. 2
2	Road cut (L=50 ft; S=25%)	0.54	105	0.28	2.67	0.02	1.6	0.9
3	Road cut (L=100 ft; S=25%)	1.37	105	0.37	4.59	0.02	3.6	4.9
4a	Main embankment (L=15 ft; S=10%)	0.84	105	0.28	0.40	0.55	6.5	5.4
4b	Main embankment (L=200 ft; S=16%)	0.33	105	0.37	4.56	0.17	30.1	9.9
4c	Main embankment (L=300 ft; S=10%)	1.15	105	0.17	3.09	0.07	3.9	4.4
5	Parking area (L=500 ft; S=0.2%)	5.5	105	0.28	0.06	0.02	0.03	0.2
5a	Parking area (L=500 ft; S=0.2%) Active construction	5	105	0.28	0.06	1	1.8	8.8
6	Building areas (L=250 ft; S=0.2%)	5.53	105	0.35	0.06	0.02	0.04	0.2
7a	Road segment (L=200 ft; S=3%)	0.26	105	0.17	0.57	0.02	0.2	0.1
7b	Road segment (L=400 ft; S=1%)	0.95	105	0.28	0.22	0.02	0.1	0.1
7c	Road segment (L=250 ft; S=0.5%)	0.37	105	0.28	0.10	0.02	0.1	0.02
Total site		27.07						35 tons over 5.5 months

[1] 30% of annual R; annual R is 350, so final project phase partial R is: (0.30)(350) = 105
[2] from county soil map and anticipated surface soils during this phase
[3] C factors based on native good cover for undisturbed areas, erosion control mats for road cuts, planted vegetation or tacked mulches on embankments, and gravel pads for parking, building, and road areas. The vegetation C factor was calculated based on plant growth stages during this construction phase.

Table 4-22 illustrates the same site for the final phase, when building finishing is occurring and all grading and final erosion controls are in place and well established. The calculated erosion rate for this site for this last construction phase is also quite low, being only about 2 tons per acre for this 5 month period. Obviously, this rate represents the established values with low C factors and assuming careful maintenance of the soil-protecting mulches.

Table 4-22. Example RUSLE Calculations for Final Grading Phase

Site areas	Area description	Land area (acres)	R for phase period (March 1 to July 31)[1]	K soil factor[2]	LS slope length factor	C cover factor[3]	Calculated unit area soil loss (tons/acre/period)	Calculated total area soil loss (tons/period)
1a	Undisturbed area (L=50 ft; S=3%)	1.51	196	0.15	0.30	0.001	0.01	0.01
1b	Undisturbed area (L=100 ft; S=5%)	3.72	196	0.17	0.68	0.005	0.11	0.4
2	Road cut (L=50 ft; S=25%)	0.54	196	0.28	2.67	0.02	2.93	1.6
3	Road cut (L=100 ft; S=25%)	1.37	196	0.37	4.59	0.02	6.66	9.1
4a	Main embankment (L=15 ft; S=10%)	0.84	196	0.28	0.40	0.55	12.07	10
4b	Main embankment (L=200 ft; S=16%)	0.33	196	0.37	4.56	0.17	56.22	19
4c	Main embankment (L=300 ft; S=10%)	1.15	196	0.17	3.09	0.07	7.21	8.3
5	Parking area (L=500 ft; S=0.2%)	10.5	196	0.28	0.06	0.02	0.07	0.7
6	Building areas (L=250 ft; S=0.2%)	5.53	196	0.35	0.06	0.02	0.08	0.5
7a	Road segment (L=200 ft; S=3%)	0.26	196	0.17	0.57	0.02	0.38	0.1
7b	Road segment (L=400 ft; S=1%)	0.95	196	0.28	0.22	0.02	0.24	0.2
7c	Road segment (L=250 ft; S=0.5%)	0.37	196	0.28	0.10	0.02	0.11	0.04
Total site		27.07						50 tons over 5 months

[1] 56% of annual R; annual R is 350, so final project phase partial R is: (0.56)(350) = 196
[2] from county soil map and anticipated surface soils during this phase
[3] C factors based on native good cover for undisturbed areas, erosion control mats for road cuts, planted vegetation or tacked mulches on embankments, and gravel pads for parking, building, and road areas. The vegetation C factor was calculated based on plant growth stages during this construction phase.

This is an example of a phase-specific erosion control plan that is possible using modern techniques. If these eroding soils are mostly clay loams, the total volume of sediment eroded from this site during the total construction period would be about 1,700 cubic yards, with almost all occurring during the initial grubbing and clearing operation and before the site is contoured to its final contours. This amount of material would be an important consideration when designing a sediment pond downstream of the eroding areas, as it would require about 2 or 3 feet of sacrificial volume in a well-functioning and properly-designed sediment pond (see Chapter 6). However, it is likely that excessive erosion associated with failure of the erosion control materials on the steeper slopes may occur. As an example, more than 50 tons per acre could be lost for every month that one of the 10% slopes was not controlled and the erosion control materials were in disrepair.

If this site had no erosion controls, an expected 3,900 tons of sediment could be eroded over the 13.5 months of construction. This is about 130 tons per acre per year, typical for locally-monitored construction sites. These erosion controls are expected to reduce these losses to about 1,600 tons, or a reduction of approximately 60%. Most of the sediment losses are expected to occur during the initial clearing and grubbing operations when the slopes have not been reduced. The percentage reductions of sediment losses during the final grading operations may be about 90%. Effective sediment controls, as described in Chapter 6, also will be needed for further reductions, especially for the grubbing operations, and in case of periodic slope-cover failures.

Evaluating Timing Options for Construction Operations

Timing of specific construction operations may have an important effect on the estimated soil erosion rate. As an example, the distribution of rainfall energy in Alabama indicates that for most of the state, June through September is the period having the highest erosion potential. These 4 months have about half of the total annual erosion-rainfall-related energy. October through February are usually the driest Alabama months, with only about 30% of the annual rainfall related energy occurring during these 5 months. Therefore, if possible, construction activities near sensitive waters could beneficially be scheduled during these drier months, though highly erosive rains may still occur during any period of the year.

Planning for vegetative covers also must consider the growing season and the need for supplemental irrigation. Table 4-18 showed how the C cover factors dramatically change for different growth stages. Obviously, plants that rapidly germinate, become established, and mature early, are important for erosion control. Mature crops with extensive canopies are also desired. Local NRCS and agricultural extension services can provide suitable lists of plants with these attributes for a local site. If using erosion control mats or sod, differences in cover C factors with time are not very large, and excellent control is available as soon as these are installed. This is especially important for channel linings. If relying on seeded plantings, several weeks to months may pass before the C factor reduces to less than 0.25 for sloped areas, and much more time is needed to establish a strong root system to withstand flowing waters. However, because of the high costs of erosion control mats, they are usually only used in the most critical areas, with less expensive mulches used over prepared seed beds whenever possible. Information presented in other chapters allow site hydrologic conditions and associated shear stresses to be calculated for specific site conditions, ensuring the most efficient use of the different cover products.

Comparing Different Slope Design Options

The information presented in Table 4-10 enables the erodibility of different slope conditions to be evaluated. In most cases, these conditions cannot be changed easily, as they were established for the most cost-effective development options. However, it is obvious that developments with very steep slopes are not preferred. Erosion on slopes greater than 15% can dominate the total erosion sediment amount from a construction site. Efforts should be made to terrace long and/or steep slopes, shortening the flow paths down their embankments. Chapter 5 will outline the procedures for evaluating specific erodibility and erosion-control solutions for slopes.

Terracing can be considered as a control option with relatively little effect on the use of the land. Long slopes can be divided into separate sections with great benefit. The terraces can be built as diversion swales to carry the accumulated water to a collection point. A reinforced drop chute then can be used to minimize the water flowing across downslope areas. Table 4-23 illustrates some options for modifying slopes with terracing. The slope angles will increase as slope length is decreased by the width of the terrace/diversion, which would somewhat offset the decrease in slope length, if no additional land was used for the slope. This table shows that significant reductions in expected erosion can occur with terracing, even with the slightly increased slopes. The largest benefits likely are associated with steeper initial slopes. Of course, almost all slopes will need to be stabilized with erosion control mats (likely required if steep), or at least tacked mulches (if less steep and relatively short). These slope protection calculations are presented in Chapter 5. They will show that terracing also decreases the cost of this needed slope protection.

Table 4-23. Alternative Slope Configurations and Corresponding Reductions in Erosion

Original Slope			Alternative Terrace 1 (1 mid-slope bench)				Alternative Terrace 2 (5 benches)			
Slope	Length	LS factor	New slope	Length (and terrace width)	Approx. new LS factor	Estimated erosion reduction	New slope	Length (and terrace width)	Approx. new LS factor	Estimated erosion reduction
0.5%	300 ft.	0.10	0.54%	150 (10) ft.	0.095	5%	0.56%	50 (5) ft.	0.09	10%
3.0	300	0.69	3.2	150 (10)	0.51	26	3.3	50 (5)	0.29	58
10	300	3.09	10.7	150 (10)	1.9	39	11.1	50 (5)	1.0	68
25	300	10.81	26.8	150 (10)	6.0	44	27.8	50 (5)	2.8	74
50	300	22.57	53.6	150 (10)	10.6	53	55.6	50 (5)	5.0	78

Sidebar*: Erosion and Construction Scheduling*

The following is excerpted from a homework assignment prepared by Heather Hill, a student at the University of Alabama at Birmingham, as part of the Construction Site Erosion and Sediment Control Class taken during the summer of 2005.

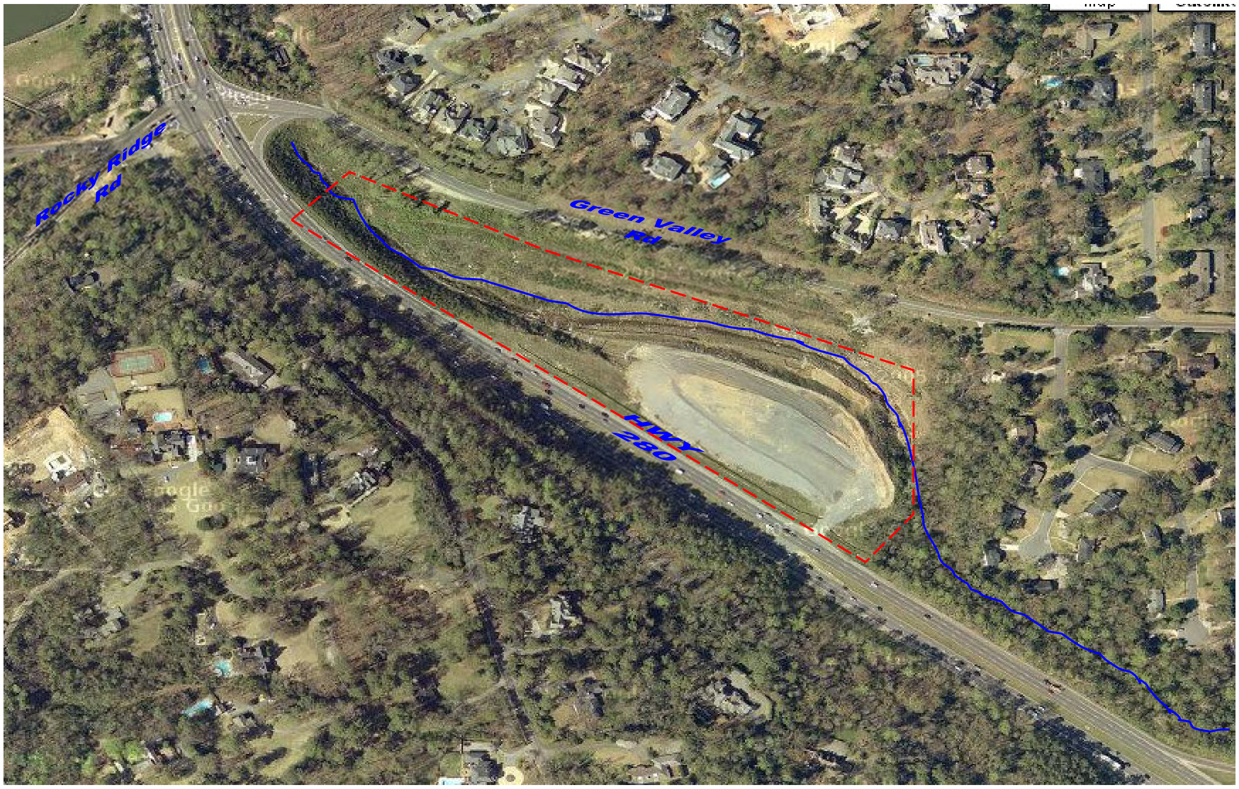
The soils on the site are silty clay and clayey sand according to the site project manager. The county soil survey described the soils as a silty loam. The northern portion of the site is a sandstone and shale ridge. The mound consisted of a variety of soils, rock, and debris.

The site was densely vegetated in areas along the creek and the ridge with underbrush and mature trees and weeds. The mound and the access road for the site had sparse vegetation and mainly weeds and little grass.

The assignment:

1. Describe the different construction phases for your site (initial grubbing and clearing, using pre-development contours; final grading contours during active construction activities, at least). Describe site soils and land cover. Describe the timing of the construction site erosion and sediment controls for your site.

The project site includes a large pile of previously excavated dirt placed on a 16-acre site near Birmingham, AL. The site contractor worked 6 days per week, 12 hours per day. The following is an aerial photograph of the site, showing the site boundaries and nearby roads.



The first phase of construction was to build a 15' diameter corrugated metal pipe to channel the flow of the tributary of Little Shades Creek that runs through the site. In order to do this, a series of pump systems had to be installed for water diversions. One pump was installed at the beginning of the creek to collect the water before entering the active area of the construction site. This was done by placing riprap in the creek bed and lining the upstream side with plastic. The water was then collected and pumped approximately 1000 feet downstream and released in a basin and allowed to settle before releasing into the original creek bed. The other pump was installed at the catchbasin that collects the site runoff water and then routes it to the holding pond. The water was then released into a set of baffles for sedimentation control in the pond and then released back to the creek.

A culvert pipe was also placed in the stream to allow access to the construction site on the other side of the creek. A road was cut from Green Valley Road to access the stream and install the pump. Another road was also cut around the side of the mound to access the area for the holding pond and a laydown area for the fabrication of the 15' diameter culvert. At the same time, Highway 280 was modified to create turn lanes for access to this new commercial area. Curbs were installed and then the road was paved and the median and the edge of the property were grassed and had excelsior blankets placed over them.

Construction phase II was started during this assignment period. This phase included the major site grading. The dirt pile was excavated and sieved to acquire good backfill for the site. The final site grading consisted of covering the 15' culvert with approximately 25' of backfill and taking the dirt pile down to near the original site grade (approximate elevation of 750'). The entire site was fairly flat and consisted mainly of parking lots, roads and buildings. Green Valley Road was rerouted to come down the center of the site and the prior Green Valley Road alignment become part of the commercial development.

Construction schedule for the site work was as follows:

Task	Start	Finish
Culvert Procurement	June 13, 2005	August 8, 2005
Culvert Preparation Work	June 27, 2005	July 25, 2005
Grading/Undercut for grocery store	July 5, 2005	October 17, 2005
Culvert Installation	July 26, 2005	September 19, 2005
Culvert Backfill	August 9, 2005	October 3, 2005
Grading North of Green Valley	November 1, 2005	November 21, 2005
Retail/Residential Grading	March 22, 2006	May 16, 2006
Parking Lot Construction	May 17, 2006	September 22, 2006

Silt fences were installed in some areas and excelsior blankets were placed on the flat seeded areas that were disrupted. The pumps were working and the holding basin collected water. Silt fences and berms were installed around the creek channel to divert water to the catchbasins. Approximately 6 acres of the site was undergoing active construction with silt fencing surrounding the area. Final plans for the site cover consisted of asphalt parking lots, landscaping and sod at the entrance and around the parking lot. ALDOT seed mix will be used on the cut/fill areas.

2. Apply RUSLE for each of the project phases.

Initial Grubbing, predevelopment contours

Site Areas	Area Description	Land Area (acres)	R for phase period (6/27-9/19)[1]	K soil factor[2]	LS slope length factor	C cover factor[3]	Calculated unit area soil loss (tons/acre/ period)	Calculated total area soil loss (tons/ period)
A	Undisturbed (L=120', S=25%)	9	143.5	0.1	5.1	0.003	0.22	2.0
B	Future Development Mulch /Straw (L=20', S=0.2%)	1	143.5	0.24	0.05	0.2	0.344	0.344
C	Active Construction Mound (L=70', S=28%)	4	143.5	0.15	3.67	1	79	316
D	Active Construction Roads (L=1000', S=3%)	2	143.5	0.15	1.23	1	26	53
Total Site		16						371 tons over 3 months

[1] 41% of Annual R, annual R is 350, so initial project phase partial R is (350)(0.41)=143.5

² from Jefferson County soils map and anticipated surface soils during this phase

³ C factors are based on native good cover for undisturbed areas, grubbing debris and 1 ton/ac of straw tacked on newly denuded areas, and no cover on active construction areas

Final Grading contours (after active construction, all land covered)

Site Areas	Area Description	Land Area (acres)	R for phase period (9/20-11/21)[1]	K soil factor[2]	LS slope length factor	C cover factor[3]	Calculated unit area soil loss (tons/acre/period)	Calculated total area soil loss (tons/period)
A1	Road (L=500', S=5%)	1.1	35	0.28	1.71	0.02	0.34	0.37
A2	Road (L=450', S=2%)	1.3	35	0.17	0.5	0.02	0.060	0.0775
B1	Parking Lot (L=300', S=2%)	3.7	35	0.15	0.43	0.02	0.045	0.17
B2	Parking Lot (L=150', S=2%)	3.1	35	0.28	0.33	0.02	0.065	0.20
C	Area to be Landscaped (L=75', S=10%)	1.3	35	0.28	1.2	0.2	2.4	3.1
D	Runoff Pond (L=25, S=30%)	0.5	35	0.15	1.86	0.2	2.0	0.98
E	Undisturbed Area (L=100', S=50%)	1	35	0.15	9.13	0.003	0.14	0.14
F1	Building 1 (L=120', S=0.2%)	1.8	35	0.28	0.05	0.02	0.0098	0.018
F2	Building 2 (L=350', S=0.2%)	1.7	35	0.28	0.06	0.02	0.012	0.020
G	Slopes (L=50', S=25%)	0.5	35	0.15	2.67	0.2	2.8	1.4
Total Site		16	35					6.4 tons over 2 months

¹ 10% of Annual R, annual R is 350, so final project phase partial R is (350)(0.1)=35

² from county soils map and anticipated surface soils during this phase

³ C factors are based on native good cover for undisturbed areas, gravel pads for roads, buildings, and parking lots, and mulch in areas and slopes to be landscaped and the runoff pond.

3. Select the appropriate temporary and permanent plants to be used for construction site erosion control at your site, and describe planting and mulching conditions, etc. Consider the likely dates for the plantings.

Temporary cover for the holding pond and the areas disrupted during the installation of the turn lanes were millet and ryegrass for this time of year. Millet is suggested for use in Central Alabama for April 1 to August 15 and ryegrass for September 1 to October 15. Most of the areas needed to be covered with straw or a temporary erosion control blanket. Most of the area seeded and mulched was flat with less than 2% grade. The holding basin area had about 30% slopes. Permanent plantings were mainly sod. The area for sod was relatively flat, with about a 3% slope. The site was ready for sodding in August and September and bermudagrass and fescue were appropriate. The entrance to the site was planted with ornamental trees and shrubs with perennial flowers that will be changed with the seasons.

Predicting the Benefits of Alternative Mulches

The USLE (and now the RUSLE) has long been used to estimate the benefits of different management systems on reducing erosion rates from construction sites. This has mostly been done by estimating C and P values for different control strategies. Mulches have been directly studied at many erosion test plots, enabling some basic C factors to be determined. These earlier measured C factors did not include the modern erosion control mats. Many of the mat producers have sponsored independent evaluations of C factors and tolerable shear stress conditions for their mats to enable the developer to select suitable selection of different materials. Chapter 6 will present this additional information.

Use and Selection of Vegetation at Construction Sites

As is obvious from the preceding discussions, erosion prevention at construction sites is critical. The following chapters will show that sediment control to remove particulates and other pollutants from the water flowing from a construction site is generally much costlier and less effective than preventing the erosion from occurring in the first place. The use of vegetation to protect disturbed areas soon after clearing and grading is one of the most important erosion preventive practices. The following information in this chapter presents additional information on “vegetation controls” that can be used to meet these local needs, mostly summarized from the *Alabama Handbook for Erosion Control, Sediment Control, and Stormwater Management on Construction Sites and Urban Areas* (ASWCC 2018) – an example of the type of guidance information usually available from regional construction site “handbooks.” These other guidance documents are usually available for other local areas and need to be used whenever available.

As stated in the *Alabama Handbook*, a dense, vigorous growing vegetative cover protects the soil surface from raindrop impacts, a major force in causing erosion losses. Also, vegetation will shield the soil surface from the scouring effects of overland flows and decrease the erosive capacity of the flowing water by reducing its velocity. The shielding effect of a plant canopy is augmented by roots and rhizomes that hold the soil together, improve its physical condition, and increase the rate of infiltration, further decreasing runoff. Plants also reduce the moisture content of the soil through transpiration, thus increasing its capacity to absorb water. Suitable vegetative cover therefore offers excellent erosion protection. It is also essential to the design and stabilization of many structural erosion control practices. Vegetative cover is relatively inexpensive to achieve and maintain. Also, it is often the only practical, long-term solution to stabilization and erosion control on many disturbed sites. Planning from the start for vegetative establishment reduces its cost, minimizes maintenance and repair, and makes structural erosion control measures more effective and less costly to maintain.

Plant selection should be considered early in the process of preparing the erosion and sedimentation control plan. A wide diversity of plant species can be grown in Alabama due to the variation in both soils and climate. However, for practical, economic stabilization and long-term protection of disturbed sites, plant selection should be made with care. Many plants are inappropriate for soil stabilization because they do not protect the soil effectively, or they cannot be established quickly and easily. Some plants may be very effective for soil stabilization but are not aesthetically acceptable on some sites. Some plants may even become troublesome pests.

Sidebar: The Story of Kudzu

Kudzu covering a pasture in Alabama.

Kudzu covering trees in Alabama.

Figure 4-20. Kudzu (rumored to have been imported into the US for land conservation purposes) can readily take over and kill the existing vegetation.

Excerpted from the "Amazing Story of Kudzu" (http://www.cptr.ua.edu/kudzu/):

> "In Georgia, the legend says
> That you must close your windows
> At night to keep it out of the house.
> The glass is tinged with green, even so...
>
> From the poem, *Kudzu*, by James Dickey

Kudzu was introduced to the United States in 1876 at the Centennial Exposition in Philadelphia, Pennsylvania. Countries were invited to build exhibits to celebrate the 100th birthday of the U.S. The Japanese government constructed a beautiful garden filled with plants from their country. The large leaves and sweet-smelling blooms of kudzu captured the imagination of American gardeners who used the plant for ornamental purposes.

Florida nursery operators Charles and Lillie Pleas discovered that animals would eat the plant and promoted its use for forage in the 1920s. Their Glen Arden Nursery in Chipley sold kudzu plants through the mail. A historical marker there proudly proclaims "Kudzu Developed Here." During the Great Depression of the 1930s, the Soil Conservation Service promoted kudzu for erosion control. Hundreds of young men were given work planting kudzu through the Civilian Conservation Corps.

Farmers were paid as much as eight dollars an acre as incentive to plant fields of the vines in the 1940s.

The problem is that it just grows too well! The climate of the Southeastern U.S. is perfect for kudzu. The vines grow as much as a foot per day during summer months, climbing trees, power poles, and anything else they contact. Under ideal conditions kudzu vines can grow sixty feet each year.

While they help prevent erosion, the vines can also destroy valuable forests by preventing trees from getting sunlight. This problem led Dr. James H. Miller of the U.S. Forest Service in Auburn, Alabama, to research methods for killing kudzu. In eighteen years of research, he has found that one herbicide actually makes kudzu grow better while many have little effect. Miller recommends repeated herbicide treatments for at least four years, but some kudzu plants may take as long as ten years to kill, even with the most effective herbicides."

Currently, kudzu covers about seven million acres of the south. The USDA declared it a weed in 1972.

Plant Hardiness Zones

The US Department of Agriculture has produced plant hardiness zone maps that are normally used to help determine the suitability of different plants for an area. These maps are based on the annual average low temperatures and are therefore most appropriate for permanent vegetation. Short-term vegetation use does not necessarily have to following the same selection guidelines needed for permanent vegetation. In all cases, it is important to contact the local NRCS office, or other erosion control specialists, for the most suitable vegetation to consider for a specific site. Figure 4-21 and Table 4-24 shows the current USDA hardiness zone map and the annual average minimum temperatures for selected cities.

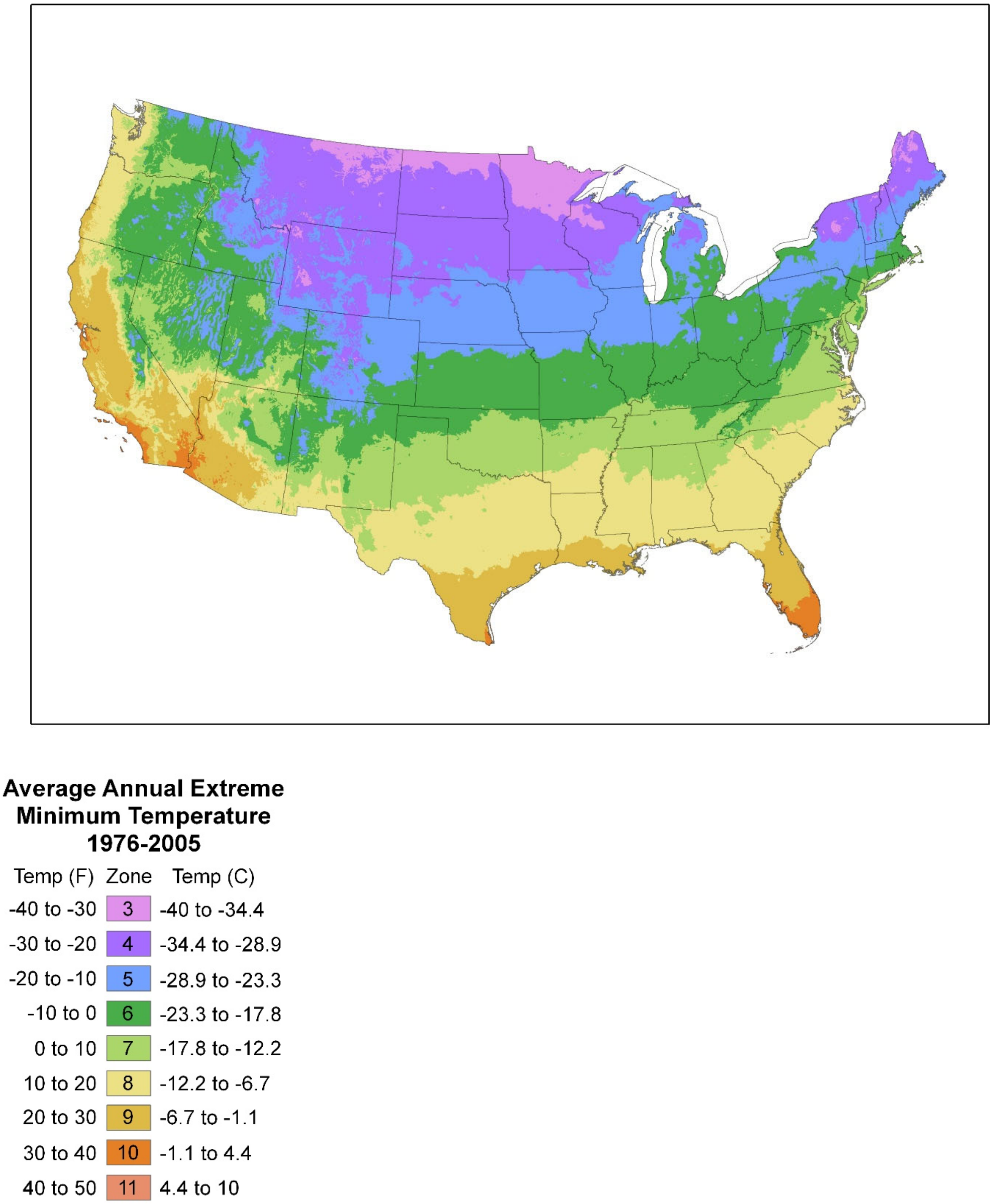


Figure 4–21. USDA Plant Hardiness Zone Map (https://planthardiness.ars.usda.gov/PHZMWeb/).

Table 4-24. Annual Average Minimum Temperatures for Selected Cities

Fahrenheit	Celsius	Example Cities
Below -50 F	Below -45.6 C	Fairbanks, Alaska; Resolute, Northwest Territories (Canada)
-50 to -45 F	-42.8 to -45.5 C	Prudhoe Bay, Alaska; Flin Flon, Manitoba (Canada)
-45 to -40 F	-40.0 to -42.7 C	Unalakleet, Alaska; Pinecreek, Minnesota
-40 to -35 F	-37.3 to -39.9 C	International Falls, Minnesota; St. Michael, Alaska
-35 to -30 F	-34.5 to -37.2 C	Tomahawk, Wisconsin; Sidney, Montana
-30 to -25 F	-31.7 to -34.4 C	Minneapolis/St.Paul, Minnesota; Lewistown, Montana
-25 to -20 F	-28.9 to -31.6 C	Northwood, Iowa; Nebraska
-20 to -15 F	-26.2 to -28.8 C	Des Moines, Iowa; Illinois
-15 to -10 F	-23.4 to -26.1 C	Columbia, Missouri; Mansfield, Pennsylvania
-10 to -5 F	-20.6 to -23.3 C	St. Louis, Missouri; Lebanon, Pennsylvania
-5 to 0 F	-17.8 to -20.5 C	McMinnville, Tennessee; Branson, Missouri
0 to 5 F	-15.0 to -17.7 C	Oklahoma City, Oklahoma; South Boston, Virginia
5 to 10 F	-12.3 to -14.9 C	Little Rock, Arkansas; Griffin, Georgia
10 to 15 F	-9.5 to -12.2 C	Tifton, Georgia; Dallas, Texas
15 to 20 F	-6.7 to -9.4 C	Austin, Texas; Gainesville, Florida
20 to 25 F	-3.9 to -6.6 C	Houston, Texas; St. Augustine, Florida
25 to 30 F	-1.2 to -3.8 C	Brownsville, Texas; Fort Pierce, Florida
30 to 35 F	1.6 to -1.1 C	Naples, Florida; Victorville, California
35 to 40 F	4.4 to 1.7 C	Miami, Florida; Coral Gables, Florida
above 40 F	above 4.5 C	Honolulu, Hawaii; Mazatlan, Mexico

It is possible to simplify this map into fewer zones for some vegetation types. As an example, the Patten Seed company simplified the map into five zones for the purpose of selecting permanent turf grasses. This was possible because these grasses are generally adaptable to a broader range of temperatures than other plants, such as flowers, shrubs and trees. The following lists their recommendations for turf grasses in each of these consolidated areas. Not all of these turf grasses are suitable for erosion control applications, but this list does illustrate a simplified approach:

> **"Area 1** - This area includes lower coastal North Carolina, coastal South Carolina, coastal and south Georgia, all of Florida, and lower and coastal sections of Alabama, Mississippi, Louisiana, and Texas. This area should use the Hot Climate Grasses which include Bermuda, Bahia, Centipede, Carpet, St. Augustine, and Zoysia.
>
> **Area 2** - This zone is north of Area 1 and includes north coastal North Carolina, much of central South Carolina, central Georgia, north and central Alabama, northern Louisiana, south west Tennessee, all except the most northern part of Arkansas, most of central Texas, and the southern portion of Oklahoma. This area should use a limited set of the Hot Climate Grasses including Bermuda, Centipede, and Zoysia.
>
> **Area 3** - This area covers much of the middle U.S. including parts of New Jersey, Maryland, Delaware, Virginia, western North Carolina, western Tennessee, western Kentucky, southern Indiana, southern Illinois, southern Missouri, southern Kansas, northern Oklahoma, northern Texas, most of New Mexico, southern Arizona, and most of coastal California. This area should use Cool Season Grasses including Tifway Bermuda, Meyer Zoysia, and Zenith Zoysia.
>
> **Area 4** - This area covers a band of the upper central U.S., including parts of Rhode Island and Connecticut, a small portion of southern New York, northern New Jersey, eastern Pennsylvania, eastern West Virginia, northern Virginia, east Tennessee, central Kentucky, most western Ohio, northern Indiana, southern Michigan, northern Illinois, southern Iowa, northern Missouri, southern Nebraska, northern Kansas, central Colorado, northwest New Mexico, northern Arizona, southeast

Utah, the southern tip of Nevada, much of central California, coastal Oregon, and south coastal Washington. This zone should use Cool Season Grasses including Meyer Zoysia, and Zenith Zoysia.

Area 5 - This area covers the upper U.S., north of Area 4 and should use Cool Season Grasses."

Cebeco International Seeds provides an example of seed selection guidance for erosion control. This information is specifically for the Pacific Northwest, but many of these grass types are used in other areas of the country. The following is a description of introduced grass species commonly used for erosion-control seed mixtures, excerpted from a summary paper by Craig Edminster of Cebeco International Seeds. The following excerpt from this paper illustrates the importance of proper seed selection and the assistance of an expert:

"Ryegrass has been used extensively as a short-lived component in erosion control mixtures. Their key attribute in erosion control is rapid seedling establishment, tolerance to slightly acidic soils and excellent spring, and fall forage growth when rainfall is abundant in the Pacific Northwest. In addition, they serve as an excellent nurse crop in low input plantings. Ryegrass is intolerant of droughty, nutrient-deficient soils, and therefore may senescence and die during the early establishment period, which provides an excellent growing environment for long lived, grass species. *Lolium perenne* (Perennial ryegrass) tetraploid and diploid sources are commonly used in erosion control plantings, the diploid being more tolerant of grazing pressure (mowing) and more persistent than the larger leafed, more robust and less cold tolerant tetraploid. The use of very late maturing diploid perennials, such as Elka and Essence®, has been recommended to reduce reseeding potential and enhance long lived species establishment.

Annual ryegrass (*Lolium multiflorum*) is the most commonly used cool-season grass in conservation and erosion control in the Pacific Northwest. Annual ryegrass has the best seedling vigor and lowest cost per pound of all the cool season grass species. At low planting rates it can provide good to fair nurse or companion crop attributes. At extremely high seeding rates it can provide living mulch attributes. Annual ryegrass has excellent reseeding capability and seeds can remain dormant in soil for up to five years. Therefore, its use is often discouraged where mixed-species longevity is desired. Westerwold ryegrass, and genetic mixtures containing high percentages of Westerwold germplasm, are readily available in the Pacific Northwest (cv Gulf, Oregon Common). Westerwold ryegrass requires a very short floral induction period for plant vernalization and results in reseeding potential. Under these circumstances, annual ryegrass can become a weedy grass in erosion-control mixtures. True Italian ryegrass cultivars (cv Sultan, Total), developed in Europe, that require significantly more floral induction to induce seed production should be considered as an alternative if annual ryegrass is used.

There are six species of fine fescue recognized for their use in turf and forage production systems in the Pacific Northwest. They include, but are not limited to, chewings fescue *F. rubra* L. subsp. *commutata*, hard fescue *F. longifolia*, and sheeps or blue fescue *F. ovina*; and the rhizomatous type: slender creeping red fescue *F. rubra* L. subsp. *tricholphylla* and strong creeping red fescue *Festuca rubra* L. subsp. *rubra*. Strong creeping red fescue has been used extensively in conservation and erosion control mixtures primarily because of excellent seedling vigor, tolerance to acidic soils, good shade tolerance (understory), and rhizomatous growth habit. Strong creeping red fescue requires very little supplemental fertilization once established, and grows well on shallow- and rocky-cut bank riparian and upland sites. Strong creeping red fescue is a moderately tall plant species and is highly compatible with many other tall and short serial species of introduced grass.

Timothy (*Phleum pratense*) has been used as a minor component in mixtures for wetland, bottomland and stream bank restoration where imperfect soil drainage may be a limiting factor. It is poorly adapted for erosion control mixtures because of its lack of seedling vigor. Therefore, mixtures containing rapid establishing species as a nurse crop are advised. Timothy is also intolerant of drought soils so its establishment on well-drained, sloped areas in riparian and upland sites is not recommended.

Orchardgrass (*Dactylis glomerata*) is a bunchgrass that has been used extensively in erosion control mixtures in West Coast Mountain Region. It has good seedling vigor, early spring forage growth, but requires well drained soil sites to persist. It is tolerant of mild soil acidity, and moderately shade tolerant, but requires supplemental fertilizer for proper growth. Orchardgrass cultivars are segregated into different maturity groups (early, medium and late) for their relative feed value when used in legume-based forage production systems. Early-maturing short-statured varieties such as Paiute, Palestine are often recommended because they enter dormancy during the summer when soil moisture is depleted in the Pacific Northwest. Upon dehydration in the fall, they regrow and persist.

Tall fescue (*Festuca arundinacea*) has been used on occasions in conservation and erosion control with mixed results. Tall fescue has poor seedling vigor, but exhibits good shade tolerance. Once established, it is a very dominate forage producer and may require aggressive management to constrain growth (mowing, burning). Tall fescue is tolerant of acidic, poorly-drained, shallow-soil sites, but prefers well-drained sandy loam soil sites. In contrast to other cool-season grasses, tall fescue may not enter into summer-induced dormancy or rest period. Its deep, extensive root system facilitates deep soil-profile water uptake during the summer, and tall fescue can dominate a riparian, upland or wetland site.

Kentucky bluegrass (*Poa pratensis*) has been used to a limited extent in the Pacific Northwest. Its most redeeming characteristic is the presence of rhizomes, which provides good soil and plant interface to reduce soil erosion potential. Its most limiting factors are that it has the poorest seedling vigor of all cool-season grasses and is intolerant of slightly acidic to acidic soils. To persist, it must be established in soils with excellent internal drainage. It also requires moderate to high soil nutrition and does best in a diurnal environment where summers are hot and winters cold.

Creeping bentgrass (*Agrostis palustris*), "the golf course greens grass," has been used to a very limited extent for erosion control in the Pacific Northwest. Bentgrass is very tolerant of acidic, poorly drained soils and exhibits fair to poor seedling vigor. If hydrated throughout the season, it can dominate a planting site because of its short, aggressive stoloniferous growth habit. It is therefore incompatible in grass seed mixtures. Established stands of creeping bentgrass will require burning or very short mowing to enhance persistence.

Highland bentgrass (*Agrostis castellana*) is very tolerant of acidic, poorly-drained, or shallow-soil sites and exhibits good to fair seedling vigor. It also exhibits better summer drought tolerance than creeping bentgrass. Highland bentgrass has larger, more robust stolons than creeping bentgrass, and provides more forage for grazing animals and wildlife. Similar to creeping bentgrass, it can dominate a planting site because of its aggressive stoloniferous growth habit and is therefore considered incompatible in grass seed mixtures.

Little colonial bentgrass (*Agrostis tenuis*) has been used in conservation and erosion control projects in the Pacific Northwest. This is more the result of short seed supplies than a lack of its adaptation in conservation program. Colonial bentgrass is the only Agrostis species that is compatible in mixture with other cool-season grass species. This short, acid-tolerant, fine-leaved species has short prolific stolons that grow more upright than prostate. It exhibits excellent drought tolerance, requires only modest soil fertility and has good to fair seedling germination."

Selecting the Right Grasses and/or Legumes

The Alabama Handbook (ASWCC 2018) states that single-species plantings are desired in some cases, but most of the time a mixture is more desirable. Mixtures can be selected that may provide protective cover more quickly and can be more enduring than a single species. Mixtures need not be elaborate. The addition of a quick-growing annual or short-lived perennial provides early protection and facilitates establishment of a slower-growing and longer-living perennial. It is important to evaluate the merits and weakness of each species in selecting the mixtures for the specific site to be treated. The addition of a companion or "nurse" crop (quick-growing annual or weak perennial added to permanent mixtures) is a good practice on difficult sites, when late seeding, or in situations where the development of permanent cover is likely to be slow. The companion crop germinates and grows rapidly, holding the soil until the perennial species becomes established. Seeding rate of the companion crop must be limited to avoid crowding, especially under optimum growing conditions.

Detailed information on plant species adapted for soil stabilization use in Alabama is contained in the following discussions and from the Internet sources listed at the end of this chapter. Most of these commercial suppliers of seeds and sod will help select the most appropriate species for local site conditions. Local USDA Agricultural Extension offices may also be able to provide updated guidance. Using this information makes plant selection more straightforward for most situations. Specific seeding rates and planting instructions are presented in specifications for local conditions. They often are provided by regulatory agencies. For example, state Departments of Transportation will often provide seed specifications for both permanent and temporary seeding for different growing conditions which are obviously tailored for the states geographic region and soil conditions.

Temporary Seeding

Annual plants grow rapidly, mature, and die in one growing season. They are useful for quick, temporary cover or as a companion crop for slower growing perennials. Rye (cereal) is usually superior to other small grains (wheat, oats, or barley) for temporary cover. It has more cold hardiness than other annuals and will germinate and grow at lower temperatures. It will provide more fall and early winter growth and matures earlier than other small grains. Rye germinates quickly and is tolerant of poor soils. Including rye in fall-seeded perennial mixtures is particularly helpful on difficult soils and erodible slopes or when seeding is late. However, seeding rates of rye should be limited to the suggested rates because a thick stand will suppress the growth of the desired perennial seedlings. No more than 60 lb/acre should be planted when rye is used as a companion crop. Rye does grow fairly tall in the spring which may be undesirable. If this is a problem, some of the shorter growing varieties of wheat may be used. Annual ryegrass is not recommended for use as a companion crop in perennial mixtures in Alabama. It is highly competitive and, if included in mixtures, crowds out most other species before it matures in late spring or early summer, leaving little or no lasting cover. It will provide dense cover rapidly, so it can be effective as a temporary seeding, but if allowed to mature, the seed volunteers and can seriously interfere with subsequent efforts to establish permanent cover.

Millets (Browntop, Foxtail) are warm-season annuals, useful for temporary seeding or as a nurse crop. Browntop millet has early rapid growth, growing two to three feet in height. It is adapted to fine and medium textured soils of moderate productivity. Foxtail is a fine stemmed plant growing to a height of four to five feet. The leaves are broad and flat. Foxtail millets do best under fairly abundant moisture conditions. German millet is a type of foxtail millet.

Sudangrass and sorghum-sudangrass hybrids, like the millets, are warm-season annuals which are useful for temporary vegetation. They are better adapted to medium- to heavy-textured soils. The small-stemmed, shorter-growing varieties are more satisfactory for temporary vegetation than the tall coarse-stemmed varieties.

Annual oats and winter wheat are often specified in cold regions of the U.S. for temporary seeding. Oats are specified for spring and summer plantings and winter wheat or rye for fall plantings (starting after September 1) by the Wisconsin Department of Transportation. Seeding rates need to be reduced compared to permanent seeding to prevent shading which promotes weed growth.

Annual lespedeza is a warm-season, reseeding annual legume growing to a height of six to twelve inches. It is tolerant of low fertility and is adapted to the climate and most soils throughout Alabama. It is not adapted to alkaline soils of the Black Belt or to deep sands. It is a good companion crop for spring-planted sericea lespedeza, filling in weak or spotty stands the first season without suppressing the sericea. Annual lespedeza can heal damaged areas in the perennial cover for several years after initial establishment. Two species of annual lespedeza are grown in Alabama. “Common” annual lespedeza volunteers in many parts of Alabama and is sold under the variety name Kobe. Korean lespedeza is a slightly larger, coarser and earlier-maturing plant sold under several variety names. Kobe is superior on sandy soils and generally preferable in south Alabama. Korean is better in north Alabama as the seeds mature earlier. The preferred seeding dates for annual lespedeza are in the late winter to early spring. It can be mixed with fall seeding, in which case some seeds remain dormant over the winter and germinate the following spring.

Permanent Seeding

Perennial plants, once established, will live for more than one year. They may die back during a dormant period, but will grow back from their underground tubers or rhizomes in succeeding years. Stands of perennials will persist for a number of years under proper management and environmental conditions. They are the principal components of permanent vegetative covers. Cool-season perennials produce most of their growth during the spring and fall and are more cold-hardy than most warm-season species.

Tall fescue is the only cool-season perennial grass recommended for vegetating disturbed soils in Alabama. Tall fescue, a cool-season grass, is the most widely-used species in north Alabama for erosion control. It is well adapted to all of north Alabama and all but the most droughty soils of central Alabama. Also it can be grown on the Black Belt soils of south Alabama. It thrives in full sun to partial shade and is fairly easy to establish. It will provide stabilization the year of establishment. Because tall fescue has a bunch-growth habit, it is slow to fill in areas with poor stands. Therefore, some maintenance will be required on washed-out areas or areas of spotty stands to prevent further damage. A number of new varieties of tall fescue are becoming available for lawn and other turf use and several offer definite improvements. However, their higher cost over the standard, Kentucky 31, is seldom justified solely for purposes of stabilization and erosion control. Also, fescue seed infected with a fungal endophyte are preferred since endophyte-infected plants are more hardy, resulting in longer-lasting stands. Tall fescue is a fall-planted grass. Liberal fertilization and proper liming are also essential for prompt establishment, but once established, it can tolerate minimal maintenance almost indefinitely. White clover is sometimes planted with tall fescue.

Warm-season perennials initiate growth later in the spring than cool-season species and experience their greatest growth during the hot summer months. Most species of warm-season perennials do better in the southern one-half of Alabama, but there are species or varieties that will grow in north Alabama. The following grasses have proven the most useful for soil stabilization:

- Bahiagrass is a warm-season perennial grass particularly well adapted for growing on sandy soils in the southern half of Alabama. It will tolerate acid and low fertility soils, grow in full sun to light shade, and persist almost indefinitely with little or no maintenance after it is established. However, bahiagrass seedlings are small and lack the vigor some species of warm-season grasses possess; it usually takes two years to establish a good sod. Bahiagrass is established with seed. Bahiagrass does produce a fairly dense sod suitable for low maintenance areas. It has a high resistance to wear and recovers fairly fast from wear. It produces rhizomes and will fill in small bare spots fairly fast. Bahiagrass will produce seedheads about one to two feet in height throughout the growing season and, where this is not a problem, it is probably the best choice for stabilizing soil in the southern one half of the state. Pensacola is the better variety of bahiagrass for soil stabilization. It is more tolerant to upland sites and is more cold tolerant than Argentine bahiagrass.

- Common Bermudagrass is a long-lived perennial that spreads by creeping stolons and rhizomes outward several feet in a growing season. It will survive extreme heat and drought. It is not shade tolerant. Bermudagrass is best adapted to well-drained fertile soils. It does poorly on extremely droughty sandy soils and will not grow on poorly-drained soils. It responds well to fertilizer and will establish a dense sod quickly from seed. Common bermudagrass will grow in all areas of the state. Bermudagrass requires more maintenance than bahiagrass and, if a regular maintenance fertility program is not used, it will tend to slowly decline. It has a high resistance to wear and a fast recovery from wear which makes it a good choice for heavy use areas.

There are two types of bermudagrass which are important in soil stabilization. Common bermudagrass, which can be established with seeds or sprigs, and turf-type bermudagrasses which must be established from vegetative material. Common bermudagrass has longer internodes and larger leaves than the turf-type hybrid bermudagrass. When common bermudagrass will be used for permanent vegetation, only seeds that are 98% pure common bermudagrass should be planted. Common bermudagrass seeds are often contaminated with giant-type bermudagrass seeds. Giant-type bermudagrass is very competitive and fast growing, but is not cold hardy in Alabama. When common bermudagrass seed contains even a small percent of giant type bermudagrass seed, they will be choked out by the giant-type bermudagrass. Since the giant-type bermudagrass is killed by the cold, a good sod the year of establishment becomes destroyed the second year.

The turf-type hybrid bermudagrasses have fine leaves and short internodes which make them desirable for lawn, golf courses and other areas where a quality turf is desired. However, turf-type hybrid bermudagrasses are costlier to establish because they must be planted from sprigs, plugs, or solid sodded. Tifway 419 is the most commonly used turf-type hybrid bermudagrass. The agronomic varieties of hybrid bermudagrasses do not lend themselves to soil stabilization of construction areas. They too must be established with vegetative material which makes them costly to establish.

Sericea lespedeza or sericea is a deep-rooted, drought-resistant perennial legume, adapted to all but the poorly drained and deep sandy soils of the state. It is long lived, tolerant of low fertility soils, pest free, and will fix nitrogen. It can be a valuable component in most low-maintenance mixtures. Sericea is slow to establish and will not contribute much to prevention of erosion the first year; however, once established it persists indefinitely on suitable sites. Plantings that include sericea require mulch and should include a companion crop such as browntop millet, annual lespedeza, or common bermudagrass. Sericea should be planted as early as possible within the planting date range so as to reduce as much weed competition as possible. Also, sericea may be planted in the late fall and winter months because many of the seeds will lie dormant until germination the following spring. Sericea does not tolerate frequent mowing and may be considered unsightly because the old top growth breaks down slowly.

Crownvetch is a deep rooted, perennial legume adapted only to north exposures in the northern tier of counties in Alabama. However, it has been removed from the Wisconsin seed specifications as it is an invasive species and out-competes many other species, especially native plants. It is useful on steep slopes and rocky areas that are likely to be left unmoved. It can be seeded in the spring or fall. Crownvetch requires a specific inoculant.

Summary: Selection of Erosion Control Grasses

This section is excerpted from material prepared by Jason Kirby (2003) as part of his MSCE thesis investigating the hydraulics of grass swales while at the Department of Civil and Environmental Engineering, the University of Alabama. All grasses are not the same for erosion control as they vary in their ability to protect and survive in a given environment. Ryegrass is moderately dark green with good density (measured by the number of blades of grass per square inch) and a fine texture. This species is known to establish quickly and produce a stable/hearty turf. In addition to its low maintenance requirements, ryegrass has good tolerance to sun, shade, drought, temperature, and wear. Bluegrass displays a dark green color with dense uniform coverage. Bluegrass requires moderate maintenance (watering, mowing, etc.) and is less tolerant of changes in temperature, shade and drought than rye grass. Bluegrass can withstand more abuse (foot traffic, wear) than other similar grasses. Finally, Fescue has deep green blades and is known for its rapid germination and establishment. Fescue is quite tolerant to changes in temperature, wear, shade, and drought. Fescue can be maintained with limited effort. However, all of these above listed grasses are considered cool-season grasses and have limited application in the Southeast.

Bermuda, Centipede, and Zoysia share characteristics similar to the above listed grass, but are better suited to the hotter conditions in the Southeast. Commercial grass suppliers (S&S seeds, for example, at www.ssseeds.com) will recommend grass types/blends based on site location and other characteristics (slope, watering, etc.). These recommendations will identify the appropriate species and the suggested method of application, such as by seed or sod.

The decision to use seed or sod to establish a specified grass type is a crucial one. While most grasses can be established either way, the initial costs and characteristics can be significantly different. The following table is a general comparison between seeding and sodding.

	Seeding	Sod
Planting Season	Fall, and perhaps Spring	Anytime
Water Requirements	Very High for Germination/Establishment	Low to moderate (6" initially then regularly for next 4 to 6 weeks)
Soil Preparation	Tillage, fertilization, etc.	Same as for seeding
Weed control	Requires Herbicide	Minimal, if any
Uniformity	Varies based on weeds, washouts, etc.	99-100%
Usability (Traffic)	None for 2 months, then limited up to 6 months	Normal to high within 2 weeks
Erosion Control	None until established, rain will necessitate repair	Good control after installation once established. Excellent steeper slope stability when grown in permanent erosion control mats.
Cost	\$0.01 to \$0.04 per ft^2	\$7 to 10 per yd^2 (cost estimates from recent WI erosion control bids)

Sod, as a rule of thumb, cost about 20 times more than seeding to install; however, this cost is usually offset by sod's ability to be planted year-round (in the southeast, at least), uniform establishment, and instant erosion protection. Sod is available throughout the country from various national and local sod farms. These farms carry numerous species with varying levels of quality. Rapid establishment in grass-lined drainage channels is a great benefit of sod over seeding, although the use of reinforcing turf mats (described in Chapter 5) enables the use of seed in channels with immediate benefit. In fact, the combination of reinforcing turf mats and grass seed may be superior to sod in a channel (but more expensive).

High quality sod is expensive (up to \$10 per yd^2) but will contain fewer weeds and have a better appearance. Lower quality sods have more weeds/pests but save money and will still establish a good ground cover. Laying sod can cost up to \$30,000 an acre, so while it has enhanced erosion control properties, it needs to be used as a permanent control or, if temporary, on a small scale to be cost effective.

Seeding an area is much less expensive than using sod (\$250 an acre) and can provide adequate erosion protection, given time. Germination can take up to a month, and up to six months may be needed for grass establishment, depending on the grass type and planting conditions. Until full grass development, constant maintenance (watering, replanting, etc.) will be required. In addition to seeding a site for grass creation, annual species can be used to supplement established grasses that may go seasonally dormant. The extra attention seeding requires may make sod a more attractive option, depending on the site. The decision, in effect, comes down to a decision between excellent initial erosion protection at high cost, or low initial cost with less immediate erosion control.

Sod sizing will depend on the farm and grass type selected. Sod pieces can range from 1 ft x 2 ft (residential) to 8 ft x 32 ft (commercial applications, especially for golf courses). Staples may be required to anchor the sod into place until the root system is established.

Once grass has been established (seed or sod), its physical characteristics become indistinguishable (sod will have better erosion resistance initially, but once the seeds develop, the differences are minimal). Typically, grass can withstand a maximum permissible velocity of around 5 ft/s with an absolute maximum of 8 ft/s. The following table (USDA 1954) lists the permissible velocities for several grasses:

Cover	Slope Range	Erosion Resistant Soils maximum permissible velocity (ft/s)	Easily Eroded Soils maximum permissible velocity (ft/s)
Bermudagrass	0-5	8	6
	5.-10	7	5
	over 10	6	4
Kentucky Bluegrass	0-5	7	5
	5.-10	6	4
	over 10	5	3
Grass Mixture (Rye, Fescue)	0-5	5	4
	5.-10	4	3
Crabgrass	0-5	3.5	2.5
Common Lespedeza	0-5	3.5	2.5

USDA. *Handbook of Channel Design for Soil and Water Conservation*. Technical Paper TP-61. 1954.

Temporary Vegetation - Seeding

Figure 4-22. Temporary seeding used to stabilize freeway lanes after initial grading before final roadbed construction.

The following sidebar is from the Alabama Handbook (ASWCC 2018) and describes guidance for temporary vegetation. Guidance such as this is usually presented in regional erosion control handbooks and reflect local conditions. As always, it is important to review the selections of planting methods and materials with the local NRCS office and construction site review agency.

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Sidebar: ***"Temporary Seeding (TP)***

Practice Description

Temporary seeding is the establishment of fast-growing annual vegetation from seed on disturbed areas. Temporary vegetation provides economical erosion control for up to a year and reduces the amount of sediment moving off the site.

This practice applies where short-lived vegetation can be established before final grading or in a season not suitable for planting the desired permanent species. It helps prevent costly maintenance operations on other practices such as sediment basins and sediment barriers. In addition, it reduces problems of mud and dust production from bare soil surfaces during construction. Temporary or permanent seeding is necessary to protect earthen structures such as dikes, diversions, grass-lined channels and the banks and dams of sediment basins.

Planning Considerations

Temporary vegetative cover can provide significant short-term erosion and sediment reduction before establishing perennial vegetation.

Temporary vegetation will reduce the amount of maintenance associated with sediment basins. Temporary vegetation is used to provide cover for no more than 1 year. Permanent vegetation should be established at the proper planting time for permanent vegetative cover.

Certain plants species used for temporary vegetation will produce large quantities of residue which can provide mulch for establishment of the permanent vegetation.

Proper seedbed preparation and selection of appropriate species are important with this practice. Failure to follow establishment guidelines and recommendations carefully may result in an inadequate or short-lived stand of vegetation that will not control erosion.

The selection of plants for temporary vegetation must be site specific. Factors that should be considered are type of soils, climate, establishment rate, and management requirements of the vegetation. Other factors that may be important are wear, mowing tolerance, and salt tolerance of vegetation.

Seeding properly carried out within the optimum dates has a higher probability of success. It is also possible to have satisfactory establishment when seeding outside these dates. However, as plantings are deviated from the optimum dates, the probability of failure increases rapidly. Seeding dates should be taken into account in scheduling land-disturbing activities.

Site quality impacts both short-term and long-term plant success. Sites that have compacted soils should be modified whenever practical to improve the potential for plant growth.

The operation of equipment is restricted on slopes steeper than 3:1, severely limiting the quality of the seedbed that can be prepared. Provisions for establishment of vegetation on steep slopes can be made during final grading. In construction of fill slopes, for example, the last 4-6" might not be compacted. A loose, rough seedbed with irregularities that hold seeds and fertilizer is essential for hydroseeding. Cut slopes should be roughened (see practice Land Grading).

Good mulching practices are critical to protect against erosion on steep slopes. When using straw, anchor with netting or asphalt. On slopes steeper than 2:1, either hydraulic mulch or erosion control blanket is more appropriate than straw to protect the slope.

The use of irrigation (temporary or permanent) will greatly improve the success of vegetation establishment.

Design Criteria

Plant Selection

Select plants that can be expected to meet planting objectives. To simplify plant selection, use Table 4-25, Commonly Used Plants for Temporary Cover and Figure 4-23, Geographical Areas for Species Adaptation and Seeding Dates. Seeding mixtures commonly specified by the Alabama Department of Transportation are an appropriate alternative for plantings on rights-of-ways.

Figure 4-23. Geographical Areas for Species Adaptation and Seeding Dates

Note: Site conditions related to soils and aspect in counties adjacent to or close to county boundaries may justify adjustments in planting dates by qualified design professionals.

Table 4-25. Commonly Used Plants for Temporary Cover

Species	Seeding Rate/AC PLS	North	Central	South
Seeding Dates				
Millet, Browntop or German	40 lbs	Apr1-Aug 1	Apr1- Aug 15	Apr 1-Aug 15
Rye	3 bu	Sep l-Nov 15	Sep 15-Nov 15	Sep 15-Nov 15
Ryegrass	30 lbs	Aug l-Sep 15	Sep l-Oct 15	Sep 1-Oct 15
Sorghum-Sudan Hybrids	40 lbs	May l-Aug 1	Apr 15-Aug 1	Apr l-Aug 15
Sudangrass	40 lbs	May l-Aug l	Apr 15-Aug	Apr l-Aug 15
Wheat	3 bu	Sep l-Nov 1	Sep 15-Nov 15	Sep 15-Nov 15
Common Bermudagrass	10 lbs	Apr 1-July 1	Mar 15-July 15	Mar 1-July 15
Crimson Clover	10lbs	Sept 1-Nov 1	Sept 1-Nov 1	Sept 1-Nov 1

Site Preparation and Soil Amendments

Complete grading and shaping before applying soil amendments if needed to provide a surface on which equipment can safely and efficiently be used to apply soil amendments and accomplish seedbed preparation and seeding.

Lime

Apply lime according to soil test recommendations. If a soil test is not available, use 1 ton of agricultural limestone or equivalent per acre on coarse textured soils and 2 tons per acre on fine textured soils. Do not apply lime to alkaline soils or to areas which have been limed during the preceding 2 years. Other liming materials that may be selected should be provided in amounts that provide equal value to the criteria listed for agricultural lime or be used in combination with agricultural limestone or Selma chalk to provide equivalent values to agricultural limestone.

Fertilizer

Apply fertilizer according to soil test results. If a soil test is not available, apply 8-24-24 fertilizer. When vegetation has emerged to a stand and is growing, 30 to 40 lbs/acre (approximately 0.8 lbs/1000 ft^2) of additional nitrogen fertilizer should be applied.

Note: Fertilizer can be blended to meet exact fertilizer recommendations. Take soil test recommendations to local fertilizer dealer for bulk fertilizer blends. This may be more economical than bagged fertilizer.

Application of Soil Amendments

Incorporate lime and fertilizer into the top 6” of soil during seedbed preparation.

Seedbed Preparation

Good seedbed preparation is essential to successful plant establishment. A good seedbed is well pulverized, loose, and smooth. If soils become compacted during grading, loosen them to a depth of 6” to 8” using a ripper or chisel plow.

If rainfall has caused the surface to become sealed or crusted, loosen it just prior to seeding by disking, raking, harrowing, or other suitable methods. When hydroseeding methods are used, the surface should be left with a more irregular surface of clods.

Planting Methods

Seeding

Evenly apply seed using a cyclone seeder (broadcast), drill seeder, cultipacker seeder, or hydroseeder. Broadcast seeding and hydroseeding are appropriate for steep slopes where equipment cannot operate safely. Small grains should be planted no more than 1" deep, and grasses and legumes no more than ½" deep. Seed that are broadcast must be covered by raking or chain dragging, and then lightly firmed with a roller or cultipacker.

Hydroseeding

Surface roughening is particularly important when hydroseeding, as a roughened slope will provide some natural coverage for lime, fertilizer, and seed. The surface should not be compacted or smooth. Fine seedbed preparation is not necessary for hydroseeding operations; large clods, stones, and irregularities provide cavities in which seeds can lodge.

Mix seed, inoculant if required, and a seed carrier with water and apply as slurry uniformly over the area to be treated. The seed carrier should be a cellulose fiber, natural wood fiber or other approved fiber mulch material which is dyed an appropriate color to facilitate uniform application of seed. Use the correct legume inoculant at 4 times the recommended rate when adding inoculant to hydroseeder slurry. The mixture should be applied within one hour after mixing to reduce damage to seed.

Fertilizer should not be mixed with the seed-inoculant mixture because fertilizer salts may damage seed and reduce germination and seedling vigor. Fertilizer may be applied with a hydro seeder as a separate operation after seedlings are established.

Mulching

The use of appropriate mulch provides instant cover and helps ensure establishment of vegetative cover under normal conditions and is essential to seeding success under harsh site conditions (see the Mulching practice for guidance). Harsh site conditions include the following: slopes steeper than 3:1 and adverse soils (soils that are shallow to rock, rocky, or high in clay or sand). Areas with concentrated flow should be treated differently and require a practice appropriate for channel flow."

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Permanent Seeding

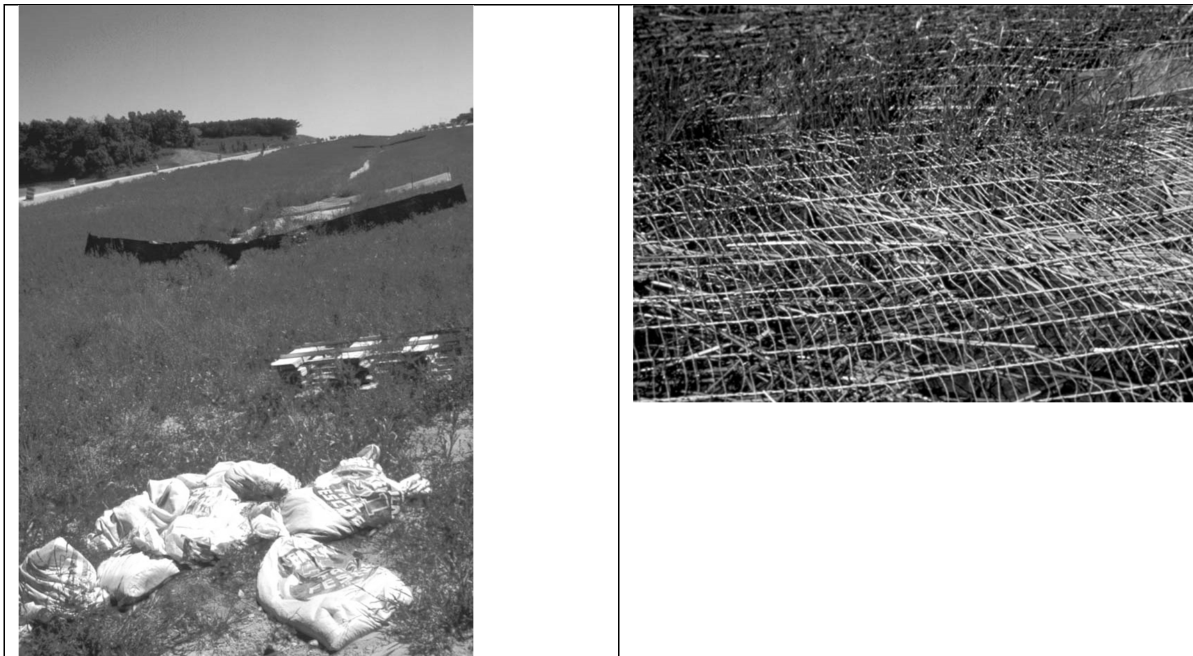

Figure 4-24. Permanent seeding along freeway

The following sidebar is from the Alabama Handbook (ASWCC 2018) and describes seedbed preparation and planting guidance for permanent vegetation. Similar guidance may be found in other regional erosion control handbooks.

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Sidebar: "Permanent Seeding (PS)

Practice Description

Permanent seeding is the establishment of perennial vegetation on disturbed areas from seed. Permanent vegetation provides economical long-term erosion control and helps prevent sediment from leaving the site. This practice is used when vegetation is desired and appropriate to permanently stabilize the soil.

Planning Considerations

The advantages of seeding over other means of establishing plants include the smaller initial cost, lower labor input, and greater flexibility of method.

Disadvantages of seeding include potential for erosion during the establishment stage, seasonal limitations on suitable seeding dates, and weather-related problems such as droughts.

The probability of successful plant establishment can be maximized through good planning. The selection of plants for permanent vegetation must be site specific. Factors that should be considered are type of soils, climate, establishment rate, and management requirements of the vegetation. Other factors that may be important are wear, mowing tolerance, and salt tolerance of vegetation.

Plant selection for permanent vegetation should be based on plant characteristics, site and soil conditions, time of year of planting, method of planting, and the intended use of the vegetated area. Climate factors can vary widely in Alabama.

Plant selection may include companion plants to provide quick cover on difficult sites, late seedings, or where the desired permanent cover may be slow to establish. Annuals are usually used for companion plants and should be selected carefully to prevent using a species that provide so much competition that it prevents the establishment of the desired species.

Seeding properly carried out within the optimum dates has a higher probability of success. It is also possible to have satisfactory establishment when seeding outside these dates. However, as plantings are deviated from the optimum dates, the probability of failure increases rapidly. Seeding dates should be taken into account in scheduling land-disturbing activities.

Site quality impacts both short-term and long-term plant success. Sites that have compacted soils, soils that are shallow to rock or have textures that are too clayey or too sandy should be modified whenever practical to improve the potential for plant growth and long-term cover success.

The operation of equipment is restricted on slopes steeper than 3:1, severely limiting the quality of the seedbed that can be prepared. Provisions for establishment of vegetation on steep slopes can be made during final grading. In construction of fill slopes, for example, the last 4-6" might not be compacted. A loose, rough seedbed with irregularities that hold seeds and lime and fertilizer is essential for hydroseeding. Cut slopes should be roughened (see Land Grading practice).

Proper mulching is critical to protect against erosion on steep slopes. When using straw, anchor with netting or asphalt. On slopes steeper than 2:1, jute, excelsior, or synthetic matting may be required.

The use of irrigation (temporary or permanent) will greatly improve the success of vegetation establishment.

Design Criteria

Plant Selection

Select plants that can be expected to meet planting objectives. To simplify plant selection, use the map showing the geographical areas for species adaptation and seeding dates and Table 4-26, Commonly Used Plants for Permanent Cover. Mixtures commonly specified by the Alabama Department of Transportation are an appropriate alternative for plantings on rights-of-ways.

The plants used for temporary vegetation may be used for companion plants provided the seeding rate of the annual species is reduced by one half. See the Temporary Seeding practice for additional information on establishing temporary vegetation. Ryegrass or other highly competitive plants should not be used as a companion plant with a permanent seeding.

Table 4-26. Commonly Used Plants for Permanent Cover with Seeding

Rates and Dates Species	Seeding Rates/Ac	North Seeding Dates	Central Seeding Dates	South Seeding Dates
Bahiagrass, Pensacola	40 lbs	--	Mar 1-July 1	Feb 1-Nov 1
Bermudagrass, Common	10 lbs	Apr 1-July 1	Mar 15-July 15	Mar 1-July 15
Bahiagrass, Pensacola Bermudagrass, Common	30 lbs 5 lbs	--	Mar 1-July 1	Mar 1-July 15
Bermudagrass, Hybrid (Lawn Types)	Solid Sod	Anytime	Anytime	Anytime
Bermudagrass, Hybrid (Lawn Types)	Sprigs 1/sq ft	Mar 1-Aug 1	Mar 1-Aug 1	Feb 15-Sep 1
Fescue, Tall	40-50 lbs	Sep 1-Nov 1	Sep 1-Nov 1	--
Sericea	40-60 lbs	Mar 15-July 15	Mar 1-July 15	Feb 15-July 15
Sericea & Common Bermudagrass	40lbs 10 lbs	Mar 15-July 15	Mar 1-July 15	Feb 15-July 15
Switchgrass, Alamo	4 Lbs	Apr 1-Jun 15	Mar 15-Jun 15	Mar 15-Jun15

Seedbed Requirements

Establishment of vegetation should not be attempted on sites that are unsuitable due to compaction or inappropriate soil texture, poor drainage, concentrated overland flow, or steepness of slope until measures have been completed to correct these problems. To maintain a good stand of vegetation, the soil must meet certain minimum requirements as a growth medium. A good growth medium should have these attributes:

• Sufficient pore space to permit root penetration.

• Enough fine-grained soil material (silt and clay) to maintain adequate moisture and nutrient supply.

• Sufficient depth of soil to provide an adequate root zone. The depth to rock or impermeable layers such as hardpans should be 12” or more, except on slopes steeper than 2:1 where topsoiling is not feasible.

• A favorable pH range for plant growth, usually 6.0-6.5.

• Sufficient nutrients (nitrogen, phosphorus and potassium) for initial plant establishment.

• Freedom from large roots, branches, stones, or large clods. Clods and stones may be left on slopes steeper than 3:1 if they are to be hydroseeded.

If any of the above attributes are not met: i.e., if the existing soil is too dense, coarse, shallow or acidic to foster vegetation – chiseling, topsoil, or special amendments should be used to improve soil conditions. The soil conditioners described below may be beneficial or topsoil may be applied. These amendments should only be necessary where soils have limitations that make them poor for plant growth or for turf establishment.

• Peat-appropriate types are sphagnum moss peat, reed-sedge peat, or peat humus, all from fresh-water sources. Peat should be shredded and conditioned in storage piles for at least 6 months after excavation.

• Sand-should be clean and free of toxic materials.

• Vermiculite-use horticultural grade.

• Rotted manure-use stable or cattle manure not containing undue amounts of straw or other bedding materials.

• Thoroughly rotted sawdust-should be free of stones and debris. Add 6 lbs of nitrogen to each cubic yard.

Soil Amendments
Liming Materials
Lime (Agricultural limestone) should have a neutralizing value of not less than 90 percent calcium carbonate equivalent and 90 percent will pass through a 10-mesh sieve and 50 percent will pass through a 60-mesh sieve.

Selma chalk should have a neutralizing value of not less than 80 percent calcium carbonate equivalent and 90 percent will pass through a 10-mesh sieve.

Other liming materials that may be selected should be provided in amounts that provide equal value to the criteria listed for agricultural lime or be used in combination with agricultural limestone or Selma chalk to provide equivalent values to agricultural limestone.

Plant Nutrients
Commercial grade fertilizers that comply with current Alabama Fertilizer Laws should be used to supply nutrients required to establish vegetation.

Lime and fertilizer needs should be determined by soil tests. Soil testing is performed by the Auburn University Soil Testing Laboratory and provides recommendations based on field tests on Alabama soils. The local county Cooperative Extension Service can provide information on obtaining soil tests. Commercial laboratories that make recommendations based on soil analysis may be used.

When soil tests are not available, use the following rates for application of soil amendments:

- Sandy soils: Use 1 ton/acre (exception on sandy soils – if the cover will be tall fescue and clover use 2 tons/acre).
- Clayey soils: 2 tons/acre.
- Do not apply lime to alkaline soils.
- Grasses alone: Use 400 lbs/acre of 8-24-24 or the equivalent. Apply 30 lbs of additional nitrogen when grass has emerged and begun growth (approximately 0.8lbs/1000 ft^2).
- Grass-legume mixtures: Use 800 to 1200 lbs/acre of 5-10-10 or the equivalent.
- Legumes Alone: Use 400 to 600 lbs/acre of 0-20-20 or the equivalent.

Note: Fertilizer can be blended to meet exact fertilizer recommendations. Take soil test recommendations to local fertilizer dealer for bulk fertilizer blends. This may be more economical than bagged fertilizer.

Application of Soil Amendments
Apply lime and fertilizer evenly and incorporate into the top 6" of soil by disking, chiseling or other suitable means during seedbed preparation. Operate machinery on the contour. On sites too steep for seedbed preparation, fertilizer and lime can be applied with a hydroseeder.

Seedbed Preparation
If needed, grade and shape to provide a surface on which equipment can safely and efficiently be used for seedbed preparation and seeding.

Install necessary sediment control practices before seedbed preparation and complete grading according to the approved plan.

Prepare a friable seedbed with tillage to a depth of at least 6". Break up large clods, alleviate compaction, and smooth and firm the soil into a uniform surface. Fill in or level depressions that can collect water.

Planting Methods
Seeding
Use certified seed for permanent seeding whenever possible. Certified seed is inspected by the Alabama Crop Improvement Association to meet high quality standards and will be tagged with a "Certified Seed" tag. (Note: all seed sold in Alabama is required by law to be tagged to identify seed purity, germination, and presence of weed seeds. Seed must meet state standards for content of noxious weeds.)

Seeding dates are determined using Figure TS-1 and Table PS-1 (refer to the guidance manual for the most up to date values).

Inoculate legume seed with the Rhizobium bacteria appropriate to the species of legume.

Plant seed uniformly with a cyclone seeder, a drill seeder, a cultipacker seeder, or by hand on a fresh, firm, friable seedbed. If the seedbed has been sealed by rainfall, it should be disked so the seed will be sown into a freshly prepared seedbed.

When using broadcast-seeding methods, subdivide the area into workable sections and determine the amount of seed needed for each section. Apply one-half the seed while moving back and forth across the area, making a uniform pattern; then apply the second half in the same way, but moving at right angles to the first pass.

Cover broadcast seed by raking or chain dragging; then firm the surface with a roller or cultipacker to provide good seed contact. Small grains should be planted no more than 1” deep and grasses and legume seed no more than ½” deep.

Hydroseeding
Surface roughening is particularly important when hydroseeding, as a roughened slope will provide some natural coverage for lime, fertilizer, and seed. The surface should not be compacted or smooth. Fine seedbed preparation is not necessary for hydroseeding operations; large clods, stones, and irregularities provide cavities in which seeds can lodge. Mix seed, inoculant if required, and a seed carrier with water and apply as a slurry uniformly over the area to be treated. The seed carrier should be a cellulose fiber, natural wood fiber or other approved fiber mulch material which is dyed an appropriate color to facilitate uniform application of seed. Use the correct legume inoculant at 4 times the recommended rate when adding inoculant to a hydroseeder slurry. The mixture should be applied within one hour after mixing to reduce damage to seed.

Fertilizer should not be mixed with the seed-inoculant mixture because fertilizer salts may damage seed and reduce germination and seedling vigor.

Fertilizer may be applied with a hydroseeder as a separate operation after seedlings are established.

Lime is not normally applied with a hydraulic seeder because it is abrasive but if necessary it can be added to the seed slurry and applied at seeding or it may be applied with the fertilizer mixture. Also, lime can be blown onto steeper slopes in dry form.

Sprigging
Hybrid bermudagrass cannot be grown from seed and must be planted vegetatively. Vegetative methods of establishing common and hybrid bermudagrass, centipedegrass and zoysia include sodding, plugging and sprigging (see Sodding practice).

When sprigs are planted with a sprigging machine, furrows should be 4-6” deep and 2 feet apart. Place sprigs no farther than 2 feet apart in the row and so that at least one rooting node is in the furrow.

When broadcasting is used for sprig planting, broadcast sprigs at the specified rate (Table PS-1 in guidance manual). Press into the top ½” to 2” of soil with a cultipacker or with a disk set nearly straight so that the sprigs are not brought back to the surface. A mulch tacking machine may be used to press sprigs into the soil.

Mulching
The use of mulch provides instant cover and helps ensure establishment of vegetation under normal conditions and is essential to seeding success under harsh site conditions (see Mulching

practice). Harsh site conditions include: slopes steeper than 3:1 and adverse soils (shallow, rocky, or high in clay or sand). Areas with concentrated flow should be treated differently and require sod, a hydromulch formulated for channels or an appropriate erosion control blanket.

Irrigation
Moisture is essential for seed germination and vegetation establishment. Supplemental irrigation can be very helpful in assuring adequate stands in dry seasons or to speed development of full cover. It is a requirement for establishment of vegetation from sod and sprigs and should be used elsewhere when feasible. However, irrigation is rarely critical for low-maintenance vegetation planted at the appropriate time of the year.

Water application rates must be carefully controlled to prevent runoff. Inadequate or excessive amounts of water can be more harmful than no supplemental water.

Maintenance
Generally, a stand of vegetation cannot be determined to be fully established until soil cover has been maintained for 1 full year from planting. Inspect vegetated areas for failure and make necessary repairs and vegetate as soon as possible.

If a stand has inadequate cover, reevaluate choice of plant materials and quantities of lime and fertilizer. Re-establish the stand after seedbed preparation or over-seed the stand. Consider a temporary seeding if the time of year is not appropriate for establishment of permanent vegetation (see Temporary Seeding practice).

If vegetation fails to grow, a soil test should be made to determine if soil acidity or nutrient imbalance is responsible.

To attain complete establishment, fertilization is usually required in the second growing season. Turf grasses require annual maintenance fertilization. Use soil tests if possible or follow the guidelines given for the specific seeding mixtures.

Protect vegetation during its establishing period from traffic that will be harmful. If appropriate, use either temporary fences or barriers to protect areas that may be damaged by excessive traffic.”

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Sodding


Figure 4-25. Sodding, or other reinforcement, is usually needed along concentrated flow pathways

The following sidebar is from the Alabama Handbook (ASWCC 2018) and is similar to sodding guidance for temporary vegetation that is usually presented in regional erosion control handbooks.

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Sidebar: "Sodding (SOD)

Practice Description

Sodding is the use of a transplanted vegetative cover to provide immediate erosion control in disturbed areas. Sodding is well suited for stabilizing erodible areas such as grass-lined channels, slopes around storm drain inlets and outlets, diversions, swales, and slopes and filter strips that cannot be established by seed or that need immediate cover.

Planning Considerations

Advantages of sod include immediate erosion control, nearly year-round establishment capability, less chance of failure than with seeding, and rapid stabilization of surfaces for traffic areas, channel linings, or critical areas.

Initially it is more costly to install sod than to plant seed; however, the higher cost may be justified for specific situations where sod performs better than a seeded cover. Sodding may be more cost-efficient in the long term.
Sod can be laid during the times of the year when seeded grasses may fail, provided there is adequate water available for irrigation in the early establishment period. Irrigation is essential, at all times of the year, to ensure establishment of sod.

Sod placed around drop inlets can prevent erosion around the inlet and help maintain the necessary grade around the inlet.

The site to be sodded should be prepared for the sod before it is delivered so that the sod can be installed immediately. Leaving sod stacked or rolled can cause severe damage and loss of plant material.

Failure to remove compaction and to address pH and soil fertility deficiencies will likely cause a sodded stand to perform poorly or fail.

Design Criteria

Sod Selection

The species of sod selected should be adapted to both the site and the intended purpose. Species used in Alabama include bermuda, zoysia, centipede, St. Augustine, tall fescue, and bahiagrass. Tall fescue and bahiagrass are not readily available but can be obtained from some growers. Species selection is primarily determined by region, availability, and intended use. Use Table 4-27 and Figure TP-1 for guidance in selecting sod (see guidance manual for updated map).

Table 4-27. Grasses Adapted for Sodding in Alabama **Warm Season Grasses**

Species	Variety [1]	Area Adapted
Bermudagrass	Tifway, TifSport, Celebration, TifGrand, Common	North, Central, South
Bahiagrass	Pensacola	Central, South
Centipede	Common, TifBlair	Central, South
St. Augustine	Common, and a few commercial varieties	South
Zoysia	Any selection available in Alabama, Zenith is seeded	Central, South
Cool Season Grasses		
Tall Fescue	Kentucky 31, Rebel (turf type)	North

[1] Listing of a variety is not an endorsement of a Company product. New and better varieties may become available over time.

Surface Preparation

Prior to laying sod, clear the soil surface of trash, debris, roots, branches, stones, and clods larger than 2” in diameter. Fill or level low spots to avoid standing water. Rake or harrow the site to achieve a smooth and mowable final grade. Apply appropriate soil amendments prior to final disking. Complete soil preparation by disking, chiseling or other appropriate means and then rolling or cultipacking to firm the soil. Limit the use of heavy equipment on the area to be sodded, particularly when the soil is wet, as this may cause excessive compaction and make it difficult for the sod to penetrate the soil and develop the root system that it should attain.

Soil Amendments

Test soil to determine the requirements for lime and fertilizer. Soil tests may be conducted by Auburn University Soil Testing Laboratory or other laboratories that make recommendations based on soil analysis. When soil test recommendations are unavailable, the following soil amendments may be sufficient:

• Agricultural limestone at a rate of 2 tons per acre (90 lbs per 1000 sq. ft.). Other liming materials that may be selected should be provided in amounts that provide equal value to agricultural lime.

• Fertilizer at a rate of 1,000 lbs per acre (25 lbs per 1000 sq. ft.) of 10-10-10.

• Equivalent nutrients may be applied with other fertilizer formulations. The soil amendments should be spread evenly over the treatment area and incorporated into the top 6" of soil by disking, chiseling or other effective, means. Minor surface smoothing may be necessary after incorporation of soil amendments.

Installing the Sod
A step-by-step procedure for installing sod is described below. Moistening the sod after it is unrolled helps maintain its viability. Store it in the shade during installation.

Rake the soil surface to break the crust just before laying sod. During the summer, lightly irrigate the soil, immediately before laying the sod to cool the soil and reduce root burning and dieback. Do not lay sod on gravel, frozen soils, or soils that have been recently sterilized or treated with herbicides.

Lay the first row of sod in a straight line with subsequent rows placed parallel to and butting tightly against each other. Stagger strips in a brick-like pattern (see Figure 4-26). Be sure that the sod is not stretched or overlapped and that all joints are butted tightly to prevent voids. Use a knife or sharp spade to trim and fit irregularly shaped areas.

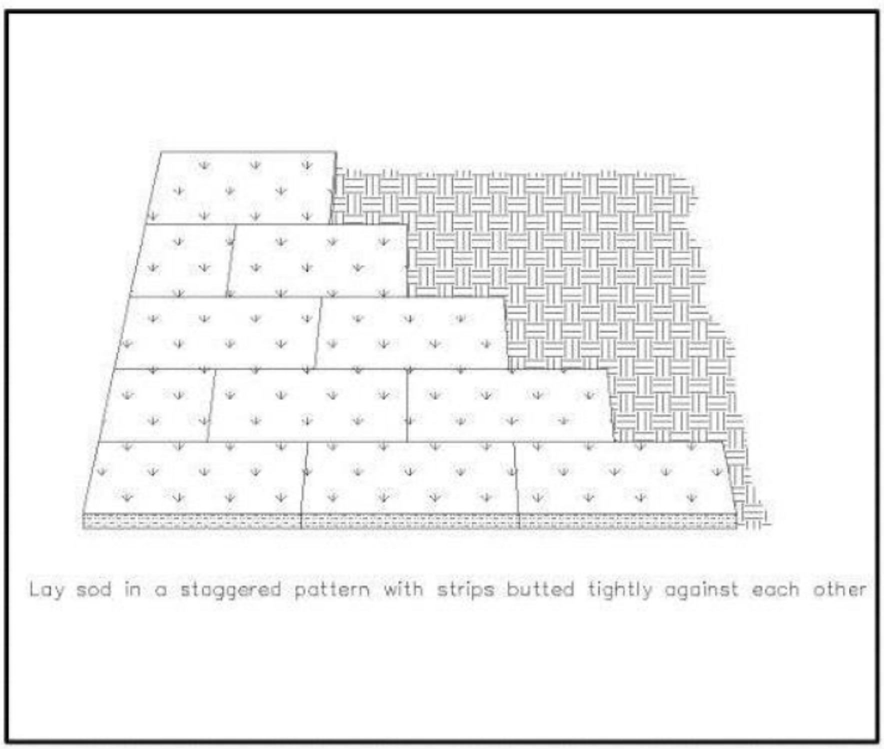

Figure 4-26. Typical Installation of Grass Sod

Install strips of sod with their longest dimension perpendicular to the slope. On slopes 3:1 or greater, in grass swales or wherever erosion may be a problem, secure sod with pegs or staples.

Jute or other netting material may be pegged over the sod for extra protection on critical areas (see Figure 4-27).

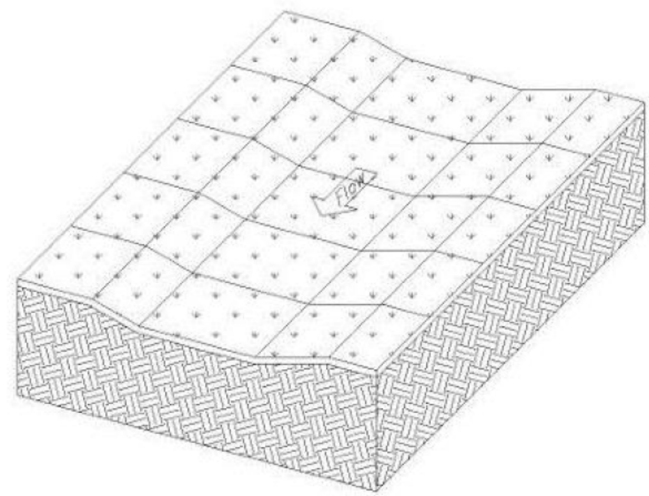

Figure 4-27. Installation of Sod in Areas with Channel Flows

As sodding of clearly defined areas is completed, use a weighted roller on the sod to provide firm contact between roots and soil.

After rolling, irrigate until the soil is wet at least 6” below the sod.

Keep sodded areas moist to a depth of 4” until the grass takes root. This can be determined by gently tugging on the sod. Resistance indicates that rooting has occurred.

Mowing should not be attempted until the sod is firmly rooted, usually in 2 to 3 weeks.”

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Mulching

 Heavy mulch at a median grass swale area	
 Hydroseeding, with mulch (SCS photo)	 Temporary hydroseeding for erosion control (SCS photo)
 Newly established grass needs frequent watering	 Straw mulch application showing fair coverage

 Straw mulch applied over previously eroded ground	 Thin straw mulch application showing poor coverage
 Hydroseeded material, with mulch and tackifier to hold in place	 Straw mulch windblown from adjacent area

Figure 4-28. Mulching at construction sites.

As noted in the preceding guidance on temporary and permanent planting, the soil on a disturbed site must be modified to provide an optimum environment for germination and growth of the plants. Addition of topsoil, soil amendments, and tillage are used to prepare a good seedbed. At planting, the soil must be loose enough for water infiltration and root penetration, but firm enough to retain moisture for seedling growth. Tillage generally involves disking, harrowing, chiseling, or some similar method of land preparation. Tillage should be done on the contour where feasible to reduce runoff and erosion. Lime and fertilizer should be incorporated during the tillage. The following sidebar is from the Alabama Handbook (ASWCC 2018) and discusses mulching of bare soil and seedbeds to protect the material from damage during erosive rains. Chapter 6 presents tools with extensive examples to assist in the selection of appropriate slope protection measures, including mulches. Site preparation guidance and mulching discussions for vegetation usually is presented in regional erosion control handbooks.

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Sidebar "Mulching (MU)

Practice Description

Mulching is the application of plant residues such as straw or other suitable fibrous materials to the soil surface. Mulch protects the soil surface from the erosive force of raindrop impact and reduces the velocity of overland flow. It helps seedlings germinate and grow by conserving moisture, protecting against temperature extremes and controlling weeds. Mulch also maintains the infiltration capacity of the soil. Mulch can be applied to seeded areas to help establish plant cover. It can also be used in unseeded areas to protect against erosion over the winter or until final grading and shaping can be accomplished except in areas with concentrated flow.

Planning Considerations

Surface mulch is the most effective, practical means of controlling runoff and erosion on disturbed land prior to vegetation establishment. Mulch absorbs the energy associated with raindrops and thereby minimizes soil particle detachment, which is the initiation step of erosion.

Mulch also reduces soil moisture loss by evaporation, prevents crusting and sealing of the soil surface, moderates soil temperatures, and provides a suitable microclimate for seed germination.

Organic mulches such as straw, wood chips and shredded bark have been found to be very effective mulch materials. Materials containing weed and grass seeds which may compete with establishing vegetation should not be used. Also, decomposition of some wood products can tie up significant amounts of soil nitrogen, making it necessary to modify fertilization rates or add fertilizer with the mulch.

Hydraulic Erosion Control Products (HECPs) as defined by the Erosion Control Technology Council (ECTC) can also be used as effective mulch applications. HECPs are designated as 5 different types based on product characteristics and performance. Information from the ECTC table dated April 2014 is provided as Table 4-28. To ensure that you use the most valid information refer to the latest HECP specifications provided by the ECTC or the manufacturer's recommendation. The Alabama Department of Transportation (ALDOT) characterizes mulches based on performance levels identified in Sections 656 and 659 of their Standard Specifications for Highway Construction.

The choice of materials for mulching should be based on soil conditions, season, type of vegetation to establish, and size of the area. Properly applied and tacked mulch is always beneficial. Mulching is especially important when conditions of germination are not optimum, such as midsummer and early winter, and on difficult sites such as cut slopes, fill slopes and droughty soils.

Straw has traditionally been the most commonly used mulching material in conjunction with seeding. Wheat straw is the most commonly used straw, and can be spread by hand or with a mulch blower. If the site is susceptible to blowing wind, the straw should be tacked down with a tackifier, or a crimper to prevent loss.

Wood chips are suitable for areas that will not be closely mowed, and around ornamental plantings. Chips do not require tacking. Because they decompose slowly they must be treated with 12 pounds of nitrogen per ton to prevent nutrient deficiency in plants. They can be an inexpensive mulch if the chips are obtained from trees cleared on the site.

Compost, peanut hulls, and pine straw are organic materials that potentially make excellent mulches but may only be available locally or seasonally. Creative use of these materials may reduce costs.

Jute mesh or the various types of netting is very effective in holding mulch in place on waterways and slopes before grasses become established.

Erosion control blankets promote seedling growth in the same way as organic mulches and are suited for use in areas with concentrated flows (see Erosion Control Blanket practice).

Table 4-28. Hydraulic Erosion Control Products (HECP) Specification Chart [1]

Type HECP[2]	Term	Functional Longevity[3]	Typical Application Rates Lbs/acre (kg/ha)	Typical Maximum Slope Gradient (H:V)	Maximum Uninterrupted Slope Length (ft)	Maximum C Factor[4, 5] (3:1 test)	Minimum Vegetation Establishment[6]
1	Ultra Short Term	1 month	1500—2500 (1700—2800)	< 5:1	20	0.3	150%
2	Short Term	2 month	2000—3000 (2250—3400)	< 4:1	25	0.2	150%
3	Moderate Term	3 month	2000—3500 (2250—3900)	< 3:1	50	0.1	200%
4	Extended Term	6 month	2500—4000 (2800—4500)	< 2:1	75	0.05	300%
5	Long Term	12 month	3000—4500 (3400—5100)	< 2:1	100	0.02	300%

1 This table is for general guidelines only. Refer to manufacturer for application rates, instructions, gradients, maximum continuous slope lengths and other site-specific recommendations.
2 These categories are independent of rolled erosion control products (RECPs) categories, despite the identical names.
3 A manufacturer's estimated time period, based upon field observations, that a material can be anticipated to provide erosion control as influenced by it composition and site-specific conditions.
4 "C" Factor calculated as ratio of soil loss from HECP protected slope (tested at specified or greater gradient, h:v) to ratio of soil loss from unprotected (control) plot based on large-scale testing.
5 Acceptable large-scale test methods may include ASTM D 6459, or other independent testing deemed acceptable by the engineer.
6 Minimum vegetation establishment is calculated as outlined in ASTM D 7322 being a percentage by dividing the plant mass per area of the protected plot by the plant mass per area of the control plot

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(Source: Erosion Control Technology Council, April 2014)

Design Criteria

Site Preparation

Before mulching, complete the required site preparation. Site preparation includes grading, if needed, and seedbed preparation and fertilizing, liming and seeding if a planting is being made by means other than hydroseeding.

Spreading the Mulch

Select a mulch material based on the site and practice requirements, availability of material, and availability of labor and equipment. Table 4-29 lists commonly used mulches.

Table 4-29. Mulching Materials and Application Rates

Material	Rate Per Acre and (Per 1000 ft^2)	Notes
Straw with Seed	1 ½-2 tons (70 lbs-90 lbs)	Spread by hand or machine to attain 75% groundcover; anchor when subject to blowing.
Straw alone (no seed)	2 ½-3 tons (115 lbs-160 lbs)	Spread by hand or machine; anchor when subject to blowing.
Wood Chips	5-6 tons (225 lbs-270 lbs)	Treat with 12 lbs. nitrogen/ton.
Bark	35 cubic yards (0.8 cubic yard)	Can apply with mulch blower.
Pine Straw	1-2 tons (45 lbs-90 lbs)	Spread by hand or machine; will not blow like straw.
Peanut Hulls	10-20 tons (450 lbs-900 lbs)	Will wash off slopes. Treat with 12 lbs. nitrogen/ton.
HECPs (Hydraulic Erosion Control Products)	0.75 – 2.25 tons (35 lbs – 103 lbs)	Refer to ECTC or Manufacturer's Specifications.

Uniformly spread organic mulches by hand or with a mulch blower at a rate which provides about 75% ground cover. Spread HECPs utilizing appropriate equipment and at rates as specified When spreading straw mulch by hand, divide the area to be mulched into sections of approximately 1000 sq. ft. and place 70-90 pounds of straw (1 ½ to 2 bales) in each section to facilitate uniform distribution. Caution, an over-application of wheat straw will reduce stand success – do not over-apply wheat straw when mulching a seeding!

When straw mulch is subject to be blown away by wind, it must be anchored immediately after spreading. It is best anchored with a mulch anchoring tool.

Application of a commercial tackifier through a hydroseeder is often practical for steep slopes and can be effective on most sites. Binders (tackifiers) may be applied after mulch is spread or may be sprayed into the mulch as it is being blown onto the soil. Applying straw and binder together is the most effective method. Liquid binders include an array of commercially available synthetic binders and organic tackifiers.

In high wind situations like roadways, crimping the mulch is the best alternative as the use of mulch binders may still result in the mulch being rolled up on the edge.

Straw mulch may also be anchored with lightweight plastic, cotton, jute, wire or paper netting which is stapled over the mulch. The manufacturer's recommendations on stapling netting should be followed.

Maintenance
Inspect all mulches periodically, and after rainstorms to check for rill erosion, dislocation, or failure. Where erosion is observed, apply additional mulch or if washout has occurred, repair the slope grade, reseed, and reinstall mulch. Continue inspections until vegetation is firmly established."

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The US EPA (1976) prepared Figure 4-30 to highlight the coverage provided by different rates of straw mulch application. Typically, good coverage requires at least 2 tons per acre of straw and the best coverage occurs at approximately 3 – 4 tons per acre.

Straw Mulch at Various Rates of Application

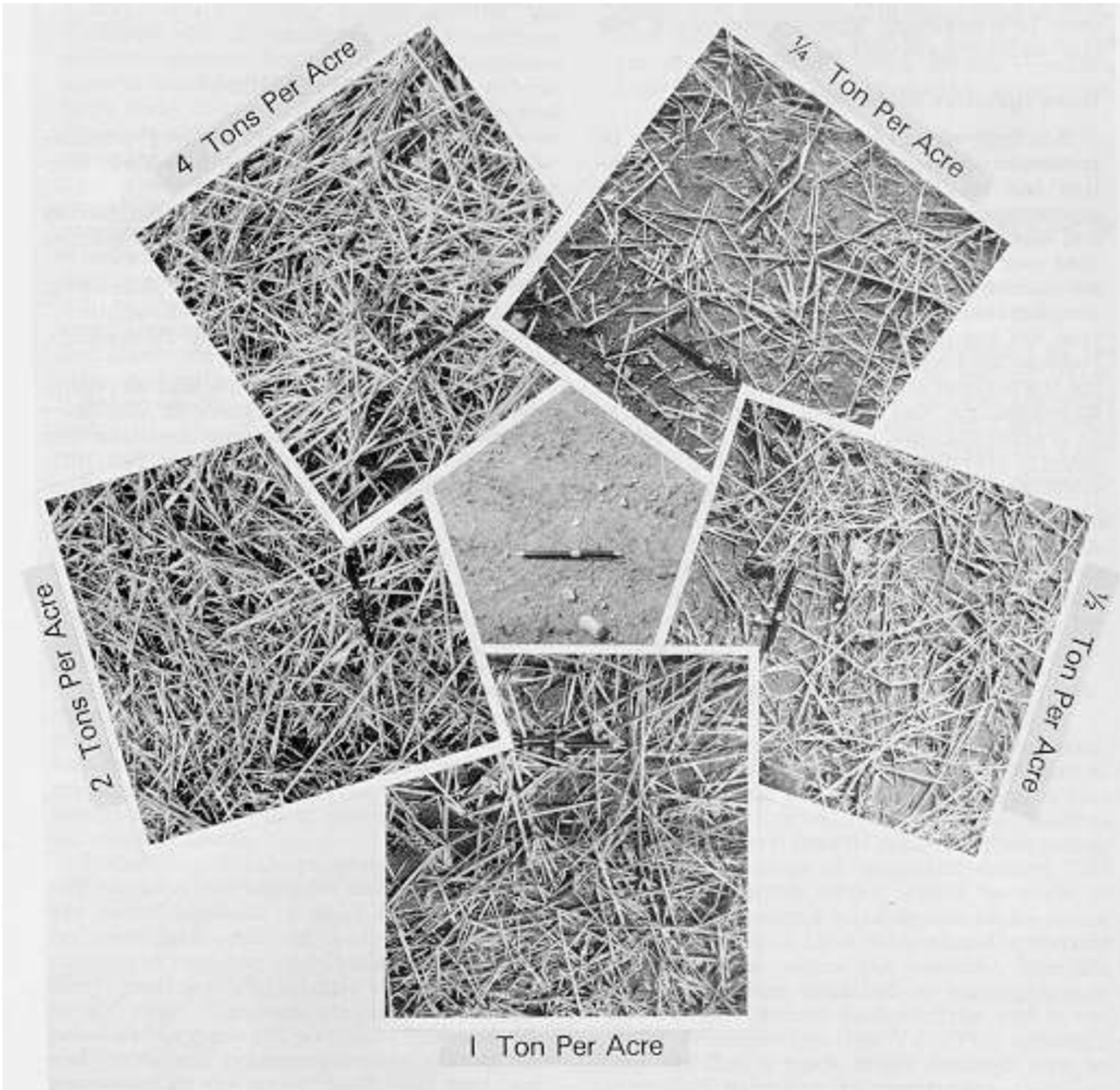

Figure 4-30. Straw mulch application rate comparison (Source: US EPA 625/3-76-006a)

Summary

This chapter introduced the Revised Universal Soil Loss Equation (RUSLE) and presented some specific information for using this model for construction sites. In addition, the application of vegetation controls that help prevent erosion from occurring were also outlined in this chapter. Several examples of how this information can be used to calculate the estimated soil erosion losses for construction sites were presented.

Useful Internet Links

Internet links change frequently, while internet search tools are very powerful. It is therefore recommended that searches be made for specific resources or products and to work with the local USDA/NRC and construction site plan review agency for their recommendations for specific solutions to local problems.

The official NRCS RUSLE2 Internet site is at: http://fargo.nserl.purdue.edu/rusle2_dataweb/Tutorial.htm. The model can be downloaded from this site, along with supporting documents and other materials.

Problems

1. Explain the effects of the following factors on soil erosion and transport. (a) Climate; (b) Soil characteristics; (c) Topography; (d) Soil cover.

2. Explain the effect each of the following have on splash erosion. (a) Adhesive forces in the soil; (b) Kinetic energy of the raindrops; (c) The type of vegetal landcover; (d) Cohesive forces in soil.

3. Which one of the following is not a factor in determining shear stress when computing bedload with the tractive-force method? (a) The shape of the soil particles; (b) The specific weight of the fluid; (c) The specific weight of the soil particles; (d) The particle diameter; (e) All of the above are factors.

4. Use the appropriate equation to estimate the kinetic energy of a raindrop for exceedance frequencies of 2, 10, and 100 yr. Use your local IDF curve and a duration of 5 min.

5. Estimate the soil loss using the RUSLE for a square 0.8-acre plot at a 3% slope in the southwestern corner of Missouri. This soil loss is being estimated for the time period required to perform the grading – a time frame of four months starting on April 16. Assume the soil is 40% silt plus very fine sand, 10% sand ($0.1 < d < 2$ mm), no organic matter, fine granular soil structure, and moderate permeability. Assume bare ground with no cover practice.

6. For the conditions of Problem 5, show the variation of the soil loss as the percentage sand varies from 0 to 30%.

7. Assuming a void ratio of 34% and a specific weight of 135 lb/ft^3, estimate the depth of soil loss for the conditions of Problem 5.

8. A proposal is made to use a rainfall erosivity factor R of 225 in the state of Missouri. Show the spatial variation across the state of the error that results from this simplification.

9. Using MUSLE, calculate the sediment yield for a 2-year storm to a sediment trap from a highway site whose disturbed area is 4 acres of road bank having a slope of 4H:1V, horizontal slope length of 200 feet, and a soil K factor of 0.28. The 2-year rainfall is 2.6 inches and the peak discharge for this storm is 6 cfs. There is no cover on the soil and the slope is uncompacted.

10. What is the expected sediment yield for the above site if the exposed soils are recently seeded and mulched at a rate of 2 tons to the acre?

11. A farmer has decided to sell his 120-acre farm to a developer, who plans to construct estate homes. The construction will be performed in three phases of approximately 40 acres each. The developer has two choices: grade each phase individually (allowing vegetation to establish between the end of one phase and the start of a new phase), or grading the entire site at one time. Assuming a construction schedule of three years (one year per construction phase), estimate the soil loss from the site using each of the development scenarios and the site information provided below. Assuming the soil is a loam, what is the difference is volume of soil material generated by erosion between the two scenarios?

    Site information:

    120 acres
    1.5% slope
    Farmland with wheat covering the entire acreage.
    Slope length of 400 ft (length from top of ridge to street level for lots with steepest grading problems)
    Assume the soil is your local (non-urban) soils.
    Use your local rain/erosion zone information.

12. Project Question:

a. Describe the different construction phases for your site (initial grubbing and clearing, using pre-development contours; and final grading contours during active construction activities, at least). Describe site soils and land cover. Describe the timing of the construction site erosion and sediment controls for your site.

b. Apply RUSLE for each of these phases (apply estimates for cover factors and durations of the phases; we will examine channels and slope protection during the next module, so this assignment will be a preliminary evaluation. However, consider different terracing options and other control choices described so far).

c. Select the appropriate temporary and permanent plants to be used for construction site erosion control at your site, and describe planting and mulching conditions, etc. Consider the likely dates for the plantings).

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Appendix 4A. Erosivity Indices by Location and Erosion Variations by Season

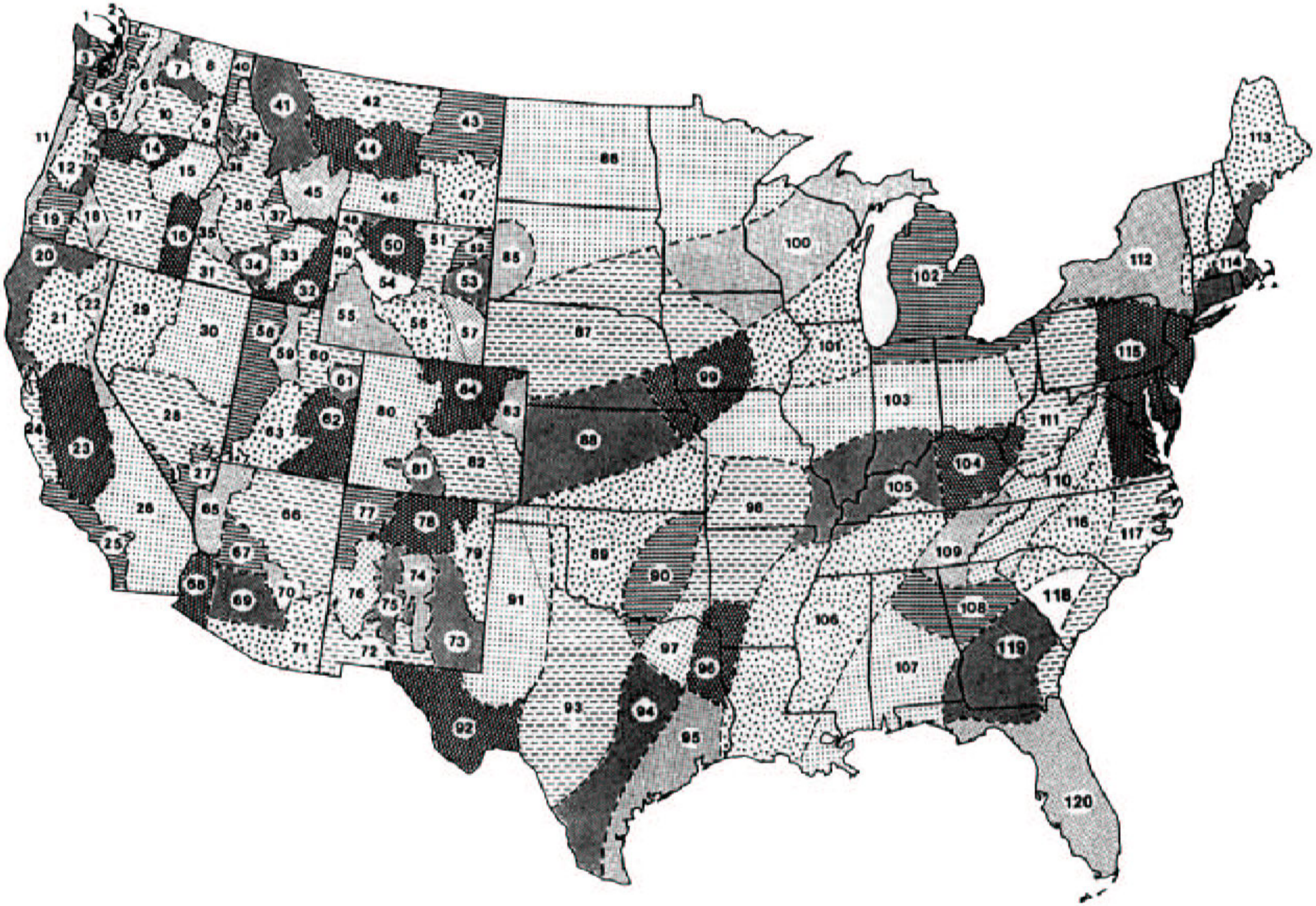


Figure 4A. Erosivity index zone map (EPA 2001).

Table 4A. Erosivity Index Table (EI as a percentage of the annual average R, computed for geographical areas) (Source: EPA 2001)

EI#	Jan 1-15	Jan 16-31	Feb 1-15	Feb 16-29	Mar 1-15	Mar 16-31	Apr 1-15	Apr 16-30	May 1-15	May 16-31	Jun 1-15	Jun 16-30	Jul 1-15	Jul 16-31	Aug 1-15	Aug 16-31	Sep 1-15	Sep 16-31	Oct 1-15	Oct 16-31	Nov 1-15	Nov 16-31	Dec 1-15	Dec 16-31
1	0.0	4.3	8.3	12.8	17.3	21.6	25.1	28.0	30.9	34.9	39.1	42.6	45.4	48.2	50.8	53.0	56.0	60.8	66.8	71.0	75.7	82.0	89.1	95.2
2	0.0	4.3	8.3	12.8	17.3	21.6	25.1	28.0	30.9	34.9	39.1	42.6	45.4	48.2	50.8	53.0	56.0	60.8	66.8	71.0	75.7	82.0	89.1	95.2
3	0.0	7.4	13.8	20.9	26.5	31.8	35.3	38.5	40.2	41.6	42.5	43.6	44.5	45.1	45.7	46.4	47.7	49.4	52.8	57.0	64.5	73.1	83.3	92.3
4	0.0	3.9	7.9	12.6	17.4	21.6	25.2	28.7	31.9	35.1	38.2	42.0	44.9	46.7	48.2	50.1	53.1	56.6	62.2	67.9	75.2	83.5	90.5	96.0
5	0.0	2.3	3.6	4.7	6.0	7.7	10.7	13.9	17.8	21.2	24.5	28.1	31.1	33.1	35.3	38.2	43.2	48.7	57.3	67.8	77.9	86.0	91.3	96.9
6	0.0	0.0	0.0	0.5	2.0	4.1	8.1	12.6	17.6	21.6	25.5	29.6	34.5	40.0	45.7	50.7	55.6	60.2	66.5	75.5	85.6	95.9	99.5	99.9
7	0.0	0.0	0.0	0.0	0.0	1.2	4.9	8.5	13.9	19.0	26.1	35.4	43.9	48.8	53.9	64.5	73.4	77.5	80.4	84.8	89.9	96.6	99.2	99.7
8	0.0	0.0	0.0	0.0	0.0	0.9	3.6	7.8	15.0	20.2	27.4	38.1	49.8	57.9	65.0	75.6	82.7	86.8	89.4	93.4	96.3	99.1	100.0	100.0
9	0.0	0.8	3.1	4.7	7.4	11.7	17.8	22.5	27.0	31.4	36.0	41.6	46.4	50.1	53.4	57.4	61.7	64.9	69.7	79.0	89.6	97.4	100.0	100.0
10	0.0	0.3	0.5	0.9	2.0	4.3	9.2	13.1	18.0	22.7	29.2	39.5	46.3	48.8	51.1	57.2	64.4	67.7	71.1	77.2	85.1	92.5	96.5	99.0
11	0.0	5.4	11.3	18.8	26.3	33.2	37.4	40.7	42.5	44.3	45.4	46.5	47.1	47.4	47.8	48.3	49.4	50.7	53.6	57.5	65.5	76.2	87.4	94.8
12	0.0	3.5	7.8	14.0	21.1	27.4	31.5	35.0	37.3	39.8	41.9	44.3	45.6	46.3	46.8	47.9	50.0	52.9	57.9	62.3	69.3	81.3	91.5	96.7
13	0.0	0.0	0.0	1.8	7.2	11.9	16.7	19.7	24.0	31.2	42.4	55.0	60.0	60.8	61.2	62.6	65.3	67.6	71.6	76.1	83.1	93.3	98.2	99.6
14	0.0	0.7	1.8	3.3	6.9	16.5	26.6	29.9	32.0	35.4	40.2	45.1	51.9	61.1	67.5	70.7	72.8	75.4	78.6	81.9	86.4	93.6	97.7	99.3
15	0.0	0.0	0.0	0.5	2.0	4.4	8.7	12.0	16.6	21.4	29.7	44.5	56.0	60.8	63.9	69.1	74.5	79.1	83.1	87.0	90.9	96.6	99.1	99.8
16	0.0	0.0	0.0	0.5	2.0	5.5	12.3	16.2	20.9	26.4	35.2	48.1	58.1	63.1	66.5	71.9	77.0	81.6	85.1	88.4	91.5	96.3	98.7	99.6
17	0.0	0.0	0.0	0.7	2.8	6.1	10.7	12.9	16.1	21.9	32.8	45.9	55.5	60.3	64.0	71.2	77.2	80.3	83.1	87.7	92.6	97.2	99.1	99.8
18	0.0	0.0	0.0	0.6	2.5	6.2	12.4	16.4	20.2	23.9	29.3	37.7	45.6	49.8	53.3	58.4	64.3	69.0	75.0	86.6	93.9	96.6	98.0	100.0
19	0.0	1.0	2.6	7.4	16.4	23.5	28.0	31.0	33.5	37.0	41.7	48.1	51.1	52.0	52.5	53.6	55.7	57.6	61.1	65.8	74.7	88.0	95.8	98.7
20	0.0	9.8	18.5	25.4	30.2	35.6	38.9	41.5	42.9	44.0	45.2	48.2	50.8	51.7	52.5	54.6	57.4	58.5	60.1	63.2	69.6	76.7	85.4	92.4
21	0.0	7.5	13.6	18.1	21.1	24.4	27.0	29.4	31.7	34.6	37.3	39.6	41.6	43.4	45.4	48.1	51.3	53.3	56.6	62.4	72.4	81.3	88.9	94.7
22	0.0	1.2	1.6	1.6	1.6	1.6	1.6	2.2	3.9	4.6	6.4	14.2	32.8	47.2	58.8	69.1	76.0	82.0	87.1	96.7	99.9	99.9	99.9	99.9
23	0.0	7.9	15.0	20.9	25.7	31.1	35.7	40.2	43.2	46.2	47.7	48.8	49.4	49.9	50.7	51.8	54.1	57.7	62.8	65.9	70.1	77.3	86.8	93.5
24	0.0	12.2	23.6	33.0	39.7	47.1	51.7	55.9	57.7	58.6	58.9	59.1	59.1	59.2	59.2	59.3	59.5	60.0	61.4	63.0	66.5	71.8	81.3	89.6
25	0.0	9.8	20.8	30.2	37.6	45.8	50.6	54.4	56.0	56.8	57.1	57.1	57.2	57.6	58.5	59.8	62.2	65.3	67.5	68.2	69.4	74.8	86.6	93.0
26	0.0	2.0	5.4	9.8	15.6	21.5	24.7	26.6	27.4	28.0	28.7	29.8	32.5	36.6	44.9	55.4	65.7	72.6	77.8	84.4	89.5	93.9	96.5	98.4
27	0.0	0.0	0.0	1.0	4.0	5.9	8.0	11.1	13.0	14.0	14.6	15.3	17.0	23.2	39.1	60.0	76.3	86.1	89.7	90.4	90.9	93.1	96.6	99.1
28	0.0	0.0	0.0	0.0	0.2	0.5	1.5	3.3	7.2	11.9	17.7	21.4	27.0	37.1	51.4	62.3	70.6	78.8	84.6	90.6	94.4	97.9	99.3	100.0
29	0.0	0.6	0.7	0.7	0.7	1.5	3.9	6.0	10.5	17.9	28.8	36.6	43.8	51.5	59.3	68.0	74.8	80.3	84.3	88.8	92.7	98.0	99.8	99.9
30	0.0	0.0	0.0	0.0	0.0	0.2	0.8	2.8	7.9	14.2	24.7	35.6	45.4	52.2	58.7	68.5	77.6	84.5	88.9	93.7	96.2	97.6	98.3	99.6

Table 4A. Erosivity Index Table (cont.)

EI#	Jan 1-15	Jan 16-31	Feb 1-15	Feb 16-29	Mar 1-15	Mar 16-31	Apr 1-15	Apr 16-30	May 1-15	May 16-31	Jun 1-15	Jun 16-30	Jul 1-15	Jul 16-31	Aug 1-15	Aug 16-31	Sep 1-15	Sep 16-31	Oct 1-15	Oct 16-31	Nov 1-15	Nov 16-31	Dec 1-15	Dec 16-31
31	0	0	0	0	0	0.2	1	3.5	9.9	15.7	26.4	47.2	61.4	65.9	69	77.2	86	91.6	94.8	98.7	100	100	100	100
32	0	0.1	0.1	0.1	0.1	0.6	2.2	4.3	9	14.2	23.3	34.6	46.3	54.2	61.7	72.9	82.5	89.6	93.7	98.2	99.7	99.9	99.9	99.9
33	0	0	0	0	0	0.6	2.3	4.2	8.8	16.1	30	46.9	57.9	62.8	66.2	72.1	79.1	85.9	91.1	97	98.9	98.9	98.9	98.9
34	0	0	0	0	0	1.8	7.3	10.7	15.5	22	29.9	35.9	42	48.5	56.9	67	76.9	85.8	91.2	95.7	97.8	99.6	100	100
35	0	0	0	0	0	2.5	10.2	15.9	22.2	27.9	34.7	43.9	51.9	56.9	61.3	67.3	73.9	80.1	85.1	89.6	93.2	98.2	99.8	99.8
36	0	0	0	0	0	0.9	3.4	6.7	12.7	18.5	26.6	36.3	46	53.5	60.2	68.3	75.8	82.6	88.3	96.3	99.3	99.9	100	100
37	0	0	0	0	0	0	0	1	3.9	9.1	19.1	26.7	36.3	47.9	61.4	75.1	84.5	92.3	96	99.1	100	100	100	100
38	0	0	0	1.1	4.3	7.2	11	13.9	17.9	22.3	30.3	43.1	55.1	61.3	65.7	72.1	77.9	82.6	86.3	90.3	93.8	98.4	100	100
39	0	0	0	0	0	1.6	6.5	11	17.8	24.7	33.1	42.8	50.3	54.9	59.7	68.9	78.1	83.6	87.5	93	96.5	99.2	100	100
40	0	0	0	0	0	1.5	6.2	10.1	16.3	23.3	32.5	42.2	50.1	55.6	60.5	67.5	74.3	79.4	84.1	91.1	95.8	99.1	100	100
41	0	0.1	0.2	0.2	0.2	0.2	0.2	0.4	1.1	6.8	22.9	40.1	54.9	63.8	70.7	81.5	89.8	96.3	98.7	99.2	99.3	99.4	99.4	99.7
42	0	0	0	0	0	0	0	0.2	0.9	5.2	17.3	33.8	53.2	66.5	75.9	87.6	93.7	97.5	99	99.7	100	100	100	100
43	0	0	0	0	0	0	0	0.1	0.4	2.7	9.5	21.9	42.7	58.6	71.1	84.6	91.9	97.1	99	99.8	100	100	100	100
44	0	1.7	2.3	2.4	2.4	2.4	2.4	2.7	3.5	7.6	18.5	34.3	52.5	64	72.3	83.3	90	95.1	97.3	98.5	98.9	98.9	98.9	99.2
45	0	0.2	0.2	0.3	0.3	0.4	0.6	0.8	1.4	3.7	10.2	22.6	41.8	54	64.5	78.7	88.4	96	98.7	99.4	99.7	99.7	99.8	99.9
46	0	0	0	0	0	0	0	0.6	2.6	7.5	19.6	32.9	48.9	63	73.5	83.3	89.5	95.6	98.3	99.6	100	100	100	100
47	0	0	0	0	0	0	0	0.4	1.6	5.8	17	33	52.5	66.4	75.7	85.5	91.3	96.5	98.8	100	100	100	100	100
48	0	0	0	0	0	0	0	0	0	2	8.1	15.4	27.8	40.7	52.6	61.1	69.3	82.6	92	98	100	100	100	100
49	0	0	0	0	0	0	0	0.7	2.7	8.3	20	27.5	35.6	44.6	56	70.2	81.3	89.2	93.6	98.5	100	100	100	100
50	0	0	0	0	0	0.1	0.4	2.4	8.2	13.7	23.8	38.8	55.1	66.1	73.6	81.8	87.7	93.8	97	99.4	100	100	100	100
51	0	0	0	0	0	0.3	1	3.1	8.7	18.8	35.8	49.6	60.4	70.2	77	84	88.8	93.8	96.6	99.1	100	100	100	100
52	0	0	0	0	0	0	0	0.6	2.5	6.8	17.5	29.8	46.1	60.5	72.7	86	92.8	96.8	98.4	99.7	100	100	100	100
53	0	0	0	0	0	0	0	0.8	3	9.5	24.2	35.3	48	63.1	76.1	87.7	93.5	97.2	98.6	99.5	99.8	99.9	100	100
54	0	0	0	0	0	0.2	0.7	2.4	7.2	14.7	27.2	37.2	47.3	58.8	67.6	74	79.2	86.7	92.6	97.9	99.8	99.9	100	100
55	0	0	0	0	0	0	0	1.3	5.4	13.3	25.5	31.6	38.8	52.5	66.8	75.5	81.2	87.9	92.8	98.3	100	100	100	100
56	0	0	0	0	0	0	0	1.3	5.1	11.4	22.3	29.5	38.5	51.1	65.2	77.8	85.6	91.7	95	98.7	100	100	100	100
57	0	0	0	0	0	0	0.1	1	3.5	9.2	21.5	31	43.5	60.4	75.1	86.1	91.6	96.2	98.1	99.4	99.9	99.9	100	100
58	0	0	0	0	0	0.2	0.9	2.9	8	13.2	21	29.1	38	45.9	54.5	65.4	74.8	82.1	87.5	95.4	98.8	99.7	100	100
59	0	0	0	0	0	0	0	2.2	8.9	15.6	24.2	31.1	38.3	46	54.9	64.2	73.2	81.9	88.5	95.7	98.6	99.4	99.7	99.7
60	0	0	0	0	0	0	0	0.4	1.5	4	9.5	13.3	20.5	33.6	52.8	66.5	76.7	88.1	94.2	98.6	100	100	100	100

Table 4A. Erosivity Index Table (cont.)

	Jan	Jan	Feb	Feb	Mar	Mar	Apr	Apr	May	May	Jun	Jun	Jul	Jul	Aug	Aug	Sep	Sep	Oct	Oct	Nov	Nov	Dec	Dec
EI#	1-15	16-31	1-15	16-29	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-31	1-15	16-31	1-15	16-31	1-15	16-31
61	0	0	0	0	0	0	0	1.3	5	8.5	15.5	29.8	41.8	46	49.2	56	65.1	71.6	78.6	91.1	97.3	99.3	100	100
62	0	0	0	0.1	0.3	0.8	2.1	3.6	6.5	9.7	13.7	16.5	20.8	27.3	40.1	56.9	72.6	83.4	89.4	95.5	98.1	99.6	100	100
63	0	0	0	0	0	0	0	0.9	3.7	7.8	13.3	15.8	19.9	29	46.8	64.7	78.3	88.8	93.9	98.5	100	100	100	100
64	0	0	0	0.7	2.8	7.4	12.4	14.4	15.6	17.3	19.4	21	24.4	32.3	48	61.4	72.1	81.9	87	90.1	92.4	98.1	100	100
65	0	3.6	7	9.6	11.4	13	14.4	16.3	17.7	18.4	19.3	20.5	23.6	32	50	66.2	77.2	85.4	88.8	90.4	91.3	92.7	94.8	97
66	0	0	0	0	0	0.1	0.5	1.1	2.2	3.6	6	7.6	11.1	19.8	38.9	59.7	74.4	83.2	88.1	94.6	97.7	99.4	100	100
67	0	0	0	0	0	0.1	0.4	0.9	1.6	1.9	2.4	5	12.1	24.8	48.3	73.6	86.5	92	94.3	96.6	97.9	99.5	100	100
68	0	2.3	4.5	7.8	10.4	12	13.3	16.3	17.7	18.1	18.2	18.3	18.4	19.9	24.5	35	54.4	69.4	78.6	85.7	89.2	91.9	93.9	97
69	0	2	3.7	5.7	7.8	10.5	12.4	13.7	14.3	14.7	15.1	15.7	17.1	22.7	36.7	50.4	63.6	75	81.8	87.8	90.8	93.2	94.9	97.5
70	0	0.5	0.7	1	1.3	1.7	2.2	2.8	3.4	3.9	4.7	5.4	7.4	15.7	36.5	55.8	70.3	80.9	86.4	90.9	93.4	96.4	98.1	99.4
71	0	0.7	1.2	1.6	2.1	2.8	3.3	3.6	4	4.5	5.6	6.5	9.1	18.5	40.6	59.7	74	86.3	91.7	94.7	96	96.7	97.3	98.8
72	0	0	0	0	0	0	0.1	0.2	0.7	0.8	1.3	3.5	9.9	24.7	51.4	71.5	83.6	93.8	97.7	99.2	99.8	99.9	99.9	100
73	0	0	0.1	0.1	0.2	0.2	0.3	0.6	1.3	4.1	11.5	18.1	28.3	40.2	54.1	67	77.2	87.7	93.3	97.5	99.1	99.6	99.8	100
74	0	0	0	0	0	0.1	0.2	0.5	1.2	2.7	6.4	10.2	18.4	31	50.7	68.7	81.2	91.6	96.1	98.4	99.2	99.8	100	100
75	0	0.1	0.1	0.1	0.2	0.5	1.3	1.9	3	4.1	6.6	10	17.6	28.3	44.7	59.4	71.6	83.9	90.3	94.7	96.7	98.8	99.6	99.9
76	0	0	0	0	0	0.1	0.2	0.6	1.3	2	3.5	4.9	8.4	17.4	37.3	57.5	72.9	83.7	89.5	95.8	98.4	99.6	100	100
77	0	0.2	0.3	0.3	0.4	0.8	1.5	2	2.8	3.9	5.9	7.2	10.3	21.5	46.5	66.3	78.3	86.5	90.8	96	98.2	99.1	99.5	99.8
78	0	0	0	0	0	0	0.2	0.5	1.6	3.8	8.9	13.2	21.8	35.8	56.6	75.4	86	92.9	95.9	98.2	99.2	99.8	100	100
79	0	0	0	0	0	0.2	0.7	1.3	2.7	5.8	12.7	18.8	28.8	41.6	58.4	75.7	86.5	94.2	97.3	98.9	99.5	99.9	100	100
80	0	0.6	1.2	1.6	2.1	2.5	3.3	4.5	6.9	10.1	15.5	19.7	26.6	36.4	51.7	67.5	79.4	88.8	93.2	96.1	97.3	98.2	98.7	99.3
81	0	0.1	0.1	0.2	0.4	0.5	0.8	0.9	1.5	3.9	9.9	12.8	18.2	30.7	54.1	77.1	89	94.9	97.2	98.7	99.3	99.6	99.7	99.9
82	0	0	0.1	0.1	0.2	0.2	0.5	1.2	3.1	6.7	14.4	20.1	29.8	44.5	64.2	83.1	92.2	96.4	98.1	99.3	99.7	99.8	99.8	99.9
83	0	0	0.1	0.1	0.1	0.3	0.9	1.6	3.5	8.3	19.4	30	44	59.2	72.4	84.6	91.2	96.5	98.6	99.5	99.8	99.9	100	100
84	0	0	0.1	0.1	0.2	0.3	0.6	1.7	4.9	9.9	19.5	27.2	38.3	52.8	68.8	83.9	91.6	96.4	98.2	99.2	99.6	99.8	99.8	99.9
85	0	0	0	0	0	0	1	2	3	6	11	23	36	49	63	77	90	95	98	99	100	100	100	100
86	0	0	0	0	0	0	1	2	3	6	11	23	36	49	63	77	90	95	98	99	100	100	100	100
87	0	0	0	0	1	1	2	3	6	10	17	29	43	55	67	77	85	91	96	98	99	100	100	100
88	0	0	0	0	1	1	2	3	6	13	23	37	51	61	69	78	85	91	94	96	98	99	99	100
89	0	0	1	1	2	3	4	7	12	18	27	38	48	55	62	69	76	83	90	94	97	98	99	100
90	0	1	2	3	4	6	8	13	21	29	37	46	54	60	65	69	74	81	87	92	95	97	98	99

Table 4A. Erosivity Index Table (cont.)

	Jan	Jan	Feb	Feb	Mar	Mar	Apr	Apr	May	May	Jun	Jun	Jul	Jul	Aug	Aug	Sep	Sep	Oct	Oct	Nov	Nov	Dec	Dec
EI#	1-15	16-31	1-15	16-29	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-31	1-15	16-31	1-15	16-31	1-15	16-31
91	0	0	0	0	1	1	1	2	6	16	29	39	46	53	60	67	74	81	88	95	99	99	100	100
92	0	0	0	0	1	1	1	2	6	16	29	39	46	53	60	67	74	81	88	95	99	99	100	100
93	0	1	1	2	3	4	6	8	13	25	40	49	56	62	67	72	76	80	85	91	97	98	99	99
94	0	1	2	4	6	8	10	15	21	29	38	47	53	57	61	65	70	76	83	88	91	94	96	98
95	0	1	3	5	7	9	11	14	18	27	35	41	46	51	57	62	68	73	79	84	89	93	96	98
96	0	2	4	6	9	12	17	23	30	37	43	49	54	58	62	66	70	74	78	82	86	90	94	97
97	0	1	3	5	7	10	14	20	28	37	48	56	61	64	68	72	77	81	86	89	92	95	98	99
98	0	1	2	4	6	8	10	13	19	26	34	42	50	58	63	68	74	79	84	89	93	95	97	99
99	0	0	0	1	1	2	3	5	7	12	19	33	48	57	65	72	82	88	93	96	98	99	100	100
100	0	0	0	0	1	1	2	3	5	9	15	27	38	50	62	74	84	91	95	97	98	99	99	100
101	0	0	0	1	2	3	4	6	9	14	20	28	39	52	63	72	80	87	91	94	97	98	99	100
102	0	0	1	2	3	4	6	8	11	15	22	31	40	49	59	69	78	85	91	94	96	98	99	100
103	0	1	2	3	4	6	8	10	14	18	25	34	45	56	64	72	79	84	89	92	95	97	98	99
104	0	2	3	5	7	10	13	16	19	23	27	34	44	54	63	72	80	85	89	91	93	95	96	98
105	0	1	3	6	9	12	16	21	26	31	37	43	50	57	64	71	77	81	85	88	91	93	95	97
106	0	3	6	9	13	17	21	27	33	38	44	49	55	61	67	71	75	78	81	84	86	90	94	97
107	0	3	5	7	10	14	18	23	27	31	35	39	45	53	60	67	74	80	84	86	88	90	93	95
108	0	3	6	9	12	16	20	24	28	33	38	43	50	59	69	75	80	84	87	90	92	94	96	98
109	0	3	6	10	13	16	19	23	26	29	33	39	47	58	68	75	80	83	86	88	90	92	95	97
110	0	1	3	5	7	9	12	15	18	21	25	29	36	45	56	68	77	83	88	91	93	95	97	99
111	0	1	2	3	4	5	6	8	11	15	20	28	41	54	65	74	82	87	92	94	96	97	98	99
112	0	0	0	1	2	3	4	5	7	12	17	24	33	42	55	67	76	83	89	92	94	96	98	99
113	0	1	2	3	4	5	6	8	10	12	17	22	31	42	52	60	68	75	80	85	89	92	96	98
114	0	1	2	4	6	8	11	13	11	13	21	26	32	38	46	55	64	71	77	81	85	89	93	97
115	0	1	2	3	4	5	6	8	10	14	19	26	34	45	56	66	76	82	86	90	93	95	97	99
116	0	1	3	5	7	9	12	15	18	21	25	29	36	45	56	68	77	83	88	91	93	95	97	99
117	0	1	2	3	4	5	7	9	11	14	17	22	31	42	54	65	74	83	89	92	95	97	98	99
118	0	2	4	6	8	12	16	20	25	30	35	41	47	56	67	75	81	85	87	89	91	93	95	97
119	0	1	2	4	6	7	9	12	15	18	23	31	40	48	57	63	72	78	88	92	96	97	98	99
120	0	8	16	25	33	41	46	50	53	54	55	56	56.5	57	57.75	58	58.75	60	61	63	66.5	72	80	90

Table 4A. Erosivity Index Table (cont.)

0	Jan	Jan	Feb	Feb	Mar	Mar	Apr	Apr	May	May	Jun	Jun	Jul	Jul	Aug	Aug	Sep	Sep	Oct	Oct	Nov	Nov	Dec	Dec
EI#	1-15	16-31	1-15	16-29	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-31	1-15	16-31	1-15	16-31	1-15	16-31
121	0	7	14	20	25.5	33.5	38	43	46	50	52.5	54.5	56	58	59	60	61.5	63	65	68	72	79	86	93
122	0	4	8	12	17	23	29	34	38	44	49	53	56	59	62	65	69	72	75	79	83	88	93	96
123	0	4	9	15	23	29	34	40	44	48	50	51	52	53	55	57	60	62	64	67	72	80	88	95
124	0	7	12	17	24	30	39	45	50	53	55	56	57	58	59	61	62	63	64	66	70	77	84	92
125	0	9	16	23	30	37	43	47	50	52	54	55	56	57	58	59	60	62	64	67	71	77	86	93
126	0	8	15	22	28	33	38	42	46	50	52	53	53	53	53	54	55	57	59	63	68	75	83	92
127	0	8	15	22	29	34	40	45	48	51	54	57	59	62	63	64	65	66	67	69	72	76	83	91
128	0	9	16	22	27	32	37	41	45	48	51	53	55	56	57	57	58	59	61	64	68	73	79	89
129	0	10	20	28	35	41	46	49	51	53	55	56	56	57	58	59	60	61	62	65	69	74	81	90
130	0	8	15	22	28	33	38	41	44	47	49	51	53	55	56	58	59	60	63	65	69	75	84	92
131	0	10	18	25	29	33	36	39	41	42	44	45	46	47	48	49	51	53	56	59	64	70	80	90
132	0	8	16	24	32	40	46	51	54	56	57	58	58	59	59	60	60	61	62	64	68	74	83	91
133	0	12	22	31	39	45	49	52	54	55	56	56	56	56	57	57	57	57	58	59	62	68	77	88
134	0	7	15	22	30	37	43	49	53	55	57	58	59	60	61	62	63	65	67	70	74	79	85	92
135	0	11	21	29	37	44	50	55	57	59	60	60	60	60	61	61	61	62	63	64	67	71	78	89
136	0	10	18	25	30	39	46	51	54	57	58	59	59	60	60	60	61	62	63	64	67	72	80	90
137	0	11	22	31	39	46	52	56	58	59	60	61	61	61	61	62	62	62	63	64	66	71	78	89
138	0	8	14	20	25	32	37	42	47	50	53	55	56	58	59	61	63	64	66	68	71	76	85	93
139	0	10.6	21.2	28.6	36	41.4	46.8	49.3	51.8	52.5	53.2	53.5	53.7	53.9	54	54.3	54.7	55.7	56.8	61.6	65.3	73.9	82.5	91.2
140	0	0.2	0.3	0.3	0.3	0.3	0.3	0.8	1.3	5.3	9.3	30.1	50.8	56.8	62.9	67.5	72.2	75.8	79.4	85.6	91.7	95.9	100	100
141	0	10.7	21.4	28.7	36	41.7	47.3	50.3	53.2	54.5	55.7	56.2	56.7	56.9	57	57.4	57.8	59	60.2	64.1	67.9	76.1	84.2	92.1
142	0	2.7	5.5	5.7	5.9	7.1	8.4	10	11.7	15.3	19	22.6	26.1	29	31.9	36.6	41.2	46	50.7	62.3	73.9	83.5	93.1	96.6
143	0	8.7	17.5	25.2	33	39.9	46.7	50.8	54.8	56.2	57.6	58	58.4	58.9	59.4	60.8	62.3	64.1	65.9	68.8	71.7	78.6	85.5	92.7
144	0	4.3	8.6	9.3	10.1	11.1	12	15.3	18.6	22.7	26.7	28.7	30.7	31.3	32	34	36	44.4	52.9	60.1	67.3	78.2	89.2	94.6
145	0	11.7	23.3	33.5	43.7	50.7	57.6	60.3	63	63.5	64.1	64.2	64.2	64.5	64.8	66.1	67.3	68.6	69.8	70.7	71.6	79.2	86.7	93.4
146	0	4.8	9.6	13.1	16.5	22.6	28.7	30.8	32.8	33.3	33.8	34	34.2	36.4	38.6	43	47.5	56	64.5	66.2	67.9	77.9	88	94
147	0	0	4.7	9.4	10.8	12.2	13.2	14.3	14.9	15.5	24.2	32.8	45.5	58.2	67.9	77.6	86.3	95.1	95.6	96.1	98	100	100	100
148	0	5.5	11	19.2	27.5	36.6	45.7	47.8	50	50.9	51.7	52.1	52.5	54.2	55.9	60.1	64.4	70.5	76.7	81.2	85.7	90.4	101	97.6
149	0	2.4	4.9	7.4	9.9	11.7	13.6	14.6	15.6	16.2	16.8	17.2	17.7	24.7	31.7	46.9	62.1	67	72	80.7	89.3	92.3	95.3	97.7

Chapter 5: Channel and Slope Stability for Construction Site Erosion Control

Contents

Introduction

This chapter reviews the basic approaches and techniques available for the design of stable channels and slopes. Several alternatives that can be used are briefly described. Example problems are also presented. Specific issues associated with construction sites are stressed in this chapter, compared to the more general applications for which some of these techniques are usually applied. The information presented in Chapter 3 (Regional rainfall conditions and site hydrology for construction site erosion evaluations) and Chapter 4 (Erosion mechanisms and the Revised Universal Soil Loss Equation) is used in this chapter to design stable diversion, on-site, and downslope channels, and to ensure stable slopes. These are some of the most critical erosion control practices on a construction site, as these are preventative measures that are always more effective than sediment control (treatment) practices applied after erosion has occurred. The design approaches described in this chapter can be also modified to meet different criteria, based on allowable erosion yield objectives.

General Channel Stability Shear Stress Relationship

An important reference on general shear stress relationships and channel bed movement is *Engineering and Design: Channel Stability Assessment for Flood Control Projects* (COE 1994; EM 1110-2-1418). Although this reference is specifically for large channels, many of the basic concepts are similar to what occurs at construction sites. These are specifically addressed in the following discussion. More extensive information on these topics is available in numerous textbooks and manuals on sediment transport and channel design, along with COE HEC-15 (https://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=15&id=32).

Figure 5-1. Massive streambank failure after new development and a new outfall in a suburban area (WI DNR photo).

 J. Voorhees photo	 J. Voorhees photo


D. Lake photo


J. Voorhees photo

Figure 5-2. Lined temporary bypass channels at construction sites


E. Hahn photo


E. Hahn photo


D. Lake photo


D. Lake photo

Figure 5-3. Gravel lined swales at construction sites

Post-Agnes Stream Stabilization
Sometimes desperate times require desperate measures. On June 21, 1972 Hurricane Agnes made its way up the east coast of the U.S. into the southern tier of New York and north central Pennsylvania. The resulting flooding and economic impact was dramatic and devastating. Downtown Elmira, New York recorded a flood depth of 17 feet above street level from the Chemung River. Across the valley from Elmira on a tributary to the river (Seeley Creek), people were trying to protect their property in any way that they could.

This photo, taken in July 1973, one year after the storm, shows a number of automobiles that were pushed over the creek bank to help prevent it from washing away. Although a gravel bar has created during the storm due to comparatively-reduced velocity and some “windshield vegetation” has been established, the effort is not in compliance with water quality standards. Many comprehensive streambank stabilization methods can be employed that both protect against erosion and provide aquatic habitat enhancements. These techniques are covered in many stream restoration and ecological engineering guidelines, handbooks, and textbooks.

Figure 5-4. Scrap Metal Stream Stabilization


Figure 5-5. Bioengineered channel slopes (IECA photo)

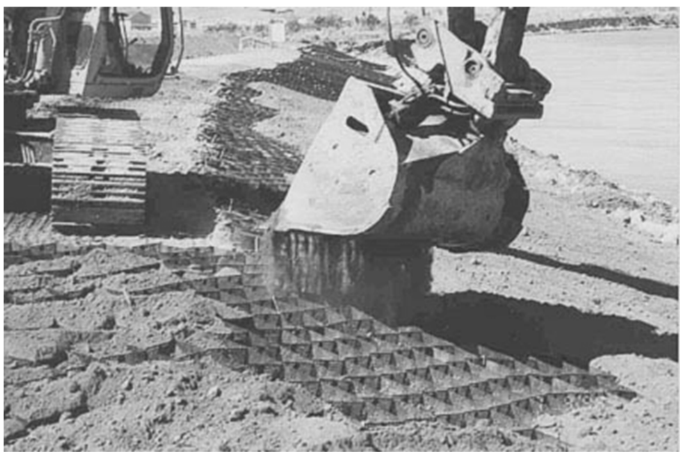


Figure 5-6. Geogrids being filled with sand for bank protection (IECA photo)

Allowable Velocity Approach to Channel Design
Allowable velocity and allowable shear stress have been used to design stable channels that would have minimal channel erosion. Modifications of allowable velocity or shear stress to account for sediment transport have been proposed in a few references, but generally are not useful for construction site applications (see the discussion on the "regime" theory in McCuen 1998, for example).

The concept of allowable velocities for various soils and materials dates from the early days of hydraulics. An example of simple velocity criteria is given by Table 5-1 (COE undated, EM 1110-2-1601). Table 5-2 is a similar table from U.S. Bureau of Reclamation research (Fortier and Scobey 1926, reprinted by McCuen 1998) that also shows the corresponding allowable shear stresses and Manning's roughness values.

Table 5-1. Example of Simple Allowable Velocity Objectives (From COE undated, EM 1110-2-1601)

Channel Material	Mean Channel Velocity (ft/sec)
Fine Sand	2.0
Coarse Sand	4.0
Fine Gravel	6.0
Earth	
Sandy Silt	2.0
Silt clay	3.5
Clay	6.0
Grass-lined Earth (Slopes less than 5%)	
Bermuda Grass	
Sandy Silt	6.0
Silt Clay	8.0
Kentucky Blue Grass	
Sandy Silt	5.0
Silt Clay	7.0
Poor Rock (usually sedimentary)	10.0
Soft Sandstone	8.0
Soft Shale	3.5
Good Rock (usually igneous or hard metamorphic)	20.0

Table 5-2. Maximum Permissible Velocities and Corresponding Unit Tractive Force (Shear Stress) (U.S. Bureau of Reclamation research, Fortier and Scobey 1926)

		Clear Water (diversion structures)		Water Transporting Colloidal Silts (on site and down slope)	
Material	**n**	**V (ft/sec)**	τ_o **(lb/ft²)**	**V (ft/sec)**	τ_o **(lb/ft²)**
Fine sand, colloidal	0.020	1.50	0.027	2.50	0.075
Sandy loam, noncolloidal	0.020	1.75	0.037	2.50	0.075
Silt loam, noncolloidal	0.020	2.00	0.048	3.00	0.11
Alluvial silts, noncolloidal	0.020	2.00	0.048	3.50	0.15
Ordinary firm loam	0.020	2.50	0.075	3.50	0.15
Volcanic ash	0.020	2.50	0.075	3.50	0.15
Stiff clay, very colloidal	0.025	3.75	0.26	5.00	0.46
Alluvial silts, colloidal	0.025	3.75	0.26	5.00	0.46
Shales and hardpans	0.025	6.00	0.67	6.00	0.67
Fine gravel	0.020	2.50	0.075	5.00	0.32
Graded loam to cobbles when noncolloidal	0.030	3.75	0.38	5.00	0.66
Graded silts to cobbles when noncolloidal	0.030	4.00	0.43	5.50	0.80
Coarse gravel, noncolloidal	0.025	4.00	0.30	6.00	0.67
Cobbles and shingles	0.035	5.00	0.91	5.50	1.10

Note:

- an increase in velocity of 0.5 ft/sec can be added to these values when the depth of water is greater than 3 ft.
- a decrease in velocity of 0.5 ft/sec should be subtracted when the water contains very coarse suspended sediments.
- for high and infrequent discharges of short duration, up to 30% increases in velocity can be added

Figure 5-7 is another guidance illustration and is based on SCS data (USDA 1977). This figure differentiates between “sediment-free” and “sediment-laden” flow, similar to the distinction made in the sediment quantity in the runoff water in Table 5-2.

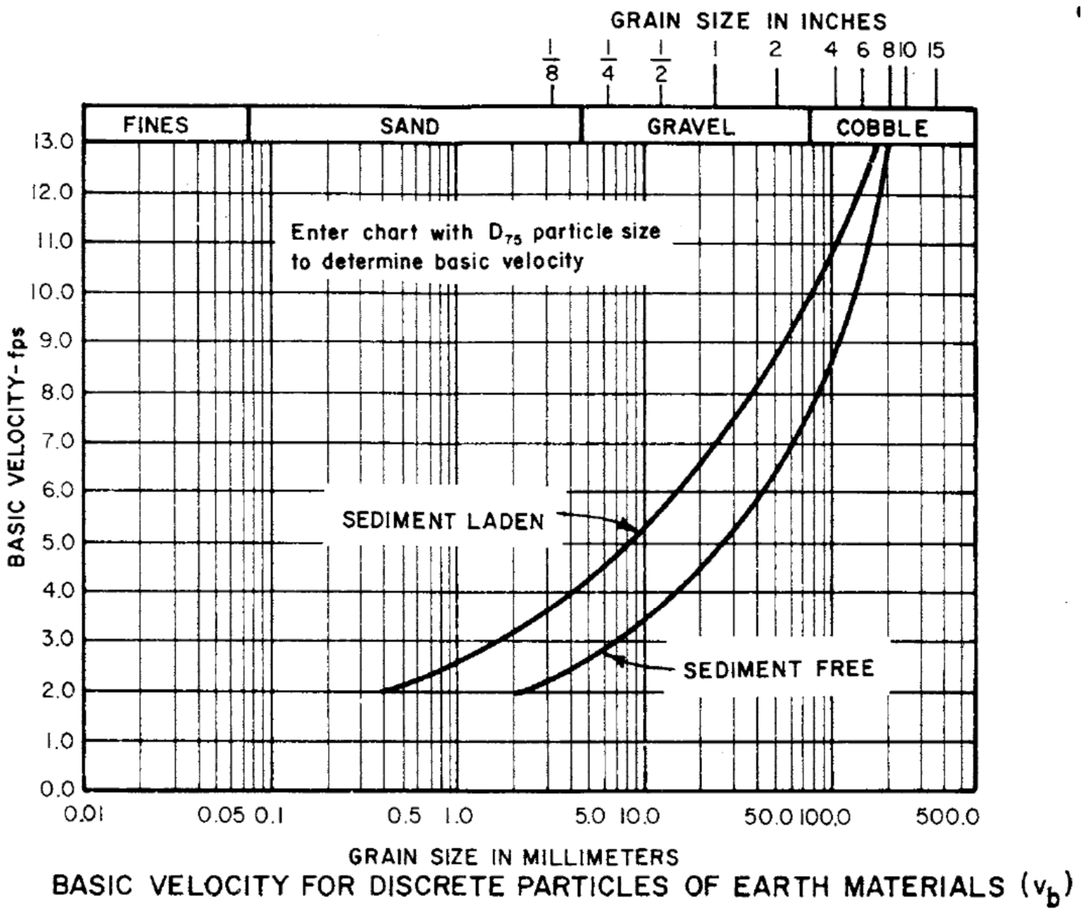


Figure 5-7. Example of allowable velocity data with provision for sediment transport (USDA 1977)

Allowable Shear Stress Calculations

By the 1930's, boundary shear stress (sometimes called tractive force) was generally accepted as a more appropriate erosion criterion than allowable velocity. The average boundary shear stress in uniform flow is calculated by

$$\tau_o = \gamma RS \quad \text{(lb/ft}^2\text{)}$$

where:

γ = specific weight of water (62.4 lbs/ft^3)
R = hydraulic radius (ft)
S = hydraulic slope (ft/ft)

Figure 5-8 (Chow 1959) shows a typical distribution of the shear stresses in a channel, indicating how, for straight channel reaches having constant depths, the maximum shear stress is applied along the center of the channel.

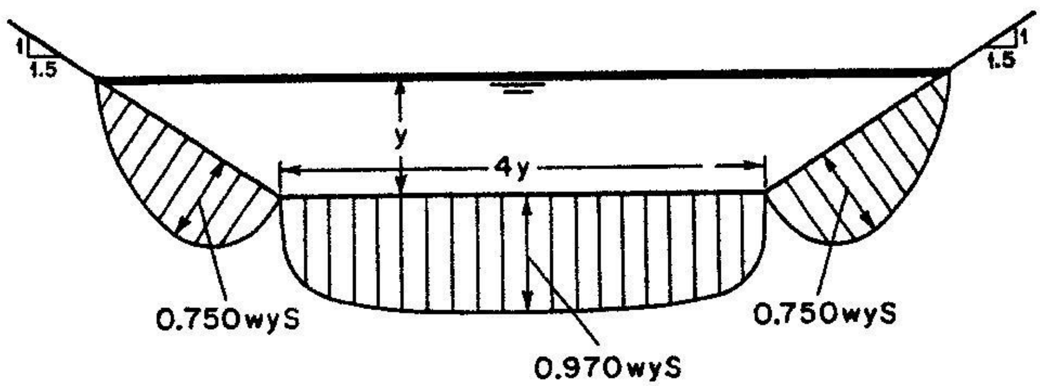


Figure 5-8. Typical shear stress distributions in a trapezoidal channel (Chow 1959).

If the maximum shear stress is desired (typical for design conditions), then the flow depth is used instead of the hydraulic radius. For sheetflow conditions, the hydraulic radius (R) is very close to the depth of flow, and the above equation is modified, as shown in Figure 5-9, by using the depth of flow to replace the hydraulic radius.

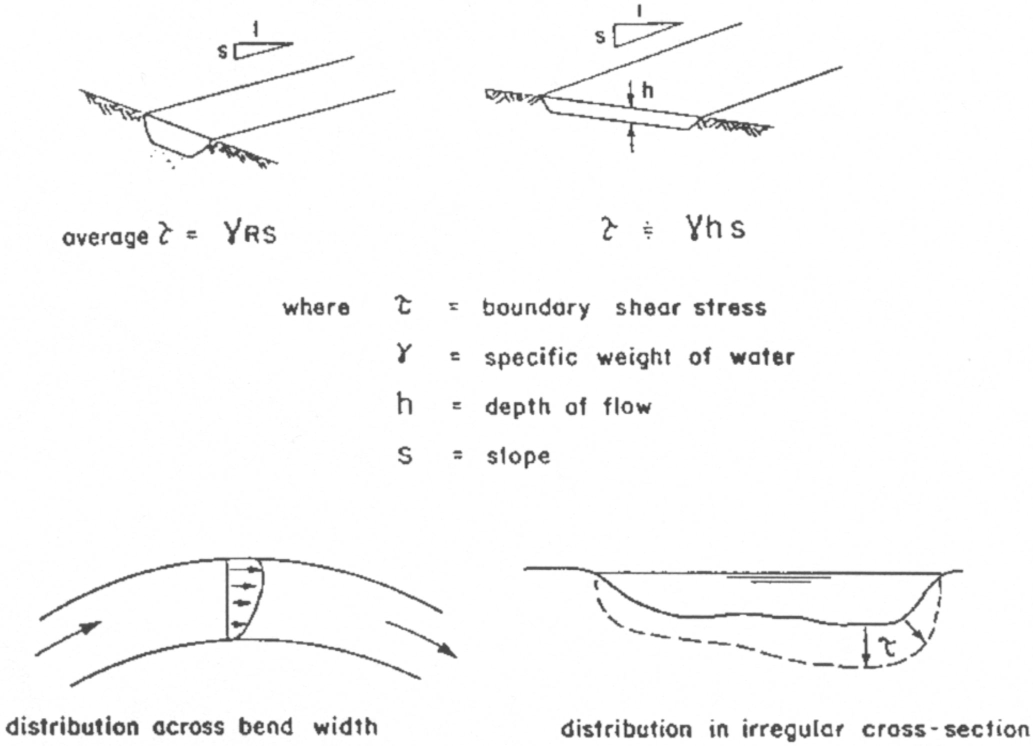


Figure 5-9. Boundary shear stress in uniform flow (COE 1994).

Flow characteristics predicting the initiation of motion of sediment in noncohesive materials are usually presented in nondimensional form in the Shield's diagram (Figure 5-10). This diagram indicates the initial movement, or scour, of noncohesive uniformly graded sediments on a flat bed. The diagram plots the Shield's number (or mobility number), which combines shear stress with grain size and relative density, against a form of the Reynolds number that uses grain size as the length variable. The ASCE *Sedimentation Manual* (1975) uses a dimensionless parameter, shown on Figure 5-10, to select the dimensionless stress value. This stress value is calculated as follows:

$$\frac{d}{\nu}\left[0.1\left(\frac{\gamma_s}{\gamma}-1\right)gd\right]^{0.5}$$

where:

- d = particle diameter (meters)
- g = gravitational constant (9.81 m/sec^2)
- ν = kinematic viscosity (1.306 x 10^{-6} m^2/sec for 10^{o}C)
- γ_s = specific gravity of the solid
- γ = specific gravity of water

A series of parallel lines on Figure 5-10 represent these calculated values. The dimensionless shear stress value (τ_*) is selected where the appropriate line intersects the Shield's curve. The critical shear stress can then be calculated by:

$$\tau_c = \tau_*(\gamma_s - \gamma)d$$

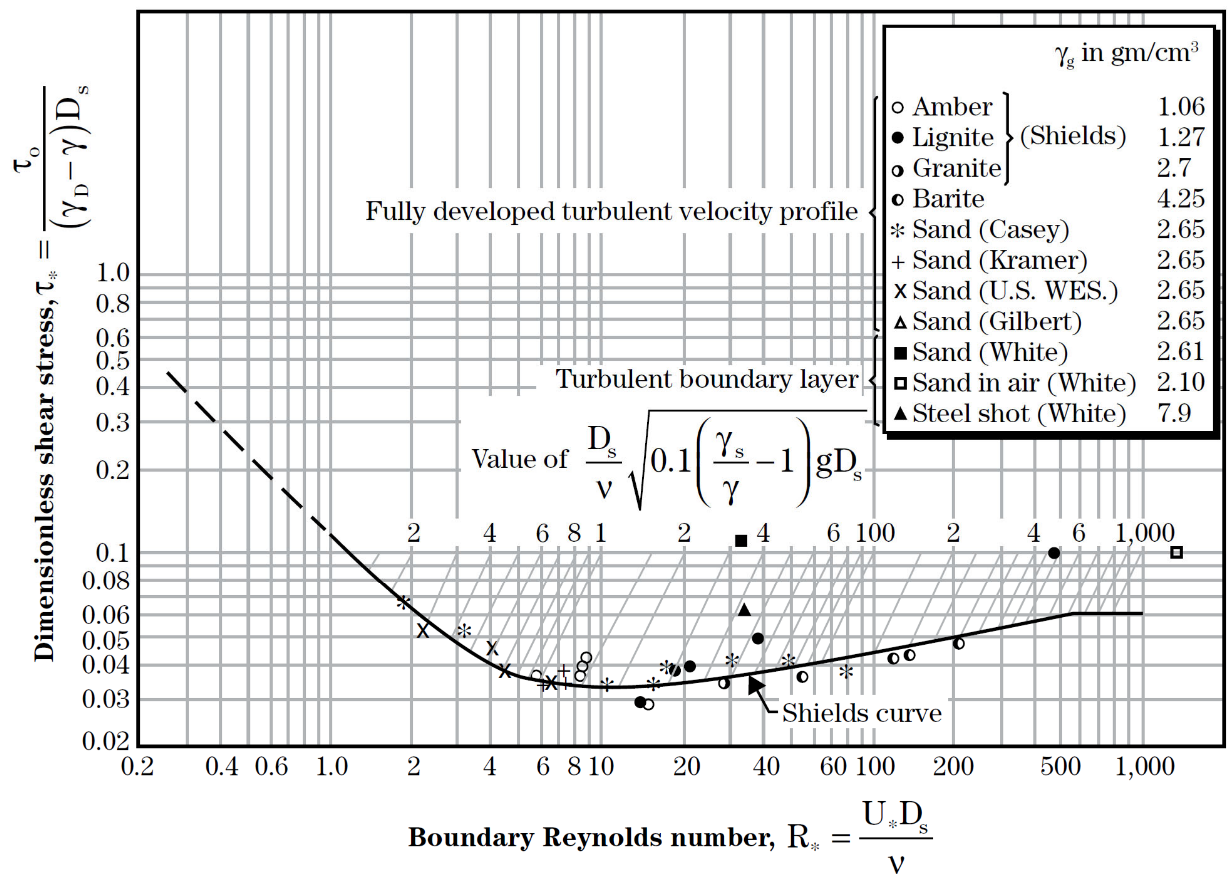


Figure 5-10. Shield's diagram for dimensionless critical shear stress (COE 1994).

Example:

The following example (in SI units), presented by Chang (1988), illustrates the use of the Shield's diagram:

> "Determine the maximum depth of a wide canal for which scour of the bed material can just be prevented. The canal has rigid banks and an erodible bed; it is laid on a slope of 0.0005. The bed material has a median size of 2.5 mm and its specific gravity is 2.65. Assume a temperature of 10°C."

Therefore:

d = particle diameter (meters) = 2.5 mm = 0.0025 m
g = gravitational constant = 9.81 m/sec^2
ν = kinematic viscosity = 1.306 x 10^{-6} m^2/sec for 10°C
γ_s = specific gravity of the solid = 2.65
γ = specific gravity of water = 1

$$\frac{d}{\nu}\left[0.1\left(\frac{\gamma_s}{\gamma}-1\right)gd\right]^{0.5} = \frac{0.0025}{1.306x10^{-6}}\left[0.1\left(\frac{2.65}{1}-1\right)(9.81)(0.0025)\right]^{0.5} = 121.8$$

This line intersects the Shield's curve at $\tau_* = 0.043$. The critical shear stress is therefore:

$$\tau_c = \tau_*(\gamma_s - \gamma)d = 0.043(2.65-1)0.0025 = 1.74N/m^2$$

Using the basic shear stress formula:

$$\tau_c = \gamma DS$$

Rearranging gives (with the specific weight of water being 9.808kN/m^3, or 999.7 kg/m^3 at 10^{o}C):

$$D = \frac{\tau_c}{\gamma S} = \frac{1.74N/m^2}{(9{,}808N/m^3)(0.0005)} = 0.35m$$

The critical depth of flow (D) is therefore 0.35 meters.

For sediments in the gravel size range and larger, the Shield's number for beginning of bed movement is essentially independent of the Reynolds number. For wide channels, the relationship can then be expressed as:

$$\frac{dS}{(s-1)D} = \text{constant}$$

where:

S = channel slope
s = dry relative density of sediment
D = grain size
d = depth of flow

The constant is shown as 0.06 in Figure 5-10, but it is often taken as 0.045, or even as low as 0.03 if absolutely no movement is allowed. For widely graded bed materials, the median grain size by weight (D_{50}) is generally taken as the representative size, although some favor a smaller percentile, such as D_{35}.

An example evaluation is given by the COE (1994) in their assessment manual. In their example, the use of the Shield's diagram is shown to likely greatly over-predict the erodibility of the channel bottom material. The reason they give is that the Shield's diagram assumes a flat bottom channel and the total roughness is determined by the size of the granular bottom material. The actual Manning's roughness value is likely much larger because it is largely determined by bed forms, channel irregularities, and vegetation. They recommend, as a more realistic assessment, that empirical data based on field observations be used. In the absence of local data, they present Figure 5-11 (from Chow 1959) for applications to channels bedded in granular materials. This figure shows the permissible unit tractive force (shear stress) as a function of the average particle diameter and the fine sediment content of the flowing water. For construction-site diversion channels intercepting upland water from stable sites, the “clear” water curve is recommended. However, if the channel is on, or below, the construction site, the “high content” curve is more suitable.

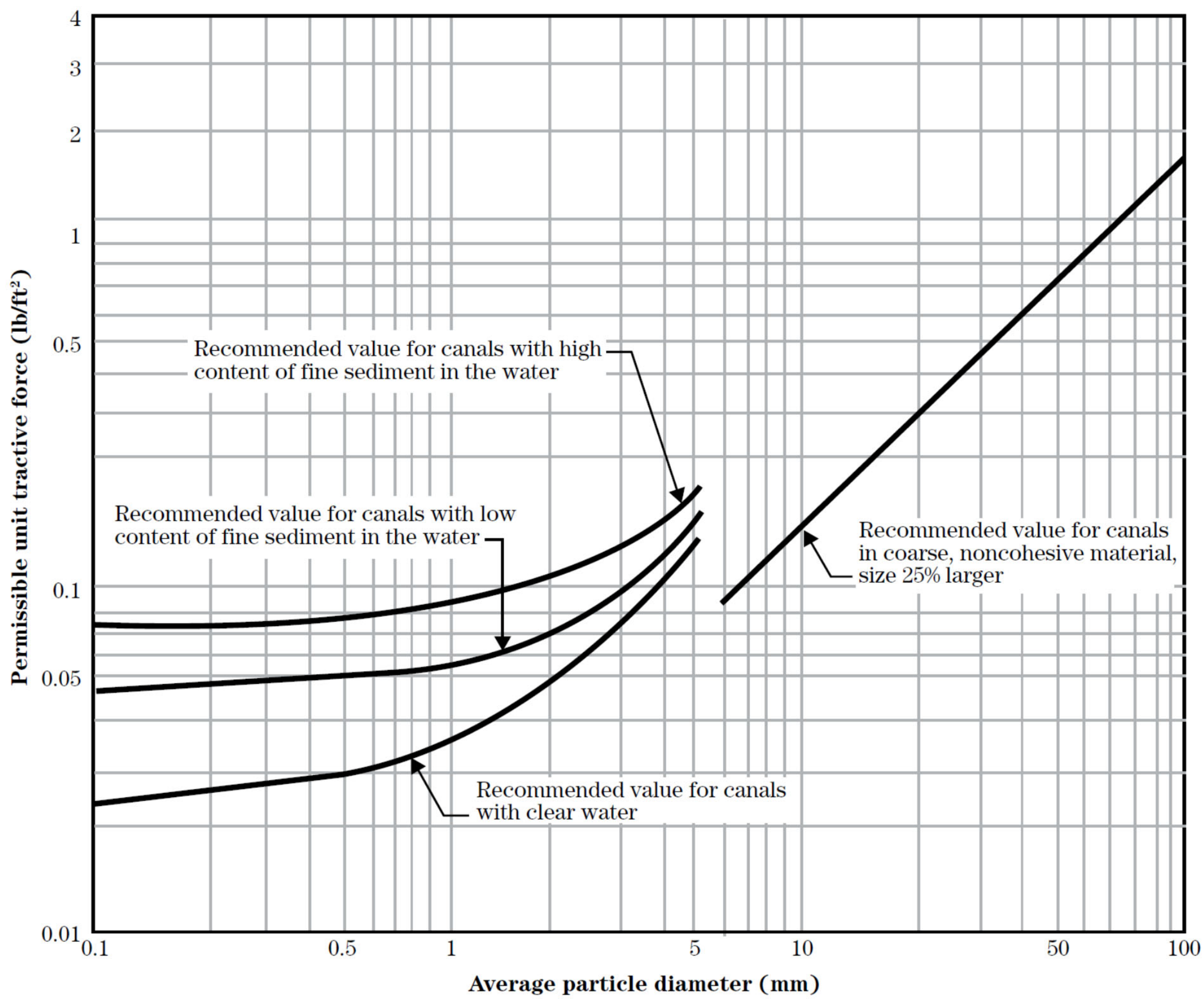


Figure 5-11. Allowable shear stresses (tractive forces) for canals in granular materials (U.S. Bureau of Reclamation, reprinted in Chow 1959).

The allowable shear stress concept has also been applied to semicohesive and noncohesive soils, but the values do not correlate well with standard geotechnical parameters because the resistance to erosion is affected by such factors as water chemistry, history of exposure to flows, and weathering (Raudkivi and Tan 1984). Figure 5-12 gives an example of allowable shear stresses for a range of cohesive materials. Again, the COE recommends that local field observations or laboratory testing results be given preference to the values from the graphs.

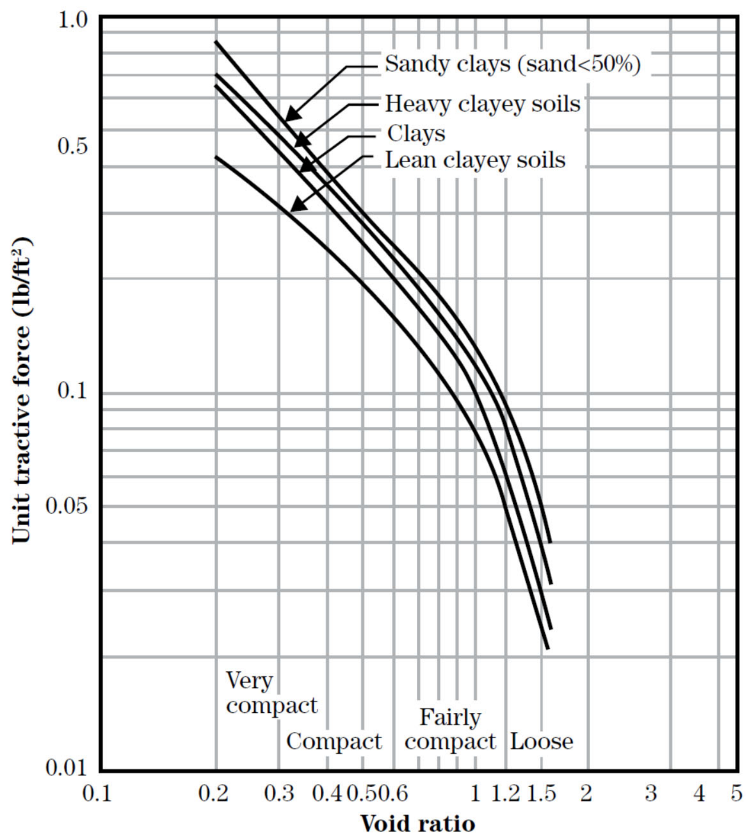


Figure 5-12. Example of allowable shear stresses (tractive forces) for cohesive materials (COE 1994). Note: Leon clayey soils are hardpan soils where the soil grains become cemented together with bonding agents such as iron oxide or calcium carbonate, forming a hard, impervious mass.

Shear Stress in Channels having Bends

The basic shear stress formulas can be modified to account for the increased shear stress after bends in channels. Normally, the maximum shear stress is along the center part of a channel (usually the deepest area), but, after a change in direction, a hydrodynamic force is applied to the outside bend. Along the outside of the bend, increased water velocity and shear stress will increase the erosion potential, while sedimentation may occur along the inside of the bend where the water velocity slows. The basic shear stress formula is modified with a bend coefficient, as follows:

$$\tau_o = \frac{\gamma RS}{K_b}$$

where:

γ = specific weight of water (62.4 lbs/ft^3)
R = hydraulic radius (ft) (can be estimated by water depth, for relatively wide channels or sheetflows)
S = hydraulic slope (ft/ft)
K_b = bend coefficient

The bend coefficient can be estimated by (Croke 2001):

$$K_b = \frac{R_c}{B}$$

where:

R_c = bend curvature (radius of the bend)
B = bottom width of the channel

As the bend curvature, R_c, increases, the effect of the bend decreases. These parameters are illustrated in Figure 5-13 (North American Green). This formula obviously cannot be used for a V-shaped channel, where the bottom width is zero.

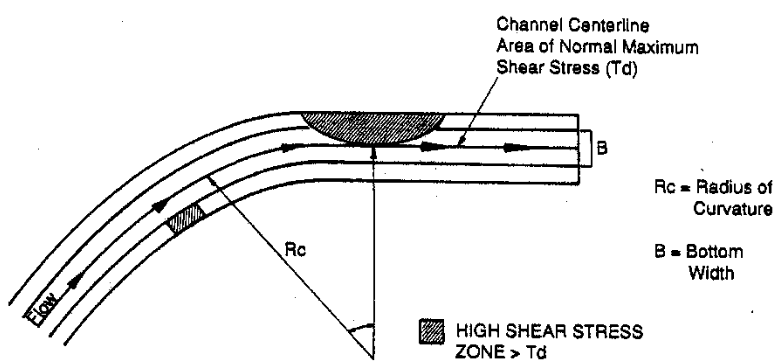


Figure 5-13. Location of increased shear stress due to channel bend (North American Green).

The area being affected by the increased shear stress due to channel bends is usually assumed to begin immediately after the bend at the tangent to the downstream channel, as shown in Figure 5-13. The length of extra shear stress can be estimated by the following formula (after Croke 2001):

$$L_p = \frac{0.604R^{1.17}}{n}$$

where:
L_p = length of extra protection needed due to increased shear stress on outside of bend (same units as R)

R = hydraulic radius = ratio of cross-sectional area of flow to wetted perimeter (A/P)
n = Manning's roughness coefficient for liner in the channel bend

As an example, assume the following conditions:
R = 3.0 ft
n = 0.042

then:

$$L_p = \frac{0.604(3)^{1.17}}{0.042} = 52 \text{ ft}$$

In addition to the increased shear stress being exerted along the outside bend, water elevations also will rise due to centrifugal force This will create an additional channel depth needing protection along the outside bends.

Cautions Regarding Allowable Velocity or Shear Stress. The COE (1994) lists the following limitations of the allowable velocity and allowable shear stress approaches:

- For channels with substantial inflows of bed material, a minimum velocity or shear stress to avoid sediment deposition may be as important as a maximum value to avoid erosion. Such a value cannot be determined using allowable data for minimal erosion. [See the discussion of the "regime" theory in McCuen (1998)]. The Hjulström curve (Figure 5-14) can be used to estimate the velocities in a channel or stream required to deposit, transport, or erode sediment. The curve was developed for flowing streams with hydraulic radii of approximately 3 feet. However, additional research using it to design inclined plate settlers has shown that it can be used at much smaller different hydraulic radii (Clark, *et al.* 2009). The Hjulström diagram can provide a rapid assessment of whether particles of specific sizes could be expected to erode, transport, or settle.

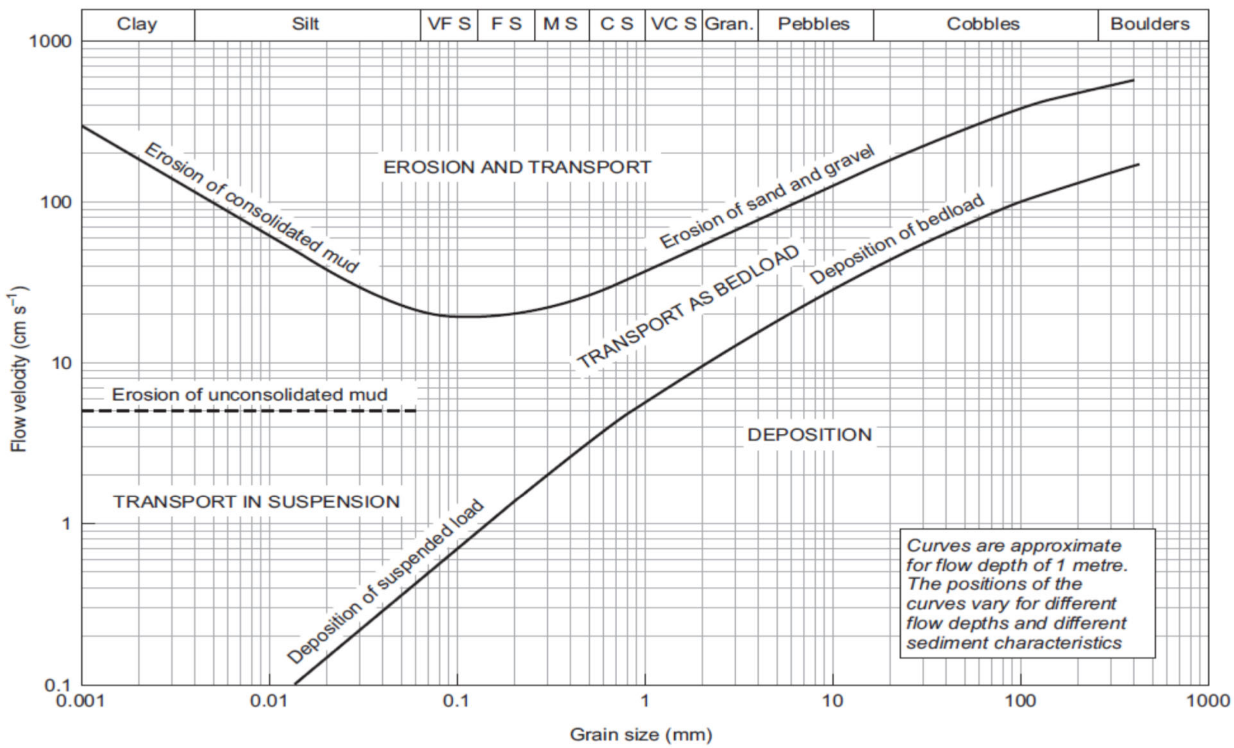


Figure 5-14. The Hjulström curve for channel transport of sediment.

- In bends and meandering channels, bank erosion and migration may occur even if average velocities and boundary shear stresses are well below allowable values. Conversely, deposition may occur in local slack-water areas, even if average values are well above the values indicated for maximum deposition. Information on cross-sectional distributions of velocity and shear stress in bends is provided in COE (undated) (EM 1110-2-1601). Authors' note: There are design curves in many sediment transport books that allow the user to estimate if the flow will encourage scour or deposition, based on particle diameter, hydraulic radius and flow rate.

- The Shield's relationship (Figure 5-10) should be applied primarily to uniform flow over a flat bed. In sand-bed channels especially, the bed is normally covered with bed forms such as ripples or dunes, and shear stresses required for significant erosion may be much greater than indicated by the Shield's diagram. Bed forms and irregularities occur also in many channels with coarser beds. More complex approaches have been used that involve separating the total shear stress into two parts associated with the roughness of the sediment grains and of the bed forms. Then, only the first part contributes to erosion. In general, however, the Shield's approach is not very useful for the design of channels in fine-grained materials.

- The length of time that the channel is submerged also must be considered when selecting an allowable velocity. Figure 5-15 highlights the effect of duration on allowable velocity.

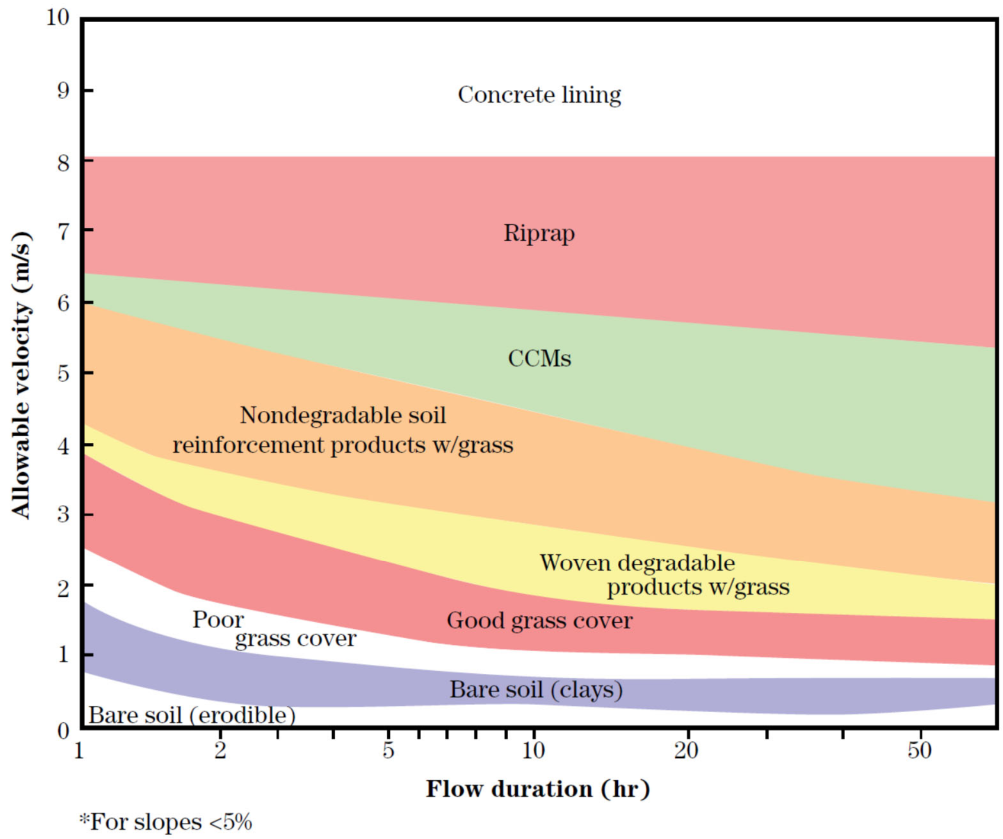


Figure 5-15. Impact of flow duration on allowable velocity. (Source: NRCS 2007)

Guidelines for Applications. The following guidelines are suggested by the COE (1994) for performing the computations and following the procedures listed for the allowable velocity and shear stress concepts:

- If cross sections and slope are reasonably uniform, computations can be based on an average section. Otherwise, divide the project length into reaches and calculate values for small, medium, and large sections.

- Determine the discharge that would cause the initiation of erosion from the stage-velocity or discharge-velocity curve, and determine its frequency from a flood-frequency or flow-duration curve. This may give some indication of the potential for instability. For example, if bed movement has a return period measured in years, which is the case with some cobble or boulder channels, the potential for extensive profile instability is likely to be negligible. On the other hand, if the bed is evidently active at relatively frequent flows, response to channel modifications may be rapid and extensive.

Design Steps for Maximum Permissible Velocity/Allowable Shear Stress Method

McCuen (1998) presents the following steps when designing a stable channel using the permissible velocity/allowable shear stress method:

1. For a given channel material, estimate the Manning's roughness coefficient (n), the channel slope (S), and the maximum permissible velocity (V) (such as from Tables 5-1 or 5-2).

2. Compute the hydraulic radius (R) using Manning's equation:

$$R = \left[\frac{Vn}{1.49S^{0.5}}\right]^{1.5}$$

where:

R = hydraulic radius, ft.
V = permissible velocity, ft/sec
S = channel slope, ft/ft
n = roughness of channel lining material, dimensionless

Some typical values for Manning's n for open channels (Chow 1959) are as follows:

Very smooth surface (glass, plastic, machined metal)		0.010
Planed timber		0.011
Rough wood		0.012 – 0.015
Smooth concrete		0.012 – 0.013
Unfinished concrete		0.013 – 0.016
Brickwork		0.014
Rubble masonry		0.017
Earth channels, smooth no weeds		0.020
Firm gravel		0.020
Earth channel, with some stones and weeds		0.025
Earth channels in bad condition, winding natural streams		0.035
Mountain streams		0.040 – 0.050
Sand (flat bed), or gravel channels,	d=median grain diameter, ft.	$0.034d^{1/6}$

Chow (1959) also provides an extensive list of n values, along with photographs. Most engineering hydrology and hydrologic texts (including McCuen 1998) will also contain extensive guidance on the selection of Manning's n values for different channel conditions. A later section in this chapter presents the traditional trial-and-error method for determining Manning's n values for grass-lined channels, using measured VR-n relationships for different grass types. The Pennsylvania Erosion and Sediment Control Manual (2012) provides the following n values for temporary channel linings.

Manning's Roughness Coefficient ("n") for Commonly Used Temporary Channel Linings

Lining Type	Manning's "n" Flow Depth Ranges 0 - 0.5 ft. (0 - 0.15 m)	0.5 - 2.0 ft. (0.15 - 0.61 m)	>2.0 ft (>0.61 m)
Jute Net	0.028	0.022	0.019
Curled Wood Mat	0.066	0.035	0.028
Straw with Net	0.065	0.033	0.025
Synthetic Mat	0.036	0.025	0.021
Woven Paper Net	0.016	0.015	0.015

Adapted from FHWA HEC-15

3. Calculate the required cross-sectional area, using the continuity equation and the previously determined design storm peak flow rate (Q):

$$A = \frac{Q}{V}$$

where:
A = cross-sectional area of channel (wetted portion), ft^2
Q = peak discharge for design storm being considered, ft^3/sec
V = permissible velocity, ft/sec

4. Calculate the corresponding wetter perimeter (P):

$$P = \frac{A}{R}$$

where:
P = wetted perimeter, ft
A = cross-sectional area of channel (wetted portion), ft^2
R = hydraulic radius, ft.

5. Calculate an appropriate channel base width (b) and depth (y) corresponding to a specific channel geometry (usually a trapezoid channel, having a side slope of z:1 side slopes [horizontal:vertical]).

Figure 5-16 (Chow 1959) can be used to significantly shorten the calculation effort for the design of channels by skipping step 4 above and more effectively completing step 5. This figure is used to calculate the normal depth (y) of a channel based on the channel side slopes and known flow and channel characteristics. It requires using the Manning's equation in the following form:

$$AR^{\frac{2}{3}} = \frac{nQ}{1.49S^{0.5}}$$

Initial channel characteristics that must be known include the following: z (the side slope), and b (the channel bottom width, assuming a trapezoid or a rectangular cross-section). It is easy to examine several different channel options (varying z and b) by calculating the normal depth (y) for a given peak discharge rate, channel slope, and roughness. The most practical channel can then be selected from the alternatives.

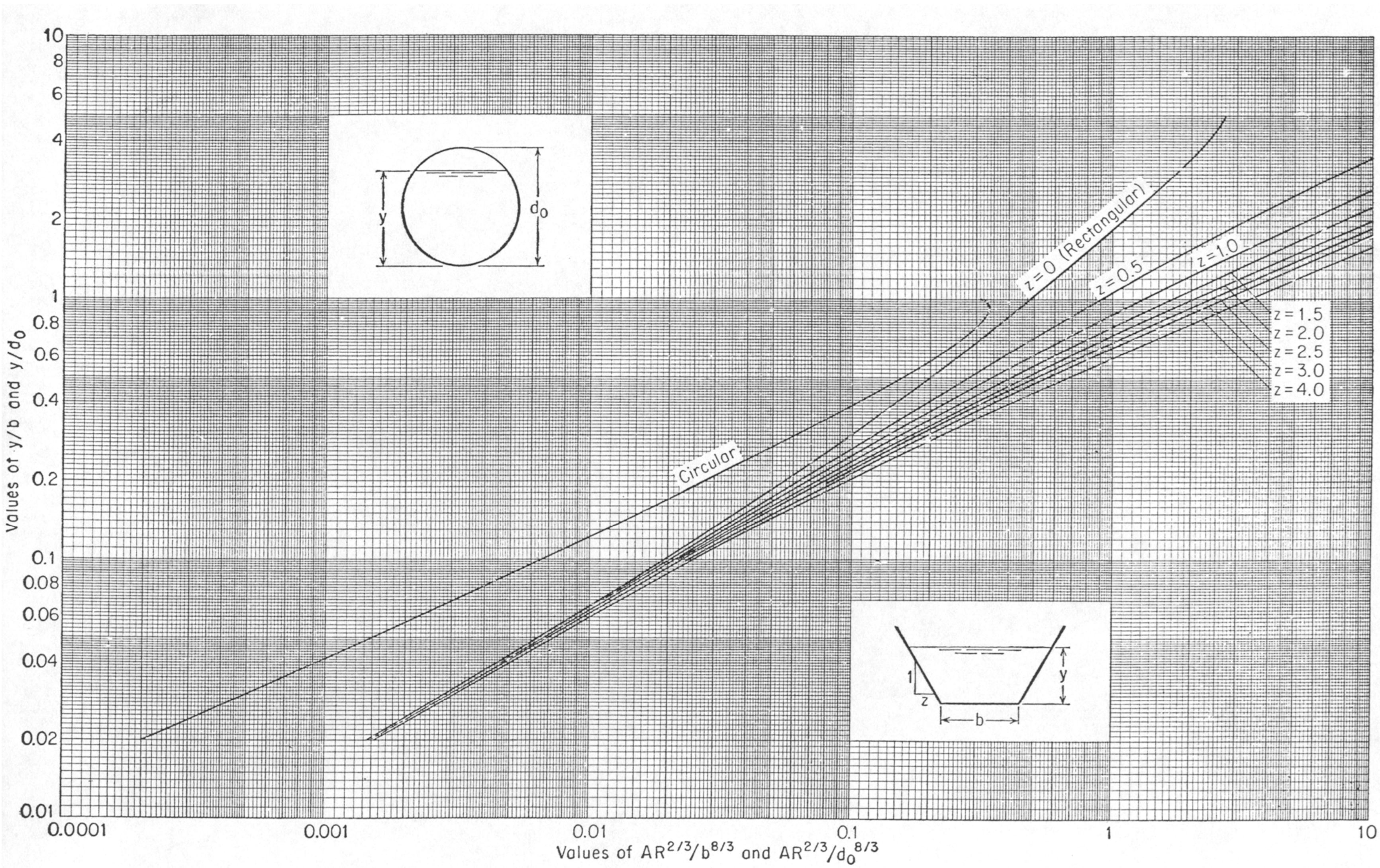


Figure 5-16. Chow (1959) curves for determining normal depth for various channel geometries.

Example:

Assume the following conditions for a bare soil-lined channel:

Noncolloidal alluvial silts, water transporting colloidal silts:
Manning's roughness coefficient (n) = 0.020
maximum permissible velocity (V) = 3.5 ft/sec
(the allowable shear stress is 0.15 lb/ft^2)

Peak discharge flow rate (Q) = 13 ft^3/sec

Channel slope = 1%, or 0.01 ft/ft

Therefore:

The hydraulic radius (R) using Manning's equation:

$$R = \left[\frac{Vn}{1.49S^{0.5}}\right]^{1.5} = \left[\frac{3.5(0.020)}{1.49(0.01)^{0.5}}\right]^{1.5} = 0.32\,ft.$$

The required cross-sectional area, using the continuity equation and the design storm peak flow rate (Q):

$$A = \frac{Q}{V} = \frac{13}{3.5} = 3.7\,ft^2$$

Therefore, AR$^{2/3}$ = (3.7)(0.32)$^{2/3}$ = 1.7, and the wetted perimeter is A/R = 3.7/0.32 = 12 ft. Table 5-3 shows the calculated normal depth (y) for different channel options that all meet the allowable velocity criteria. Also shown on this table is the calculated maximum shear stress:

γRS= (62.4 lb/ft^3) (R ft) 0.01 ft/ft) = 0.62R

Since the allowable shear stress is 0.15 lb/ft^2, the hydraulic radius must be less than 0.24 ft (less than only about 3 inches deep). This will therefore require a relatively-wide channel, as the depth of flow can be used instead of the hydraulic radius as a conservative approach to calculate the maximum shear stress for wide and shallow channels.

As the channel becomes wider, the side slopes have little effect on the normal depth and the calculated maximum shear stress, as expected. The safety factors are the ratios of the allowable shear stress (0.15 lb/ft^2) divided by the calculated maximum shear stress. None of these channels can satisfy the allowable shear stress with this natural material, unless the channel is wide. A minimum channel width between 15 and 25 ft would result in a stable channel. However, a channel liner can be used to reinforce the channel, resulting in a larger allowable shear stress, which will enable a narrower channel to transport the flow.

Table 5-3. Alternative Channel Geometries Meeting Maximum Permissible Velocity Criterion (3.5 ft/sec) and Allowable Shear Stress (0.15 lb/ft^2)

Side slope (z)	Bottom width (b), ft	$b^{8/3}$	$AR^{2/3}/b^{8/3}$	y/b	Normal depth (y), ft	Top width (T), ft	Area (A), ft^2	Wetted perimeter (P), ft	Hydraulic radius (R), ft	b/y	R/y	Maximum shear stress using y (τ), lb/ft^2	Safety factor (allowable shear stress/ max. shear stress using y)	Maximum shear stress using R (τ), lb/ft^2	Safety factor (allowable shear stress/ max. shear stress using R)
4	2	6.4	0.27	0.32	0.62	7.0	2.8	10.6	0.26	3.2	0.42	0.32	0.39	0.16	0.92
4	4	41	0.041	0.13	0.52	8.2	3.2	10.5	0.30	7.7	0.58	0.32	0.47	0.19	0.80
4	8	260	0.0066	0.046	0.37	11.0	3.5	11.9	0.30	21.6	0.80	0.23	0.65	0.18	0.81
4	15	1400	0.0012*	0.017	0.26	17.1	4.2	17.3	0.24	57.7	0.93	0.16	0.94	0.15	0.99
4	25	5300	0.00032*	0.008	0.2	26.6	5.2	26.5	0.19	125.0	0.97	0.12	**1.25**	0.12	**1.24**
2	2	6.4	0.27	0.38	0.76	5.0	2.7	6.9	0.39	2.6	0.51	0.47	0.32	0.24	0.62
2	4	41	0.041	0.14	0.56	6.2	2.9	7.0	0.41	7.1	0.73	0.35	0.43	0.26	0.59
2	8	260	0.0066	0.049	0.39	9.6	3.4	9.7	0.35	20.5	0.91	0.24	0.63	0.22	0.68
2	15	1400	0.0012*	0.017	0.26	16.0	4.0	15.9	0.25	57.7	0.98	0.16	0.94	0.16	0.95
2	25	5300	0.00032*	0.008	0.2	25.8	5.1	25.6	0.20	125.0	0.99	0.12	**1.25**	0.12	**1.21**
1	2	6.4	0.27	0.44	0.88	3.8	2.5	5.2	0.49	2.3	0.55	0.55	0.27	0.30	0.49
1	4	41	0.041	0.16	0.64	5.3	3.0	5.8	0.51	6.3	0.79	0.40	0.38	0.32	0.47
1	8	260	0.0066	0.049	0.39	8.8	3.3	8.8	0.37	20.5	0.95	0.24	0.63	0.23	0.65
1	15	1400	0.0012*	0.017	0.26	15.5	4.0	15.4	0.26	57.7	0.99	0.16	0.94	0.16	0.93
1	25	5300	0.00032*	0.008	0.2	25.4	5.0	25.3	0.20	125.0	1.00	0.12	**1.25**	0.12	**1.20**
0.5	2	6.4	0.27	0.5	1	3.0	2.5	4.7	0.53	2.0	0.53	0.62	0.24	0.33	0.45
0.5	4	41	0.041	0.16	0.64	4.6	2.8	5.2	0.53	6.3	0.83	0.40	0.38	0.33	0.45
0.5	8	260	0.0066	0.049	0.69	8.7	5.8	9.4	0.62	11.6	0.89	0.24	0.63	0.38	0.39
0.5	15	1400	0.0012*	0.017	0.26	15.3	3.9	15.2	0.26	57.7	0.99	0.16	0.94	0.16	0.93
0.5	25	5300	0.00032*	0.008	0.2	25.2	5.0	25.1	0.20	125.0	1.00	0.12	**1.25**	0.12	**1.20**

* estimated, as these values are under range from the plotted curves.

Table 5-3 compares the shear stress calculated using the hydraulic radius, R, to the larger shear stress calculated using the normal depth, y. Also shown is the ratio of the hydraulic radius to the normal depth for different channel conditions. Figure 5-17 is a plot showing how the normal depth approaches the hydraulic depth, for this example, as the channel width to normal depth ratios increases. The maximum shear stress is therefore much larger when the normal depth is used instead of the hydraulic radius for relatively narrow channels, but the results are similar for wider channels.

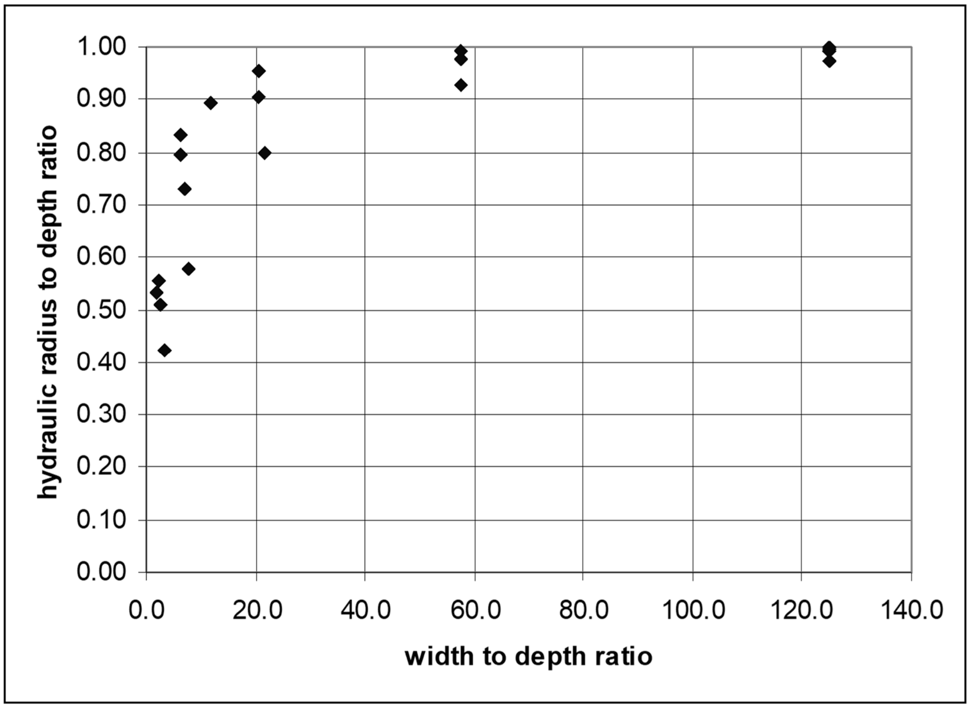


Figure 5-17. Relationship of hydraulic radius to normal depth for different channel width to depth conditions.

A more direct approach is to use Figure 5-16 in reverse order. As shown previously, the maximum depth can be calculated based on the maximum allowable shear stress and the channel slope:

$$D = \frac{\tau_c}{\gamma S} = \frac{0.15 lb/ft^2}{\left(62.4 lb/ft^3\right)\left(0.01 ft/ft\right)} = 0.24 ft$$

With the known value for $AR^{2/3}$ (3.7 x $0.32^{2/3}$ = 1.7), Table 5-5 shows the calculated maximum side slope for different channel bottom widths (b). All of these options will meet both the allowable velocity and shear stress criteria.

Table 5-5. Example Calculations for Required Side Slopes for Different Bottom Widths, Meeting Allowable Velocity and Maximum Shear Stress Criteria

b (ft)	y/b (with y = 0.24ft)	$AR^{2/3}/b^{8/3}$	Required side slope (z), or longer
8	0.030	0.0066	>4
10	0.024	0.0036	>4
15	0.016	0.0012*	5 (estimated)
20	0.012	0.00057*	any (0.5 to 4)

* estimated, as these values are under range from the plotted curves.

For this example, side slopes of about 5:1 and with a bottom width of 15 ft may be stable, or "any" side slope may be suitable for bottom widths of 20 ft, or wider. This example has shown that it may not be possible to design a stable channel only based on allowable maximum velocity. It is a good idea to also calculate the maximum shear stress based on the normal depth. Without a channel liner, most stable channels in soils will need to be relatively wide. Because of the increased use of land needed for wide channels (see the calculated top width "T" in Table 5-3), it is usually necessary to consider channel liners, either grass-lined, or re-enforced with netting mats, as described in the following sections.

Design of Grass-Lined Channels

According to Temple, *et al*. (1987) in *Stability Design of Grass-Lined Open Channels*, USDA Agricultural Handbook 667, it is assumed that grass channel linings are used to protect an erodible soil boundary and prevent channel degradation. They found that detachment begins at total stress levels small enough to be withstood by the vegetation without significant damage to the plants themselves, i.e., it is possible for the vegetation to be undercut and the weaker vegetation washed away. This vegetation loss decreases the density and uniformity of the vegetative cover, which in turn leads to greater stresses at the soil-water interface, resulting in an increased erosion rate. Supercritical channel flows cause a more severe problem compared to subcritical flows because small irregularities in the channel lining cause stress-concentration points to develop. For very erosion-resistant soils, the lining vegetation may sustain damage before the effective stress at the soil-water interface becomes large enough to detach soil material. Although the limiting condition in this case is the stress on the plants, failure progresses in a similar manner: damage to the plant cover results in an increase in effective stress on the soil boundary until conditions critical to erosion are exceeded. The resulting erosion further weakens the cover, and unraveling occurs. When plant failure occurs, it is a complex process involving removing young and weak plants, shredding and tearing leaves, and fatigue weakening stems.

Because of the many uncertainties and different methods of failure, the use of an approximate design approach is considered appropriate for most practical applications. Temple, *et al*. (1987) state that conservative design criteria are required, as the potential for rapid unraveling of a channel lining can occur once a weak point has developed, especially considering the variability of vegetative covers. Very dense and uniform covers will likely withstand stresses substantially greater than immature or spotty covers without significant damage. However, they recommend that poor maintenance should be assumed in conservative designs.

The design of a grass-lined open channel differs from the design of an unlined or structurally lined channel in that (1) the flow resistance is dependent on channel geometry and discharge, (2) a portion of the boundary stress is associated with drag on individual vegetation elements and is transmitted to the erodible boundary through the plant root system, and (3) the properties of the lining vary both randomly and periodically with time. Each of these differences requires special considerations in the design process. Temple, *et al*. (1987) presents detailed descriptions of the generalized step-by-step procedure for grass-lined channel design, including computer code.

Plant Species Selection for Vegetative-Lined Channels

The following is a general discussion and does not provide site-specific guidance for different climatic regions. However, it does describe the general problems associated with establishing plants in a channel environment. Local guidance (such as from the local USDA or University Extension services' offices) needs to be sought for specific recommendations for a particular location. Obviously, channels carrying water for long periods of the year may not be suitably lined with terrestrial vegetation. Extended wet periods will also affect plant selection. Again, local plant specialists need to be consulted for the proper selection of suitable plants for the anticipated growing conditions. The *Alabama Handbook for Erosion Control, Sediment Control, and Stormwater Management on Construction Sites and Urban Areas* (ASWCC 2003) contains further general guidance on plant selection for Alabama uses, for example.

Site Considerations

When a site will receive heavy use, such as a sports field, plant species that are wear resistant and have rapid wear recovery (such as bermudagrass) should be selected. Bermudagrass also has a fast establishment rate and is adapted to many geographical areas. Where a neat appearance is desired, plants that respond to frequent mowing should be used. As an example, likely choices for quality turf in north Alabama are bermudagrass or tall fescue, while in central or south Alabama bermudagrass, centipede, or zoysia are good choices. At sites where low maintenance is desired, low fertility requirements and vegetation persistence are particularly important. Sericea lespedeza and tall fescue are good choices in north Alabama, while bahiagrass and centipede do well in central and south Alabama. Local resources need to be consulted for recommendations of the best grass for channel-lining in specific locations, emphasizing non-invasive native plants.

Seasonal Considerations

Planting guidance is available throughout the United States. For example, in Alabama, the most effective times for planting perennial grasses and legumes generally extend from March through May and from late August through October. Outside these dates, the probability of failure is greater. Growing seasons must be considered when selecting species. Grasses and legumes are usually classified as warm or cool-season in reference to their season of growth. Cool-season species produce most of their growth during the spring and fall and are relatively inactive or dormant during the hot summer months. Therefore, fall is the most dependable time to plant them. Warm-season plants grow most actively during the summer and go dormant at the first frost in the fall. Spring and early summer are the preferred planting times for warm-season species.

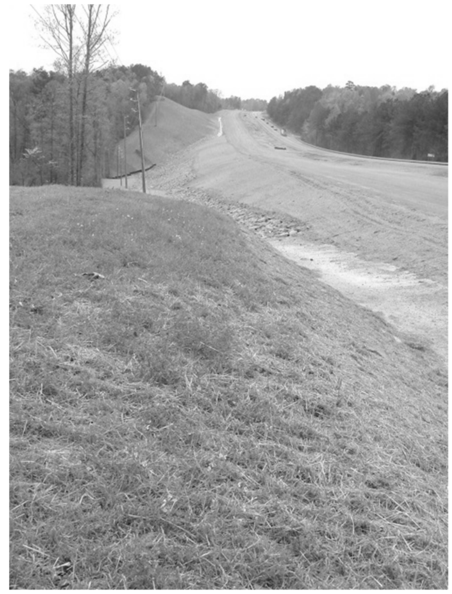
 Sod placed along a channel bottom, with grass seed along the edges	 Sod needing irrigation during dry period	 Combinations of rock, sod, seed, and mulch were used at this highway construction site.

Figure 5-18. Sod and mulch placement.

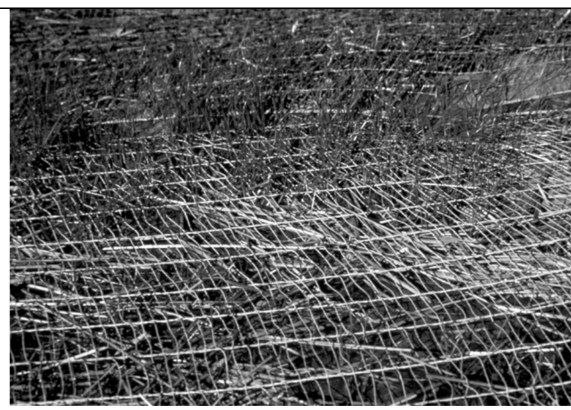
 Seeding along median strip swale of highway project	 Mesh placed over seed and mulch.

Figure 5-19. Seed and mulch placement.

Selecting the Right Grasses for Channel Lining

Information on plant species adapted for soil stabilization use is contained in most state erosion control manuals and from the Internet sources listed at the end of this chapter. Most of these commercial suppliers of seeds and sod will help select the most appropriate species for local site conditions. Local USDA Agricultural Extension offices also may be able to provide updated guidance. Using this locally-generated information makes plant selection more straight forward for most situations. Specific seeding rates and planting instructions are presented in the specifications for local conditions by regulatory agencies.

According to Temple, *et al.* (1987), the selection of grass species for use in channels is based on site-specific factors, including: (1) soil texture, (2) depth of underlying material, (3) management requirements of vegetation, (4) climate, (5) slope, and (6) type of structure or engineering design. The expected flow rates, availability of seed, ease of stand establishment, species or vegetative growth habit, plant cover, and persistence of established species are other factors that also should be considered in selecting appropriate grasses necessary for stable channel designs. Channel construction should be scheduled to allow establishment of the grass stand before subjecting the channel to excessive flows. The uses of modern channel lining systems, as discussed below, help alleviate this problem. The establishment of permanent covers involves liming and fertilizing, seed bed preparation, appropriate planting dates, seeding rates, and mulching, or placing the correct erosion mat.

Plants for Temporary Channel Linings

Based on flow tests on sandy clay channels, Temple, *et al.* (1987) recommends wheat (*Triticum aestivum L.*) for winter and sudangrass [*Sorghum sudanensis* (Piper) *Hitchc.*] for late-summer temporary covers. These temporary covers have been shown to rapidly increase the permissible discharge rate to five times that of an unprotected channel. Other recommended annual and short-lived perennials that can be used for temporary channel linings include:

- Barley (*Hordeum vulgare L*.), noted for its early fall growth;
- Oats (*Avena) sativa L*.), in areas of mild winters;
- Mixtures of wheat, oats, barley, and rye (*Secale cereale L*.);
- Field bromegrass (*Bromus spp*.); and
- Ryegrasses (*Lolium spp*.).

Summer annuals, including German and foxtail millets (*Setaria spp*.), pearl millet [*Pennisetum americanurn (L.) Leeke*], and certain cultivated sorghums other than sudangrass, may also be used for temporary mid- to late-summer covers, according to Temple, *et al.* (1987). Since millets do not continue to grow as aggressively as sorghums after mowing, they may leave a more desirable, uniformly thin mulch for subsequent permanent seeding. Temporary seedings involve minimal cultural treatment, short-lived but quick germinating species, and little or no maintenance. The temporary covers should be close-drilled stands and not be allowed to go to seed. The protective cover provided by the temporary vegetation should provide stalks, roots, and litter into which permanent grass seeds can be drilled the following spring or fall.

Plants for Permanent Channel Linings

Many grasses can be used for permanent vegetative channel linings. Temple, *et al.* (1987) lists the following tight-sod-forming grasses as the most preferred warm- and cool-season grasses for channel linings: bermudagrass [*Cyodon dactylon var dactylon (L.) Pers*.], bahiagrass (*Paspalum notatum Fluggle*), buffalograss [*Buchloe dactyloides (Nutt.) Enge1m*.], intermediate wheatgrass [*Agropyron intermedium (Host) Beauv.*], Kentucky bluegrass (*Poa ratensis L.*), reed canarygrass (*Phalaris arundinacea L.*), smooth bromegrass, (*Bromus inermis Leyss.*), vine mesquitegrass (*Panicum obtusum H.B.K.*), and Western wheatgrass (*Agropyron Smithii Rydb.*). These grasses are among the most widely used species for channel linings and grow well on a variety of soils. A grass mixture should include species adapted to the full range of soil moisture conditions anticipated to be encountered by the channel side slopes. The local NRCS and University Extension offices know the best soil-binding grass species for a particular area, as well as the associated planting and maintenance requirements. The most important characteristic of the selected grasses is their ability to survive and thrive in the channel environment.

Bermudagrass is probably the most widely-used grass in the southern region of the U.S. It will grow on many soil types, but it may require extra management. It forms a dense and persistent sod, if managed properly. Temple, *et al.* (1987) recommend that when bermudagrass is used, winter-hardy varieties should be obtained. Improved varieties, such as “Coastal,” “Midland,” “Greenfield,” “Tifton,” and “Hardie,” do not produce seed, and must be established by sprigging. Where winters are mild, channels can be established quickly with seed of “Arizona Common” bermudagrass. “Seed of bermudagrass,” a new seed-propagated variety with greater winter hardiness than Arizona Common, should be available now commercially. Bermudagrass is not shade tolerant and should not be used in mixtures containing tall grasses. However, the inclusion of winter annual legumes such as hairy vetch (*Vicia villosa Roth*.), narrowleaf vetch [*V. sativa L. subspecies nigra (L.) Ehrh.*], and/or a summer annual such as Korean lespedeza (*Lespedeza stipulacea Maxim.*), may be beneficial to stand maintenance.

The selection of grasses used in channels often depends on availability of seed or plant material. Chronic national seed shortages of some warm-season grasses, especially seed of native species, often have led to planting seed marginally suited to site situations. Lack of available seed of desired grass species and cultivars adapted to specific problem sites is a major constraint often delaying or frustrating seeding programs. In addition to the grass species or base mixture of grasses used for erosion control, carefully selected special-use plants may be added for a specific purpose or situation. Desirable wildlife food plants may be included in the mixture if they do not detrimentally compete with the base grasses used for erosion control. Locally-adapted legumes are often added if they are compatible with the grasses and noncompetitive. Additional information on establishment and maintenance of grass-lined channels is provided in Temple, *et al*. (1987).

Determination of Channel Design Parameters
The conditions governing the stability of a grass-lined open channel are the channel geometry and slope, the erodibility of the soil boundary, and the properties of the grass lining that relate to flow retardance potential and boundary protection.

Vegetation Parameters
The design of a stable grass-lined open channel needs to consider the effective stress imposed on the soil layer (Temple, *et al*, 1987). This requires the determination of two vegetation parameters: 1) the retardance curve index (C_l) which describes the potential of the vegetal cover to develop flow resistance, and 2) the vegetation cover factor (C_f) which describes the degree to which the vegetation cover prevents high velocities and stresses at the soil-water interface. These are described below.

Retardance Potential. The parameter describing the retardance potential of a vegetal cover is the retardance curve index, C_I. This parameter determines the limiting vegetation stress. Its relation to the measurable physical properties of the vegetal cover is given by:

$$C_I = 2.5\left(h\sqrt{M}\right)^{\frac{1}{3}}$$

where:

h is the representative stem length
M is the stem density in stems per unit area.

When consistent units are used, the relation is dimensionless. This factor is commonly used in the following equation to estimate the maximum allowable shear stress on the vegetation (τ_{va}, in lb/ft^2):

$$\tau_{va} = 0.75C_I$$

The stem length usually will need to be estimated directly from knowledge of the vegetation conditions at the time of anticipated maximum flow. When two or more grasses with widely differing growth characteristics are involved, the representative stem length is determined as the root mean square of the individual stem lengths.

When this equation is used to estimate the retardance potential, an estimate of the stem density is also required. The reference stem densities shown in Table 5-6 may be used as a guide in estimating this parameter. Temple, *et al.* (1987) obtained the values of reference stem densities from a review of the available qualitative descriptions and stem counts reported by researchers studying channel resistance and stability.

Table 5-6. Properties of Grass Channel Linings (Temple, *et al*. 1987)

Cover Factor (C_f) (good uniform stands)	Covers Tested	Reference stem density (M), stems/ft^2
0.90	bermudagrass	500
0.90	centipedegrass	500
0.87	buffalograss	400
0.87	kentucky bluegrass	350
0.87	blue grama	350
0.75	grass mixture	200
0.50	weeping lovegrass	350
0.50	yellow bluestem	250
0.50	alfalfa	500
0.50	lespedeza sericea	300
0.50	common lespedeza	150
0.50	sudangrass	50

Since cover conditions will vary from year to year and season to season, establishing an upper and a lower bound for the curve index (C_I) is often more realistic than selecting a single value. When this approach is taken, the lower value should be used in stability computations and the upper value should be used in determining channel capacity. Such an approach normally will result in satisfactory channel operation for lining conditions between the specified bounds. Whatever the approach used to obtain the flow retardance potential of the lining, the values selected should represent an average for the channel reach in question, since it will be used to infer an average energy loss per unit of boundary area for any given flow.

Vegetation Cover Factor. The vegetation cover factor, C_f, is used to describe the degree to which the vegetation cover prevents high velocities and stresses at the soil-water interface. Because the protective action described by this parameter is associated with the prevention of local erosion damage that may lead to channel unraveling, the cover factor should represent the weakest area in a reach, rather than an average for the cover type.

Observations of flow behavior and available data indicate that the cover factor is dominated by the density and uniformity of density in the immediate vicinity of the soil boundary. For relatively dense and uniform covers, uniformity of density is primarily dependent on the growth characteristics of the cover, which are in turn related to grass type. This relationship was used by Temple, *et al.* (1987) in the development of Table 5-5. This table cannot obviously account for such considerations as maintenance practices, or uniformity of soil fertility or moisture conditions.

Soil Parameters

Two soil parameters are required for the application of effective shear stress concepts to the design of stable lined or unlined channels having an erodible soil boundary: 1) soil grain roughness (n_s), and 2) allowable effective shear stress (τ_a). When the effective shear stress approach is used, the soil parameters are the same for both lined and unlined channels, satisfying sediment transport restrictions. The relations shown here were presented by Temple, *et al.* (1987) and were taken from the SCS (1977) channel stability criteria; the desired parameters, soil grain roughness and allowable stress, are determined from basic soil parameters. Ideally, the basic parameters should be determined from tests on representative soil samples from the site.

For effective shear stress design, soil grain roughness is defined as the roughness associated with particles or aggregates of a size that may be independently moved by the flow at incipient channel failure. Although this parameter is expressed in terms of a flow resistance coefficient (n_s), its primary importance in design of vegetated channels is its influence on effective shear stress, as shown below. Its contribution to the total flow resistance of a grass-lined channel is usually negligibly small.

The allowable shear stress is key to the effective shear stress design procedure. The allowable effective shear stress is defined as the shear stress above which an unacceptable amount of particle or aggregate detachment would occur.

Noncohesive Soil. Noncohesive soils are defined as fine- or coarse-grained, based on whether d_{75} (the diameter for which 75 percent of the material is finer) is less than, or greater than, 0.05 in. For fine-grained soils, the soil grain roughness and allowable effective shear stress are constant, while for a coarse-grained soil, these parameters are a function of particle size. The allowable effective shear stress and roughness parameters for noncohesive soils are given in Figures 5-20 and 5-21, as a function of particle size.

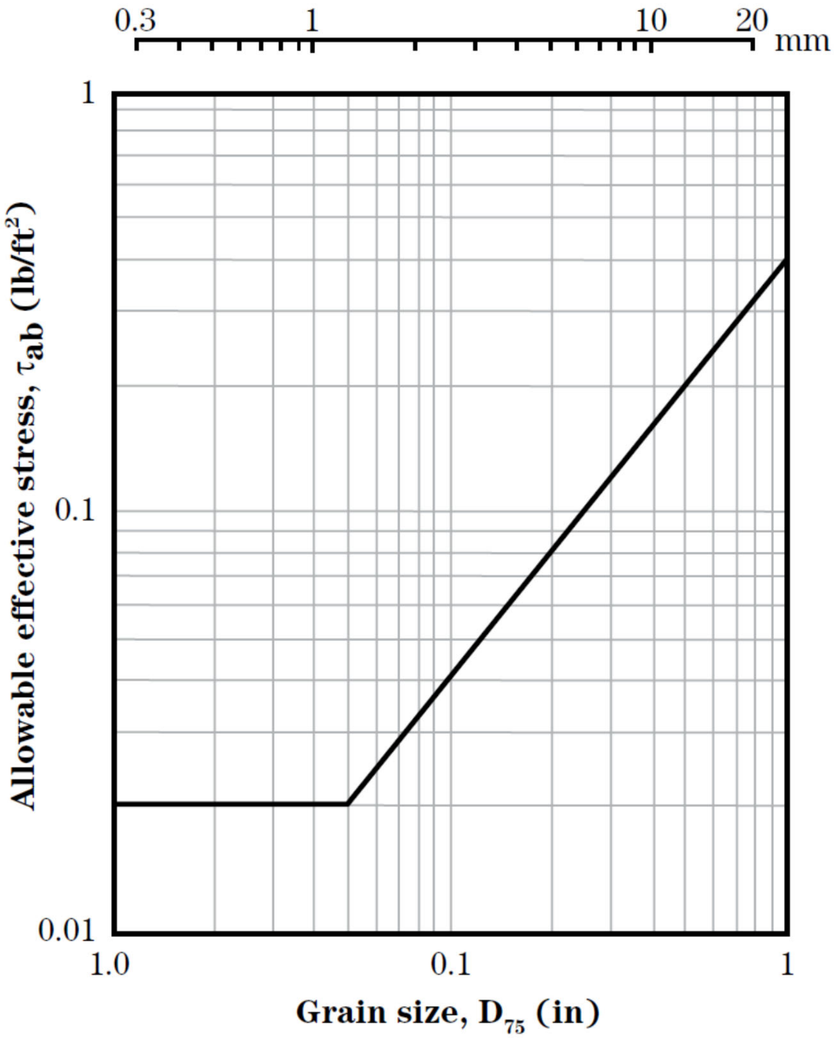


Figure 5-20. Allowable effective shear stress for noncohesive soils (Temple, *et al.* 1987).

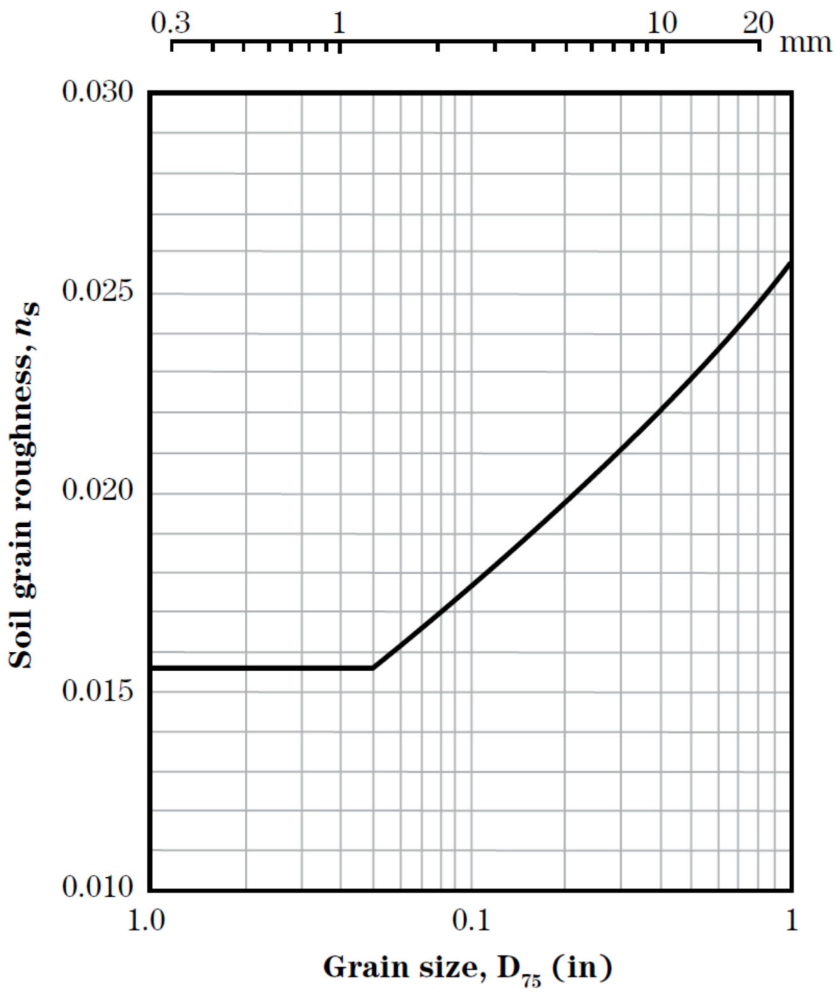


Figure 5-21. Soil grain roughness for noncohesive soils (Temple, *et al*. 1987).

Cohesive Soil. All cohesive soils are treated as fine-grained soils, having a constant soil grain roughness (about 0.0155, according to Figure 5-22). The allowable effective shear stresses presented here are taken directly from SCS (1977) permissible velocity design criteria. The soil properties required to determine the allowable effective shear stress are the soil's classification in the unified soil classification system, its plasticity index (I_w), and its void ratio (e). This calculation requires a basic allowable effective shear stress (τ_{ab}) that is determined from the soil classification and plasticity index. This basic value is then corrected for void ratio, according to the relation:

$$\tau_a = \tau_{ab} C_e^2$$

The basic allowable shear stress (τ_{ab}) is given in Figure 5-22, while the void ratio correction factor (C_e) is given in Figure 5-23. The soil classification information (plasticity index, I_w, and void ratio, e) are readily available for cohesive soils in standard soils references, and in Temple, *et al*. (1987). The previously presented Figure 5-12 (COE 1994) is a simplified figure for determining allowable shear stress for cohesive soils, if these detailed soil characteristics are not available.

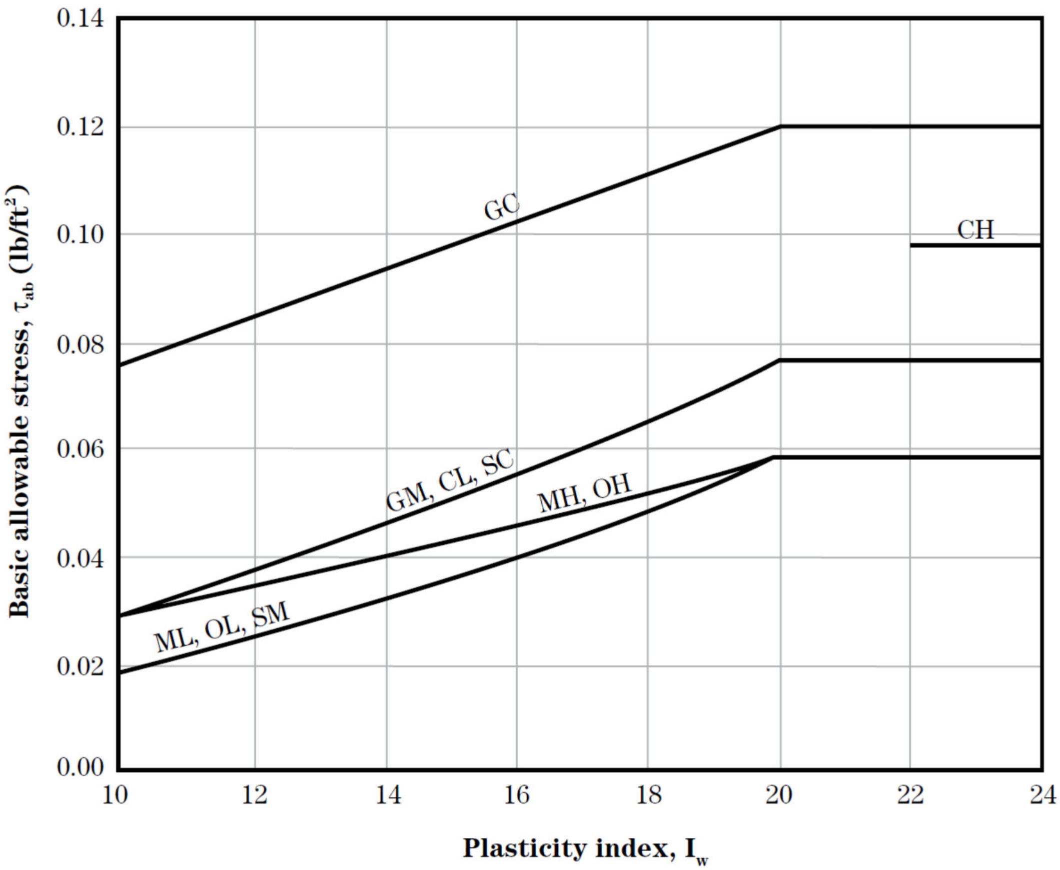


Figure 5-22. Basic allowable effective stress for cohesive soils (Temple, *et al*. 1987 and SCS 1977).

The Unified Soil Classification System (USCS) defines these cohesive soil types as:

OL = organic with low plasticity
OH = organic with high plasticity
CL = clay with low plasticity
CH = clay with high plasticity
ML = silt with low plasticity
MH = silt that is well graded (diverse particle sizes)
SC = sand/clay
SM = sand/silt
GC = gravel/clay
GM = gravel/silt

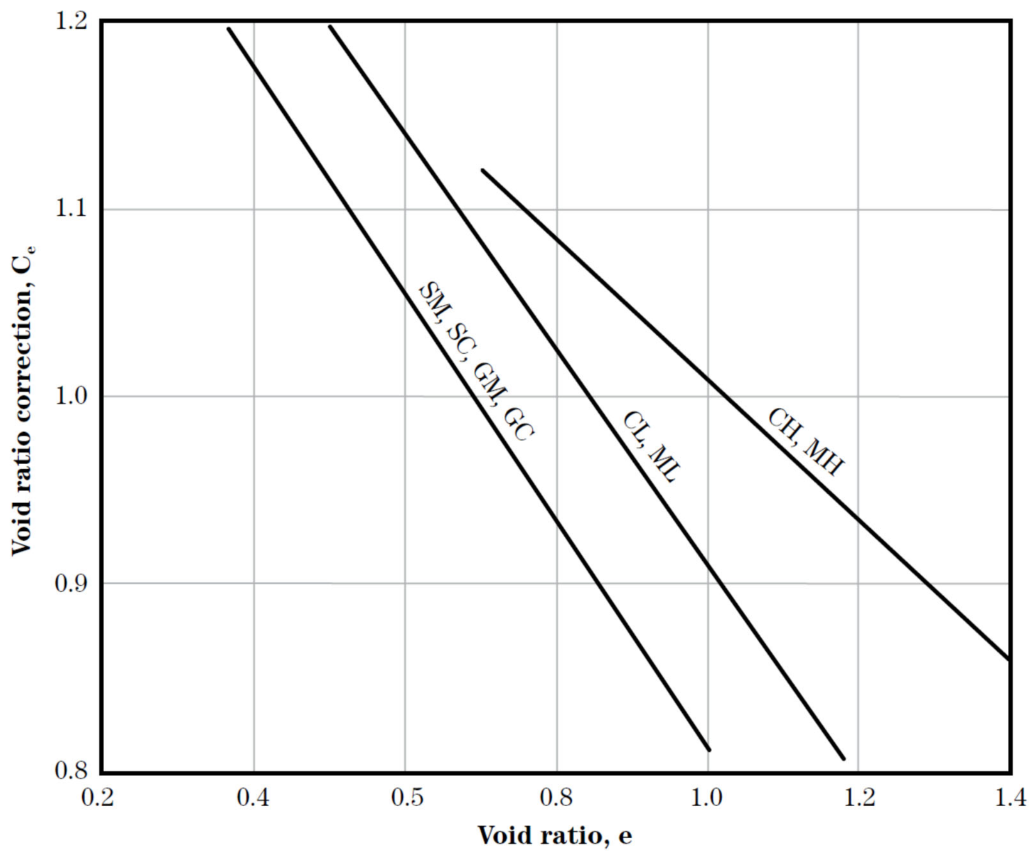


Figure 5-23. Void ratio correction factor for cohesive soils (Temple, *et al*. 1987 and SCS 1977).

Selection of Roughness Factor for Grass Lined Channels

The value of Manning's "n" in grasses is a function of grass type and the product of velocity and hydraulic radius (VR). Grasses are divided into retardance classes based on their physical characteristics (height, width, density, etc.). Most sod forming grasses are classified as type C (see HEC-15 for definitions for all classes of retardance). These grasses can have "n" values ranging from 0.03 - 0.3 depending on VR, with a typical value of 0.03 in open channels. Figure 5-24 is an example of a VR-n curve based on data from the Stillwater, OK, USDA field tests. It was extended to cover smaller VR ranges appropriate for small drainage flows during extensive field and lab tests by Kirby (2003). The following example shows how the correct n value is selected through a trial-and-error method, depending on the product of the velocity (V) and hydraulic radius (R).

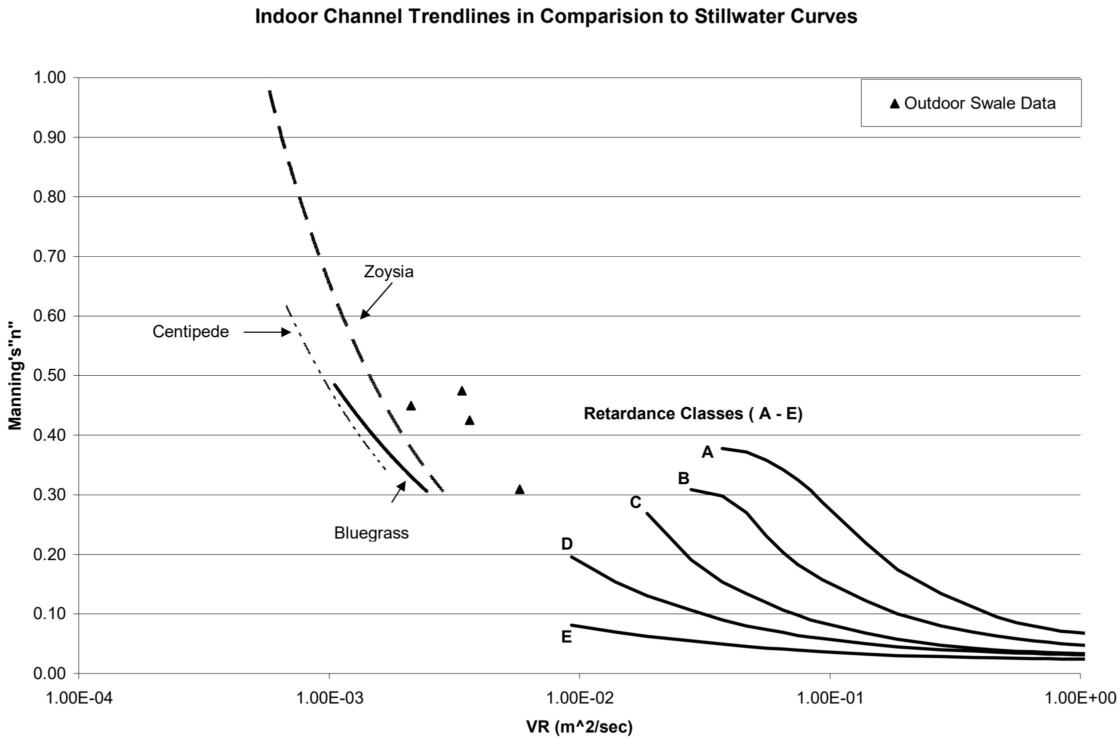


Figure 5-24. VR-n curve for different grasses, showing results for shallow flows (Kirby 2003). (Multiply m^2/sec by values by 10.87 to obtain ft^2/sec units)

Example: Selection of Roughness for Grass-Lined Channels

The appropriate Manning's "n" to use varies on the time frame: (1) bare soil retention and vegetation establishment (short-term), and (2) fully-grassed conditions (long-term) (Chow 1959). Bare soil conditions can be examined using the procedures presented earlier. Mature grass-lined channel roughness values can be determined using typical procedures as illustrated in the following example, which shows how VR-n curves can be used for the proper selection of a roughness value for a grass-lined channel:

> Determine the roughness value for a 10-year design storm of 70 ft^3/sec (2 m^3/sec) in a grass-lined drainage channel having a slope of 0.05 ft/ft and a 4-foot (1.2-m) bottom width and 1:1 side slopes. The grass cover is expected to be in retardance group D.

Long-term design, based on vegetated channel stability:

- use $Q_{peak} = Q_{10year}$ = 70 ft^3/s (2 m^3/s)
- initially assume that $n_{vegetated} = 0.05$

Determine the normal depth of flow, using Figure 5-16 (from Chow 1959):

$$AR^{\frac{2}{3}} = \frac{nQ}{1.49S^{0.5}} = \frac{0.05(70cfs)}{1.49(0.05)^{0.5}} = 10.51$$

and $b^{8/3}$ = (4 ft)$^{8/3}$ = 40.32

therefore $AR^{2/3}/b^{8/3}$ = 10.51/40.32 = 0.26

With a 1:1 side slope trapezoidal channel, the ratio of y/b from Figure 5-16 is 0.43, and the depth is therefore: 4(0.43) = 1.7 ft.

The cross-sectional area is therefore 9.7 ft^2, the velocity is (70 ft^3/sec)/(9.7 ft^2) = 7.2 ft/sec, P is 8.8 ft, and R is 9.7/8.8 = 1.1 ft. VR is therefore (7.2 ft/sec)(1.1 ft) = 7.9 ft^2/sec (=0.73 m^3/sec). From Figure 5-24, the estimated new value for n is therefore 0.032, using a retardance class of D. Figure 5-24 is used if the VR product is very small, such as for small flows in small swales, which is common for many urban applications. In that case, the VR product simply is converted from ft^2/sec to m^2/sec. The depth must therefore be recalculated, using this new value for n:

$$AR^{\frac{2}{3}} = \frac{nQ}{1.49S^{0.5}} = \frac{0.032(70cfs)}{1.49(0.05)^{0.5}} = 6.72$$

and $b^{8/3}$ = (4 ft)$^{8/3}$ = 40.32

therefore $AR^{2/3}/b^{8/3}$ = 6.72/40.32 = 0.17

With a 1:1 side slope trapezoidal channel, the ratio of y/b from Figure 5-16 is 0.34, and the depth is therefore: 4(0.34) = 1.4 ft.

The area is therefore 7.6 ft^2, the velocity is 70/7.6 = 9.2 ft/sec, P is 8.0 ft, and R is 7.6/8.0 = 0.95 ft. The revised VR is therefore (9.2 ft/sec)(0.95 ft) = 8.7 ft^2/sec (0.80 m^2/sec). Figure 5-24 shows that the revised value of n is still close to 0.032.

The maximum shear stress (using normal depth instead of hydraulic radius) is therefore:

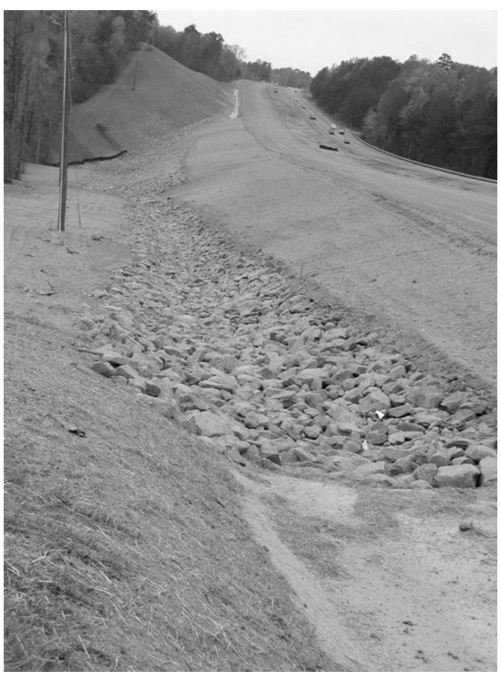
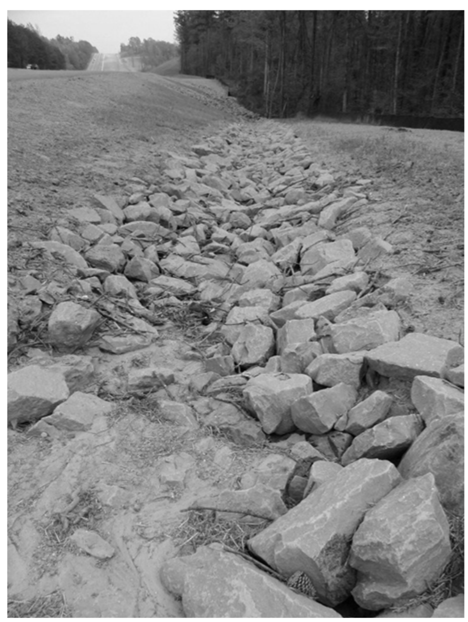
γDS= (62.4 lb/ft^3) (1.4 ft) 0.05 ft/ft) = 4.4 lb/ft^2

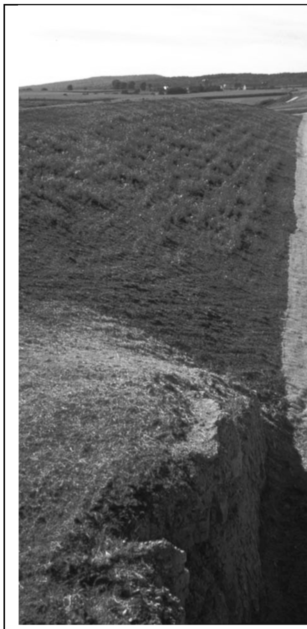
Hence, this channel would be stable if the acceptable value is greater than this rather high value. The following discussion presents additional guidance on the selection and evaluation of a turf-reinforcing mat that would likely be needed for this high shear stress condition. The use of channel-lining mats protecting immature vegetation allows immediate protection of the sensitive soil boundary layer, as described in the following discussions. Also, free computer programs, such as supplied by North American Green (http://www.nagreen.com/), greatly help in the design of the most appropriate channel cross section and liner system.

Drainage Design using Turf-Reinforcing Mats

Current practice is to design channel linings based on shear stress and less frequently on allowable velocity. Shear stress considers the weight of the water above the lining and therefore does a better job of predicting liner stability, compared to only using velocity. However, allowable velocity and the flow regime (if the flow is supercritical or subcritical) still should be examined to minimize unusual conditions.

If a channel will have intermittent flows, it is common to use turf-reinforcing mats as liners to increase the channel stability. However, if the channel will have perennial (or long-term) flows, grass will not be successful and mechanical liners must be used.

 Installation of reinforced liner along thalweg of channel, with other material along sides (VA photo).	 Concrete-lined channel, with reinforced matting along overflow area.
 Large rocks for channel reinforcement	 Close-up of rock reinforced channel, showing sediment accumulation between rocks.



Reinforced liner along channel thalweg.

Plastic tarp used as a temporary liner.

Plastic tarp, with coir logs, for a temporary liner.

Close-up of temporary plastic tarp liner, showing edge staples.

Figure 5-25. Examples of channels lined with vegetation and other materials.

According to Croke (2000), drainage channel design using turf-reinforcement mats must consider three phases: (1) the original channel in an unvegetated state to determine if the matting alone will provide the needed protection before the vegetation is established, (2) the channel in a partially vegetated state, usually at 50% plant density, and (3) the permanent channel condition with vegetation fully established and reinforced by the matting's permanent net structure. The basic shear stress equation can be modified to predict the shear stress applied to the soil beneath a channel mat (Temple, *et al*. 1987):

$$\tau_e = \gamma DS\left(1 - C_f\right)\left(\frac{n_s}{n}\right)^2$$

where:

τ_e = effective shear stress exerted on soil beneath vegetation
γ = specific weight of water (62.4 lbs/ft^3)
D = the maximum flow depth in the cross section (ft)
S = hydraulic slope (ft/ft)
C_f = vegetation cover factor (this factor is 0 for an unlined channel)
n_s = roughness coefficient of underlying soil
n = roughness coefficient of vegetation and/or erosion control blanket (if vegetated, or not)

The flow depth, rather than the hydraulic radius, is used in this equation because this will result in the maximum shear stress developed, rather than the average shear stress (Temple, *et al.* 1987). In addition, the depth value is very close to the hydraulic radius for most channels, especially as sheetflow conditions are approached. The cover factor is a function of the grass and stem density, as previously described, while the roughness coefficients are standard Manning's roughness values for channels. The permissible shear stress for a liner mat should be available from manufacture's specifications, but it will vary for different growth phases, if vegetated. Obviously, the liner matting significantly reduces the shear stress exerted on the soil. The following tables summarize some typical values for a selection of these equation parameters for turf-reinforcing mats (products supplied by North American Green from www.nagreen.com presented here as an example of the type of information available from product suppliers and manufactures. The mention of these materials should not be considered an endorsement from the authors or publishers). Included on these tables are the conservation factor, C, values used in RUSLE for slope protection, along with roughness coefficients and maximum permissible shear stress values used in channel lining analyses. Only the EroNet P300 and EroNet C350 mats shown here are permanent liners and therefore have different values for different plant growth stages.

EroNet S75 straw erosion control blanket (12 month life; 314 g/m^2 mass per unit area)

RUSLE Conservation coefficients (C):		Channel Roughness Coefficients (n)	
	Slope Gradient (S)	Flow depth	Manning's n (unvegetated)
Slope length (L)	All ≤ 3:1 slope:	≤ 0.50 ft (0.15 m)	0.055
≤ 20 ft (6 m)	0.029	0.50 – 2.00 ft	0.055 - 0.021
20 to 50 ft	0.110	≥ 2.00 ft (0.60 m)	0.021
≥ 50 ft (15 m)	0.190	Max. permissible shear stress: 1.55 lbs/ft^2 (74.4 Pa)	

EroNet S150 straw erosion control blanket (12 month life; 323 g/m^2 mass per unit area)

RUSLE Conservation coefficients (C):			Channel Roughness Coefficients (n)	
	Slope Gradient (S)		Flow depth	Manning's n (unvegetated)
Slope length (L)	≤ 3:1	3:1 to 2:1	≤ 0.50 ft (0.15 m)	0.055
≤ 20 ft (6 m)	0.004	0.106	0.50 – 2.00 ft	0.055 - 0.021
20 to 50 ft	0.062	0.118	≥ 2.00 ft (0.60 m)	0.021
≥ 50 ft (15 m)	0.120	0.180	Max. permissible shear stress: 1.75 lbs/ft^2 (84.0 Pa)	

EroNEt S150BN straw erosion control blanket (10 month life; 352 g/m^2 mass per unit area)

RUSLE Conservation coefficients (C):			Channel Roughness Coefficients (n)	
	Slope Gradient (S)		Flow depth	Manning's n (unvegetated)
Slope length (L)	≤ 3:1	3:1 to 2:1	≤ 0.50 ft (0.15 m)	0.055
≤ 20 ft (6 m)	0.00014	0.039	0.50 – 2.00 ft	0.055 - 0.021
20 to 50 ft	0.010	0.070	≥ 2.00 ft (0.60 m)	0.021
≥ 50 ft (15 m)	0.020	0.100	Max. permissible shear stress: 1.85 lbs/ft^2 (88.0 Pa)	

EroNet SC150 straw erosion control blanket (24 month life; 424 g/m^2 mass per unit area)

RUSLE Conservation coefficients (C):				Channel Roughness Coefficients (n)	
	Slope Gradient (S)			Flow depth	Manning's n (unvegetated)
Slope length (L)	≤ 3:1	3:1 to 2:1	≥ 2:1	≤ 0.50 ft (0.15 m)	0.050
≤ 20 ft (6 m)	0.001	0.048	0.100	0.50 – 2.00 ft	0.050 - 0.018
20 to 50 ft	0.051	0.079	0.145	≥ 2.00 ft (0.60 m)	0.018
≥ 50 ft (15 m)	0.100	0.110	0.190	Max. permissible shear stress: 2.00 lbs/ft^2 (96.0 Pa)	

EroNet SC150BN straw erosion control blanket (18 month life; 424 g/m^2 mass per unit area)

RUSLE Conservation coefficients (C):				Channel Roughness Coefficients (n)	
	Slope Gradient (S)			Flow depth	Manning's n (unvegetated)
Slope length (L)	≤ 3:1	3:1 to 2:1	≥ 2:1	≤ 0.50 ft (0.15 m)	0.050
≤ 20 ft (6 m)	0.00009	0.029	0.063	0.50 – 2.00 ft	0.050 - 0.018
20 to 50 ft	0.005	0.055	0.092	≥ 2.00 ft (0.60 m)	0.018
≥ 50 ft (15 m)	0.010	0.080	0.120	Max. permissible shear stress: 2.10 lbs/ft^2 (100 Pa)	

EroNet C125 coconut fiber erosion control blanket (36 month life; 274 g/m^2 mass per unit area)

RUSLE Conservation coefficients (C):				Channel Roughness Coefficients (n)	
	Slope Gradient (S)			Flow depth	Manning's n (unvegetated)
Slope length (L)	≤ 3:1	3:1 to 2:1	≥ 2:1	≤ 0.50 ft (0.15 m)	0.022
≤ 20 ft (6 m)	0.001	0.029	0.082	0.50 – 2.00 ft	0.022 – 0.014
20 to 50 ft	0.036	0.060	0.096	≥ 2.00 ft (0.60 m)	0.014
≥ 50 ft (15 m)	0.070	0.090	0.110	Max. permissible shear stress: 2.25 lbs/ft^2 (108 Pa)	

EroNet C125BN coconut fiber erosion control blanket (24 month life; 360 g/m^2 mass per unit area)

RUSLE Conservation coefficients (C):				Channel Roughness Coefficients (n)	
	Slope Gradient (S)			Flow depth	Manning's n (unvegetated)
Slope length (L)	≤ 3:1	3:1 to 2:1	≥ 2:1	≤ 0.50 ft (0.15 m)	0.022
≤ 20 ft (6 m)	0.00009	0.018	0.050	0.50 – 2.00 ft	0.022 – 0.014
20 to 50 ft	0.003	0.040	0.060	≥ 2.00 ft (0.60 m)	0.014
≥ 50 ft (15 m)	0.007	0.070	0.070	Max. permissible shear stress: 2.35 lbs/ft^2 (112 Pa)	

EroNet P300 polypropylene fiber erosion control blanket (permanent use; 456 g/m^2 mass per unit area)

RUSLE Conservation coefficients (C):	Slope Gradient (S)			Channel Roughness Coefficients (n)		Maximum Permissible Shear Stress	
Slope length (L)	≤ 3:1	3:1 to 2:1	≥ 2:1	Flow depth	Manning's n (unvegetated)		
≤ 20 ft (6 m)	0.001	0.029	0.082	≤ 0.50 ft (0.15 m)	0.049 – 0.034	Unvegetated	3.00 lb/ft^2 (144 Pa)
20 to 50 ft	0.036	0.060	0.096	0.50 – 2.00 ft	0.034 – 0.020	Partially vegetated	5.50 lb/ft^2 (264 Pa)
≥ 50 ft (15 m)	0.070	0.090	0.110	≥ 2.00 ft (0.60 m)	0.020	Fully vegetated	8.00 lb/ft^2 (383 Pa)

Additional permissible shear stress information for vegetated North American Green products (permanent liners):

	Manning's roughness coefficient (n) for flow depths:			Maximum Permissible Shear Stress	
Vegetated blanket type[1]:	0 to 0.5 ft	0.5 to 2 ft	>2 ft.	Short duration (<2 hours peak flow)	Long duration (>2 hours peak flow)
C350 Phase 2	0.044	0.044	0.044	6.00 lb/ft^2 (288 Pa)	4.50 lb/ft^2 (216 Pa)
P300 Phase 2	0.044	0.044	0.044	5.50 lb/ft^2 (264 Pa)	4.00 lb/ft^2 (192 Pa)
C350 Phase 3	0.049	0.049	0.049	8.00 lb/ft^2 (384 Pa)	8.00 lb/ft^2 (384 Pa)
P300 Phase 3	0.049	0.049	0.049	8.00 lb/ft^2 (384 Pa)	8.00 lb/ft^2 (384 Pa)

[1] Phase 2 is 50% stand maturity, usually at 6 months, while Phase 3 is mature growth

Values of C_f, the grass cover factor, were given in Table 5-5 (Temple, *et al*. 1987). They recommend multiplying the stem densities given by 1/3, 2/3, 1, 4/3, and 5/3, for poor, fair, good, very good, and excellent covers, respectively. C_f values for untested covers may be estimated by recognizing that the cover factor is dominated by density and uniformity of cover near the soil surface; the sod-forming grasses near the top of the table have higher C_f values than the bunch grasses and annuals near the bottom. For the legumes tested (alfalfa and *Lespedeza sericea)*, the effective stem count for resistance (given on the table) is approximately five times the actual stem count very close to the bed. Similar adjustments may be needed for other unusually large-stemmed, branching, and/ or woody vegetation.

Example: Channel Lining

Consider the following conditions for a mature buffalograss on a channel liner mat:

$\tau_o = \gamma DS$ = 2.83 lb/ft^2 (previously calculated), requiring a NAG P300 permanent mat, for example

n_s for the soil is 0.016
n for the vegetated mat is 0.042
C_f for the vegetated mat is 0.87
The permissible shear stress for the underlying soil is 0.08 lb/ft^2.

Therefore:

$$\tau_e = 2.83(1-0.87)\left(\frac{0.016}{0.042}\right)^2 = 0.053 \text{ lb/ft}^2$$

The calculated shear stress being exerted on the soil beneath the liner mat must be less than the permissible shear stress for the soil. In this example, the safety factor (permissible shear stress/allowable shear stress) is 0.08/0.053 = 1.5 and the channel lining system is expected to be stable.

Example: Permanent Channel Lining Design

An example of a permanent channel design and the selection of an appropriate reinforced liner is given below. The following example is for a channel that collects runoff from 14.6 acres. This channel is 900 ft. long and has an 8% slope. The peak discharge was previously calculated to be 29 ft^3/sec.

Using the Manning's equation and the Chow (1959) shortcut on channel geometry (Figure 5-16):

$$AR^{\frac{2}{3}} = \frac{nQ}{1.49S^{0.5}}$$

Where n = 0.02
Q = 29 CFS
S = 8% (0.08)

$$AR^{\frac{2}{3}} = \frac{(0.02)(29)}{1.49(0.08)^{0.5}} = 1.38$$

The following drawing illustrates the channel components for this basic analysis:

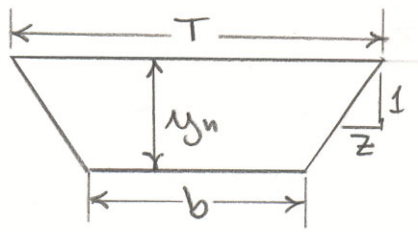
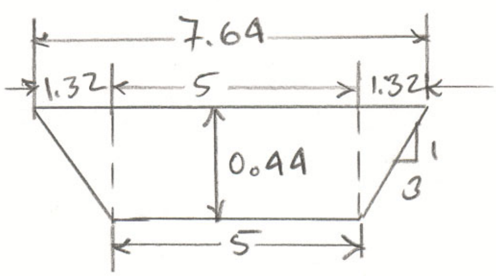


Figure 5-16 can be used to determine the normal depth (y_n) for many combinations of bottom width (b), and side slope (z). As an example, assume that the bottom width is 5 ft. and the side-slope parameter, z, is 3. The calculated $AR^{2/3}$ value (1.38) needs to be divided by $b^{8/3}$ ($5^{8/3} = 73.14$) for the shape factor used in Figure 5-16. This value is therefore: 1.38/73.14 = 0.018. For a side slope of z = 3, the figure indicates that the ratio of the depth to the bottom width (y/b) is 0.088. In this example, the bottom width was 5 ft, so the normal depth is: y_n = 0.088 (5 ft.) = 0.44 ft., which is only 5.3 inches. The following shows these dimensions on the channel cross-section:



It is now possible to calculate the velocity and shear stress associated with this set of channel conditions:

A = [(7.64+5)/2] (0.44) = 2.78 ft^2
V = Q/A = 29 ft^3/sec/2.78 ft^2 = 10.4 ft/sec
R = A/P, and P = 5 + 2(3.16)(0.44) = 7.78 ft.; R = A/P = 2.78 ft^2/7.78 ft. = 0.36 ft.

and $\tau = \gamma RS$ = (62.4lb/ft^3)(0.36 ft.)(0.08) = 1.8 lb/ft^2

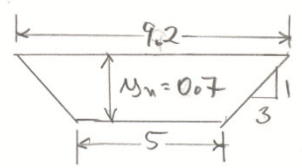
With a velocity of 10.4 ft/sec and a shear stress of 1.8 lb/ft^2, it is obvious that some type of channel reinforcement will be needed (refer to Table 5-2), or another design option will have to be considered.

Using Figure 5-16, plus liner information (such as listed previously), it is possible to create a simple spreadsheet with multiple-cross section and liner alternatives, as shown in Table 5-7. This table shows the unvegetated conditions and calculations, along with the Phase 2 and Phase 3 vegetation conditions, for several channel cross-sections, considering both NAG EroNet P300 and C350 permanent channel liner mats. The shear stress values are calculated using the normal depth of flow, assuming worst-case design conditions, instead of using the hydraulic radius.

Table 5-7. Characteristics for Alternative Designs for Drainage Channel (Q = 29 ft^3/sec and S = 8%)

		Unvegetated NAG EroNet P300, n = 0.02 (allowable shear stress = 3.0 lb/ft^2) [data not given for C350, assumed to be similar to P300 for this example]					Channel with Reinforced Liner and Vegetation						
Bottom width (b), ft	Side slope (z)	Normal depth (y_n), ft	Top width (T), ft	Hydraulic radius (R), ft	Shear stress (τ), lb/ft^2 (using depth)	Velocity (V), ft/sec	Assumed NAG material and growing conditions	Manning's roughness (n)	Normal depth (y_n), ft	Shear stress (τ), lb/ft^2 (using depth and peak Q)	Peak Velocity (V), ft/sec	Allowable shear stress for NAG product (short and long exposures), lb/ft^2	Effective soil shear stress ($τ_e$), n_s = 0.016; C_f = 0.50 phase 2 C_f = 0.87 phase 3
3	1	0.63	4.3	0.48	3.1	12.7	P300 phase 2	0.044	0.80	4.0	9.5	5.5/4.0	0.26
							P300 phase 3	0.049	0.89	4.4	8.4	8.0/8.0	0.06
6	4	0.31	8.5	0.26	1.5	12.9	P300 phase 2	0.044	0.57	2.8	6.1	5.5/4.0	0.19
							P300 phase 3	0.049	0.65	3.2	5.2	8.0/8.0	0.04
8	4	0.30	10.4	0.14	1.5	11.0	P300 phase 2	0.044	0.54	2.7	5.3	5.5/4.0	0.18
							P300 phase 3	0.049	0.88	4.4	3.4	8.0/8.0	0.06
5	3	0.44	7.6	0.36	2.2	10.4	C350 phase 2	0.044	0.66	3.3	6.3	6.0/4.5	0.22
							C350 phase 3	0.049	0.70*	3.5*	5.8*	8.0/8.0	0.05*
6	1.5	0.43	7.3	0.38	2.1	10.1	C350 phase 2	0.044	0.68	3.4	6.1	6.0/4.5	0.22
							C350 phase 3	0.049	0.72	3.6	5.7	8.0/8.0	0.05
10	3	0.26	11.6	0.26	1.3	10.4	C350 phase 2	0.044	0.49	2.4	5.2	6.0/4.5	0.16
							C350 phase 3	0.049	0.52	2.6	4.8	8.0/8.0	0.04

Example: Calculations for permanent C350 liner, 5 ft bottom width, z=3 side slope, and phase 3 vegetation plant stage (mature)

$AR^{\frac{2}{3}} = \frac{nQ}{1.49S^{0.5}} \frac{(0.049)(29)}{1.49(0.08)^{0.5}} = 3.38$ $b^{8/3}$ = $5^{8/3}$ = 73.1 $AR^{2/3}$ /$b^{8/3}$ = 3.38/73.1 = 0.046 With z = 3, y/b = 0.14 Therefore y_n = 0.14 (5) = 0.7 ft	 A = [(5+9.2)/2] (0.7) = 4.97 ft^2 P = 5 + 2(1.21) = 7.42 ft R = A/P = 4.97/7.42 = 0.67 τ = γRS = (62.4lb/ft^3)(0.67 ft.)(0.08) = 3.34 lb/ft^2 (analysis case using hydraulic radius) τ = γDS = (62.4lb/ft^3)(0.70 ft.)(0.08) = 3.49 lb/ft^2 (design case using normal depth) V = Q/A = 29 ft^3/sec/4.97 ft^2 = 5.8 ft/sec $\tau_e = \gamma DS(1 - C_f)\left(\frac{n_s}{n}\right)^2 = 3.49 lb/ft^2(1 - 0.87)\left(\frac{0.016}{0.049}\right)^2 = 0.048 lb/ft^2$ n_s = 0.016; C_f = 0.87 phase 3

Based on these calculations, either the P300 or the C350 permanent liner will be suitable for most conditions outlined in this example. When newly placed, with no vegetation growth, the Manning's n roughness is 0.02 for these liners. The maximum calculated maximum shear stress is 3.1 lb/ft^2 for the narrowest cross section examined, slightly greater than the maximum allowable value of 3.0 lb/ft^2. The calculated shear stresses are less than this allowable maximum value for the other cross-sections. Therefore, one of the wider channels should be used. Unfortunately, the velocities are all very high, ranging from 10.1 to 12.9 ft/sec before the establishment of vegetation. The use of check dams is therefore highly recommended for this channel. These can range from well-secured coir logs to rock check dams, for example (see later discussion on check dams).

The calculations after vegetative growth show that either liner is acceptable. A range of conditions were examined for Phase 2 (50% stand maturity) and Phase 3 (mature growth), with Manning's roughness values of 0.044 and 0.049. The smallest (and steepest side sloped) channel resulted in the highest shear stress of 4.4 lb/ft^2, less than the maximum acceptable values. The short exposure critical values are for peak flows of <2 hours duration. After mature plant establishment in the channel, the maximum allowable shear stress increases to 8.0 lb/ft^2 for all conditions. The effective soil shear stress also is shown, which would be applicable to evaluate temporary channel liners. During the Phase 2 plant growth stage (50% plant growth), the resulting values are larger than soil tolerance conditions, while they are acceptable during the Phase 3 growth stage (mature plant growth). This emphasizes the need for a permanent liner in this case where the additional protection provided by the vegetation is not necessary. The steep slope (8% in this case) results in these relatively extreme solutions. If the slope for this example was about 2%, or less, temporary liners may be suitable (assuming that suitable growth conditions exist).

Channel Design using Concrete and Riprap Liner Materials

For certain conditions when "soft-liner" materials are not suitable, it is common to use concrete or rocks (riprap). New advances in soft liners have produced some materials capable of withstanding large shear stresses, but the more common hard materials still are used frequently in demanding situations.

Historical practice has been to rely on concrete-lined channels for the most demanding applications. However, problems have occurred when water flows beneath the concrete structure, causing massive failure, as indicated in the following photograph. Flexible liners (including riprap) that can conform to soil stability changes may be a better choice. If moisture underneath the liner is permissible and likely, porous flexible liners, as previously described, may outperform rigid concrete.

Figure 5-26. Broken concrete channel due to undercutting (photo by Mark Burford).

The *Alabama Handbook* (ASWCC 2018), an example of a recently updated erosion and sediment control handbook, includes the following guidance for hard-lined channels, shown as a sidebar.

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Sidebar: "Lined Swale (LS)

Practice Description

A lined swale is a constructed channel with a permanent lining designed to carry concentrated runoff to a stable outlet. This practice applies where grass swales are unsuitable because of conditions such as steep channel grades, prolonged flow areas, soils that are too erodible or not suitable to support vegetation or insufficient space and where riprap-lined swales are not desired. The purpose of a lined swale is to conduct stormwater runoff without causing erosion problems in the area of channel flow.

The material that provides the permanent lining may be concrete, manufactured concrete products, or turf reinforcement mat (TRM).

Planning Considerations

A lined swale is used to convey concentrated runoff to a stable outlet in situations where a grass swale is inadequate. A lined swale can be lined with concrete, manufactured concrete products or TRM. Concrete-lined swales are the only type of lining covered in this practice. The practice Erosion Control Blanket should be referenced for criteria on TRM. Product manufacturers and qualified design professional should be consulted for design requirements for manufactured concrete linings. Concrete lined swales are generally used in areas where ripraplined swales are not desired due to aesthetics, safety, or maintenance concerns. Concrete lined swales allow easy maintenance of surrounding vegetation with normal lawn care equipment. The concrete generally provides a more visually pleasing structure than the riprap linings. Concrete lined swales are especially desirable in areas accessed by small children.

In areas where stormwater infiltration is preferred, riprap and manufactured products should be considered rather than the concrete lining.

Design Criteria

<u>Capacity</u>

Lined swales should be capable of passing the peak flow expected from a 10-year 24-hour duration storm.

Adjustments should be made for release rates from structures and other drainage facilities. Swales shall also be designed to comply with local stormwater ordinances, and should be designed for greater capacity whenever there is danger of flooding or out of bank flow cannot be tolerated.

Peak rates of runoff values used to determine the capacity requirements should be calculated using accepted engineering methods. Some accepted methods are:

- Natural Resources Conservation Service, Engineering Field Manual for Conservation Practices, Chapter 2 Estimating Runoff.
- Natural Resources Conservation Service formerly Soil Conservation Service, Technical Release 55, Urban Hydrology for Small Watersheds.
- Other comparable methods.

Slope

This practice only applies to paved flumes that are installed on slopes of 25% or less. Slopes steeper than this should be designed by a qualified design professional.

The slope in feet per 100 feet of length can be determined from a topographic map of the site or from a detailed survey of the planned lined swale location.

Cross Section

With peak flow (capacity) and slope known, the paved flume cross section can be determined by using Figures 5-27 through 5-29.

Concrete Flumes

Concrete flumes should be constructed of concrete with a minimum 28-day compressive strength of 3,000 psi. Flumes shall have a minimum concrete thickness of 4”.

Cutoff Walls

Cutoff walls shall be constructed at the beginning and end of every flume except where the flume connects with a catch basin or inlet.

Alignment

Keep paved flumes as straight as possible because they often carry supercritical flow velocities.

Inlet Section

The inlet section to the paved flume should be at least 6 feet long and have a bottom width equal to twice the bottom width of the flume itself. The bottom width should transition from twice the flume bottom width to the flume bottom width over the 6 feet length.

Outlet

Outlets of paved flumes shall be protected from erosion. The standard for Outlet Protection can be used to provide this protection. A method to dissipate the energy of low flows is to bury the last section of the flume in the ground. This will usually force the development of a “scour hole” which will stabilize and serve as a plunge basin. For the design of large capacity flumes it may be necessary to design a larger energy dissipater at the outlet.

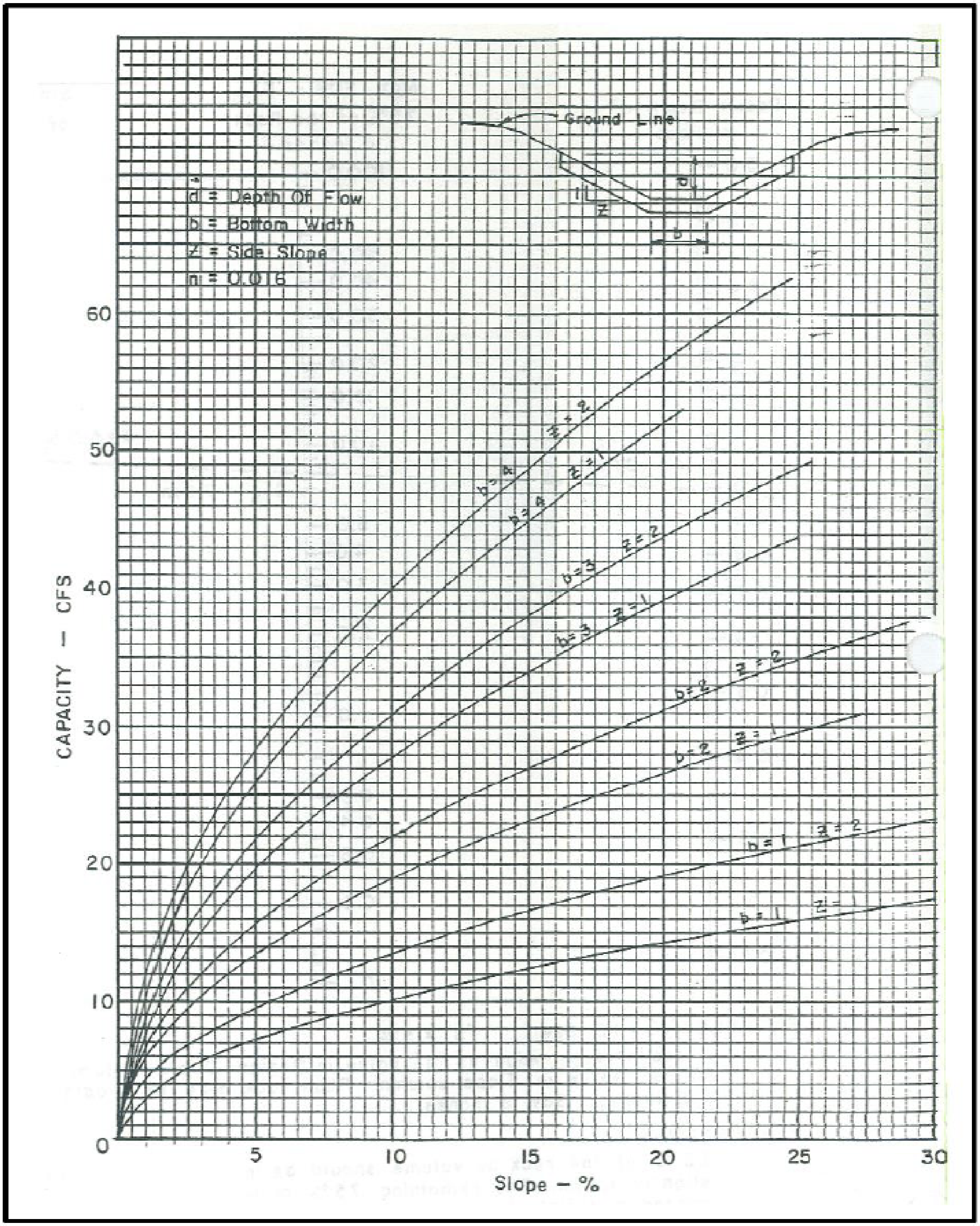


Figure 5-27. Capacity graph for concrete flumes, depth of flow = 0.50 feet.

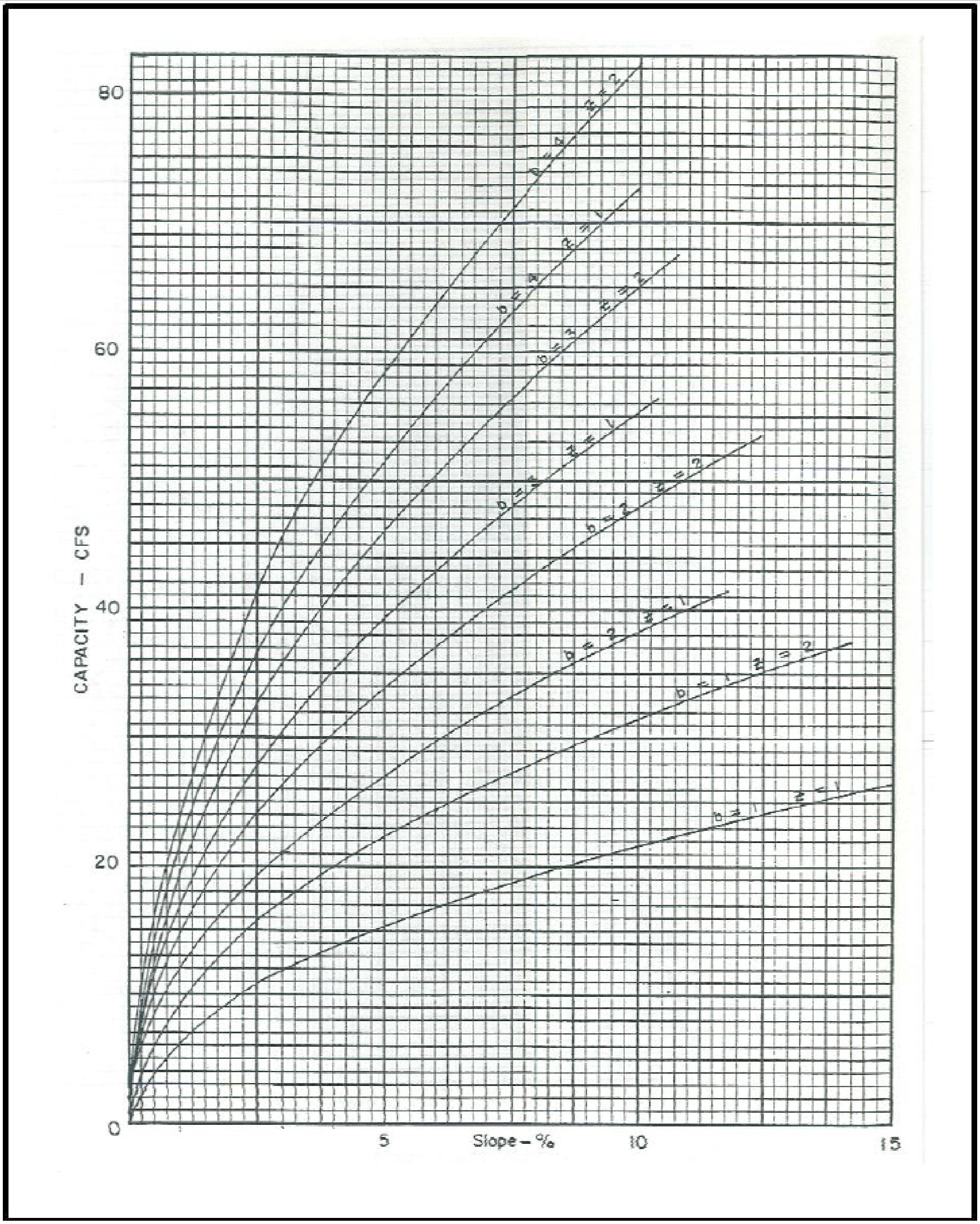


Figure 5-28. Capacity graph for concrete flumes, depth of flow = 0.75 feet.

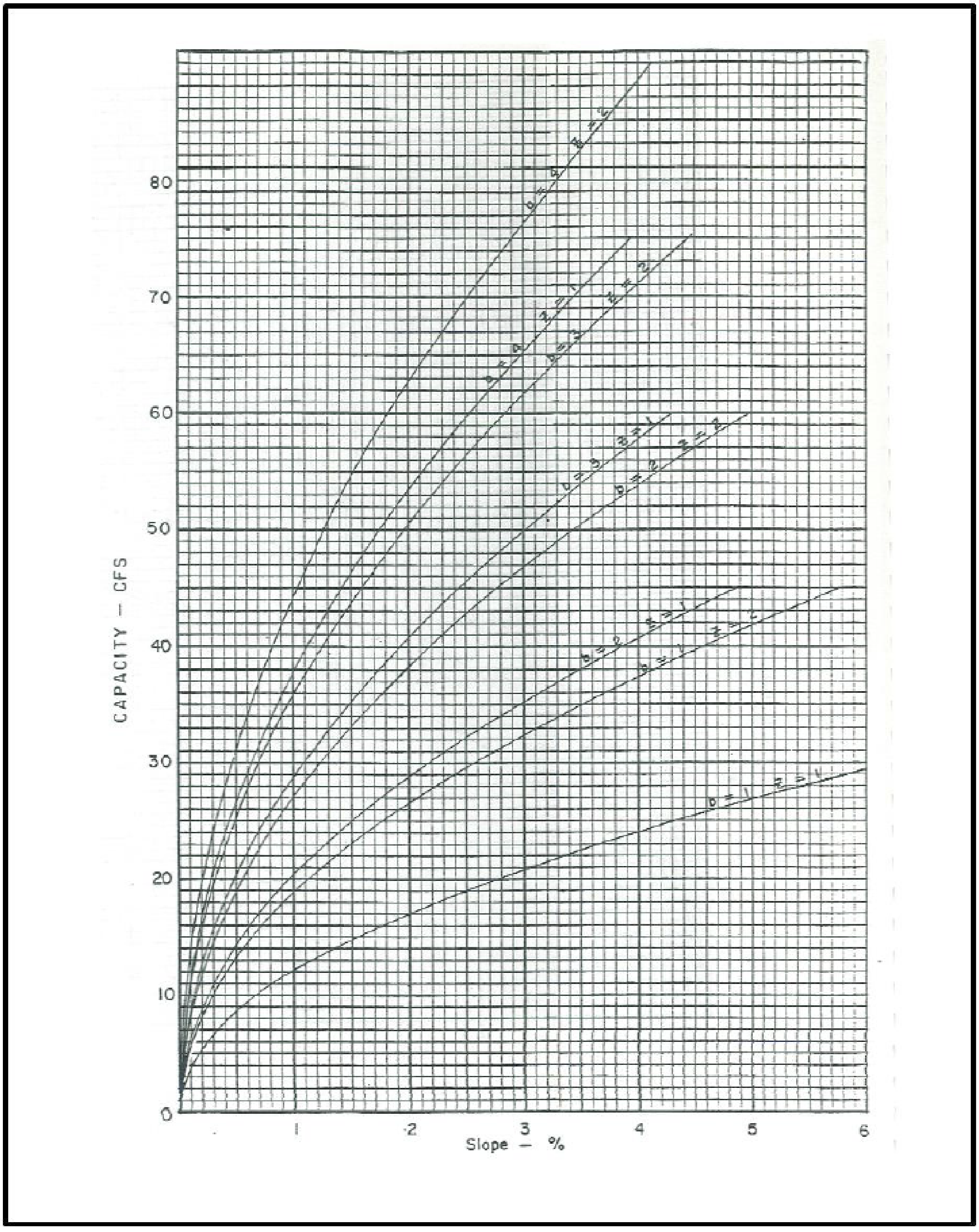


Figure 5-29. Capacity graph for concrete flumes, depth of flow = 1.00 feet

Riprap-lined Swale (RS)

Practice Description

A riprap-lined swale is a natural or constructed channel with an erosion-resistant rock lining designed to carry concentrated runoff to a stable outlet. This practice applies where grass swales are unsuitable because of conditions such as steep channel grades, prolonged flow areas, soils that are too erodible or not suitable to support vegetation or insufficient space.

Planning Considerations

Swales should be carefully built to the design cross section, shape and dimensions. Swales are hydraulic structures and as such depend upon the hydraulic parameters to serve satisfactorily. Swales may be used to:

- Serve as outlets for diversions and sediment control basins and stormwater detention basins.
- Convey water collected by road ditches or discharged through culverts.
- Rehabilitate natural draws and gullies carrying concentrations of runoff.

The design of a swale cross section and lining is based primarily upon the volume and velocity of flow expected in the swale. Riprap-lined swales should be used where velocities are in the range of 5 to 10 ft/sec. Besides the primary design considerations of capacity and velocity, a number of other important factors should be taken into account when selecting a cross section. These factors include land availability, compatibility with land use and surrounding environment, safety, maintenance requirements and outlet conditions, etc.

Riprap lined swales are trapezoidal in shape. Trapezoidal swales are often used where the quantity of water to be carried is large and conditions require that it be carried at a relatively high velocity.

Outlet conditions for all swales should be considered. This is particularly important for the transition from the riprap lining to a vegetative lining. Appropriate measures must be taken to dissipate the energy of the flow to prevent scour of the receiving swale.

Design Criteria

<u>Capacity</u>

Lined swales shall be designed to convey the peak rate of runoff from a 10-year, 24-hour rainfall event. Adjustments should be made for release rates from structures and other drainage facilities. Swales should also be designed to comply with local stormwater ordinances.

Swales should be designed for greater capacity whenever there is danger of flooding or out-of-bank flow cannot be tolerated. The maximum capacity of the swale flowing at design depth should be 200 cubic ft/sec.

Peak rates of runoff values used to determine the capacity requirements should be calculated using accepted engineering methods. Some accepted methods are:

- Natural Resources Conservation Service, National Engineering Handbook Series, Part 650, *Engineering Field Handbook*, Chapter 2, Estimating Runoff.
- Natural Resources Conservation Service formerly Soil Conservation Service, Technical Release 55, *Urban Hydrology for Small Watersheds*.

- Other comparable methods.

Cross section
The swale cross section should be trapezoidal in shape. The steepest permissible side slope of the swale should be 2:1. A bottom width should be selected based on area available for installation of the swale and available rock sizes. The bottom width will be used in determining stable rock size and flow depth.

Depth
Design flow depth should be determined by the following formula:

$z = [n(q)/1.486(S)^{0.50}]^{3/5}$

S = Bed slope, ft./ft.
z = Flow depth, ft.
q = Unit discharge, $ft^3/s/ft$
(Total discharge÷Bottom width)
n = Manning's coefficient of roughness (see formula under velocities)

The design water surface elevation of a swale receiving water from other tributary sources should be equal to or less than the design water surface elevation of the contributing source. The design water surface elevation of contributing and receiving waters should be the same, whenever practical. A minimum depth may be necessary to provide adequate outlets for subsurface drains and tributary swales.

Freeboard
The minimum freeboard is 0.25 feet. Freeboard is not required on swales with less than 1% slope and where out-of-bank flow will not be damaging and can be tolerated from an operational point of view.

Stable Rock Size
Stable rock sizes, for rock lined swales having gradients between 2 percent and 40 percent, should be determined using the following formulas from *Design of Rock Chutes* by Robinson, Rice, and Kadavy.

For swale slopes between 2% and 10%: $d_{50} = [q\ (S)^{1.5}/4.75(10)^{-3}]^{1/1.89}$

For swale slopes between 10% and 40%: $d_{50} = [q\ (S)^{0.58}/3.93(10)^{-2}]^{1/1.89}$

d_{50} = Particle size for which 50% of the sample is finer, inch
S = Bed slope, ft/ft
q = Unit discharge, $ft^3/s/ft$
(Total discharge÷Bottom width)

After the stable median stone size is determined, the gradation of rock to be used should be specified using Tables 5-8 and 5-9. Table 5-8 is used to determine the weight of the median stone size (d_{50}). Using this median weight, a gradation can be selected from Table 5-9, which shows the commercially available riprap gradations as classified by the Alabama Department of Transportation.

Table 5-8. Size of Riprap Stones

Weight (lbs)	Mean Spherical Diameter (feet)	Rectangular Shape Length Width, Height (feet)	
50	0.8	1.4	0.5
100	1.1	1.75	0.6
150	1.3	2.0	0.67
300	1.6	2.6	0.9
500	1.9	3.0	1.0
1000	2.2	3.7	1.25
1500	2.6	4.7	1.5
2000	2.75	5.4	1.8
4000	3.6	6.0	2.0
6000	4.0	6.9	2.3
8000	4.5	7.6	2.5
20000	6.1	10.0	3.3

Table 5-9. Graded Riprap

Class	Weight (lbs.)					
	d_{10}	d_{15}	d_{25}	d_{50}	d_{75}	d_{90}
1	10	-	-	50	-	100
2	10	-	-	80	-	200
3	-	25	-	200	-	500
4	-	-	50	500	1000	-
5	-	-	200	1000	-	2000

Velocities

Velocities should be computed by using Manning's Formula with a coefficient of roughness, "n", as follows:

$$n = 0.047(d_{50} * S)^{0.147}$$

Applies on slopes between 2 and 40% with a rock mantle thickness of 2 x d_{50} where:
d_{50} = median rock diameter (inch), S = lined section slope (ft/ft) ($0.02<S<0.4$)

Velocities exceeding critical velocity should be restricted to straight reaches.

Waterways or outlets with velocities exceeding critical velocity should discharge into an outlet protection structure to reduce discharge velocity to less than critical (see Outlet Protection practice).

Lining Thickness

The minimum lining thickness should be equal to the maximum stone size of the specified riprap gradation plus the thickness of any required filter or bedding.

Lining Durability

Stone for riprap should consist of field stone or rough unhewn quarry stone of approximately rectangular shape. The stone should be hard and angular and of such quality that it will not disintegrate on exposure to water or weathering and it should be suitable in all other respects for the purpose intended. The specific gravity of the individual stones should be at least 2.5.

Geotextiles
Non- woven geotextiles should be used where appropriate as a separator between rock and soil to prevent migration of soil particles from the subgrade, through the lining material. The geotextile shall be of the strength and durability required for the project to ensure the rock and soil base are stable. Generally, the non-woven geotextile should meet the requirements found in ASSHTO M288.

Filters or Bedding
Filters or bedding should be used where needed to prevent piping. Filters should be designed according to the requirements contained in the Subsurface Drain practice. The minimum thickness of a filter or bedding should be 6".

Table 5-10. Requirements for Nonwoven Geotextile

Property	Test method	Class I	Class II	Class III	Class IV[1]
Tensile strength (lb)[2]	ASTM D 4632 grab test	180 minimum	120 minimum	90 minimum	115 minimum
Elongation at failure (%)[2]	ASTM D 4632	≥ 50	≥ 50	≥ 50	≥ 50
Puncture (pounds)	ASTM D 4833	80 minimum	60 minimum	40 minimum	40 minimum
Ultraviolet light (% residual tensile strength)	ASTM D 4355 150-hr exposure	70 minimum	70 minimum	70 minimum	70 minimum
Apparent opening size (AOS)	ASTM D 4751	As specified max. no.40[3]	As specified max. no.40[3]	As specified max. no.40[3]	As specified max. no.40[3]
Permittivity sec^{-1}	ASTM D 4491	0.70 minimum	0.70 minimum	0.70 minimum	0.10 minimum

Table copied from *NRCS Material Specification 592*.
[1] Heat-bonded or resin-bonded geotextile may be used for classes III and IV. They are particularly well suited to class IV. Needle-punched geotextile are required for all other classes.
[2] Minimum average roll value (weakest principal direction).
[3] U.S. standard sieve size"

Selected U.S. Standard Sieve Sizes

U.S. Standard Sieve Sizes	Sieve Screen Opening (μm, unless otherwise noted)	Sieve Screen Opening (inch)
#4 in	100 mm	4.0
#3 in	75 mm	3.0
#2 in	50 mm	2.0
#1 in	25 mm	1.0
#3/4 in	19.0 mm	0.75
#5/8 in	16.0 mm	0.63
#3/8 in	9.5 mm	0.38
#1/2 in	12.5 mm	0.500
#1/4 in	6.3 mm	0.250
No. 4	4.75 mm	0.187
No. 6	3.35 mm	0.132
No. 8	2.36 mm	0.0929
No. 10	2.00 mm	0.0787
No. 12	1.70 mm	0.0669
No. 14	1.40 mm	0.0555
No. 16	1.18 mm	0.0465
No. 18	1.00 mm	0.0394
No. 20	850	0.0335
No. 25	710	0.0278
No. 35	500	0.0197

No. 40	425	0.0167
No. 45	355	0.0139
No. 50	300	0.0118
No. 60	250	0.0098
No. 70	212	0.0083
No. 80	180	0.0070
No. 100	150	0.0059
No. 120	125	0.0049
No. 140	106	0.0041
No. 170	90	0.0035
No. 230	63	0.0017
No. 270	53	0.0021
No. 325	45	0.0017
No. 400	38	0.0015
No. 450	32	0.0013
No. 500	25	0.0010
No. 635	20	0.0008

==

Check Dam (CD)

E. Hahn photo

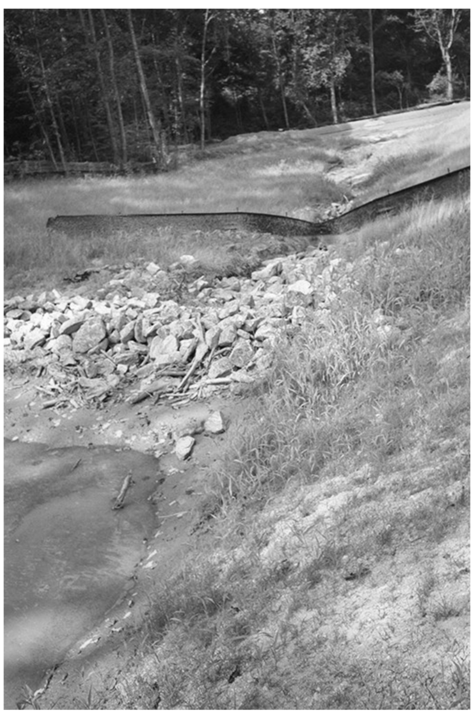
E. Hahn photo

D. Lake photo

Figure 5-30. Well-constructed rock check dams.

Filter fabrics rarely made adequate check dams

Flows commonly erode around ends of filter fabric check dams



Check dams of rock and filter fabric

Series of riprap check dams spaced to cause ponding between dams (SCS photo)

Figure 5-31. Filter fabric and rock check dams.

Figure 5-32. Check dam in new channel at construction site with mature grass (J. Voorhees phot

Monitored Performance of Check Dams in Channels at Construction Sites

These controls are included in most (check dams 83%) of the 95 erosion and sediment control guidance manuals reviewed. Recent reported monitoring results are summarized in Tables 5-11 and 5-12.

Figure 5-33. Fiber check dams (Source: McLaughlin, *et al.* 2009).

Figure 5-34. Wrapped check dams (Source: [http://www.priceandcompany.com/prod-checkdams-erosioneel.html).](http://www.priceandcompany.com/prod-checkdams-erosioneel.html)

Table 5-11. Reported Sediment Control Effectiveness of Check Dams at Construction Sites

ref	control	type of tests and general location	number of events X locations per treatment	TSS influent (mg/L) avg	TSS effluent (mg/L) avg	% TSS reduc	Turbidity influent (NTU) avg	Turbidity effluent (NTU) avg	% Turbidity reduc
Faucette, et al. 2009 JSWCS	8 inch compost filter sock	field test plots and controlled flow - North Georgia	1	4,252	1,027	76	3,628	2,592	29
Faucette, et al. 2009 JSWCS	12 inch compost filter sock	field test plots and controlled flow - North Georgia	1	4,252	1,213	71	3,628	2,934	19
Faucette, et al. 2009 JSWCS	mulch fiber berm	field test plots and controlled flow - North Georgia	1	4,252	2,069	51	3,628	3,334	8
Faucette, et al. 2009 JSWCS	straw bale	field test plots and controlled flow - North Georgia	1	4,252	1,964	54	3,628	3,201	12
McLaughlin and McCaleb 2010 ASABE	Rock check dam	field controlled tests - North Carolina	3				2000 (est)	910	55
McLaughlin and McCaleb 2010 ASABE	Rock check dam with excelsior blanket	field controlled tests - North Carolina	3				2000 (est)	410	80
McLaughlin and McCaleb 2010 ASABE	Excelsior wattle	field controlled tests - North Carolina	3				2000 (est)	450	78
McLaughlin, et al. 2009 JSWC	sediment traps and rock dams not full pools between dams	full size - North Carolina	23	15,201	n/a	n/a	3,813	n/a	n/a
McLaughlin, et al. 2009 JSWC	fiber check dam (straw wattles and coir logs)	full size - North Carolina	20	15,201	181	99	3,813	202	95
McLaughlin, et al. 2009 JSWC	standard practice 2 (sediment traps and rock dams spaced for pools)	full size - North Carolina	19	1,694	n/a	n/a	867	n/a	n/a

		number	10	7	5	5	7	8	8
		average	7.5	7,015	1,291	70	3,286	1,754	47
		median	3	4,252	1,213	71	3,628	1,751	42
		min	1	1,694	181	51	867	202	8
		max	23	15,201	2,069	99	3,813	3,334	95
		COV	1.22	0.80	0.60	0.28	0.33	0.79	0.73

Table 5-12. Reported Sediment Control Effectiveness of Check Dams with Polymers at Construction Sites

ref	control	type of tests and general location	number of events X locations per treatment	TSS influent (mg/L) avg	TSS effluent (mg/L) avg	% TSS reduc	Turbidity influent (NTU) avg	Turbidity effluent (NTU) avg	% Turbidity reduc
Faucette, et al. 2009 JSWCS	8 in compost filter sock + polymer	field test plots and controlled flow - North Georgia	1	4,252	1,028	76	3,628	1,847	49
Faucette, et al. 2009 JSWCS	12 in compost filter sock + polymer	field test plots and controlled flow - North Georgia	1	4,252	718	83	3,628	2,113	42
McLaughlin and McCaleb 2010 ASABE	Rock check dam with PAM	field controlled tests - North Carolina	3				2000 (est)	120	94
McLaughlin and McCaleb 2010 ASABE	rock check dam with excelsior blanket and PAM	field controlled tests - North Carolina	3				2000 (est)	88	96
McLaughlin and McCaleb 2010 ASABE	Excelsior wattle with PAM	field controlled tests - North Carolina	3				2000 (est)	100	95
McLaughlin, et al. 2009 JSWC	fiber check dam with PAM	full size - North Carolina	27	15,201	82	99	3,813	34	99
McLaughlin, et al. 2009 JSWC	fiber check dam with PAM 2	full size - North Carolina	9	1,694	260	85	867	115	87
		number	7	4	4	4	4	7	7
		average	7	6,350	522	86	2,984	631	80
		median	3	4,252	489	84	3,628	115	94
		min	1	1,694	82	76	867	34	42
		max	27	15,201	1,028	99	3,813	2,113	99
		COV	1.39	0.95	0.83	0.11	0.47	1.47	0.30

McLaughlin, *et al*. (2009) concluded that wattles performed better than rock ditch checks under low flow conditions, as the rock ditch checks typically had minimal upgradient pooling under the low flow conditions, resulting in upstream channel erosion. As a follow-up to these earlier tests, Donald, *et al.* (2013) conducted controlled channel tests of different installation configurations of wattle ditch check installations at the Auburn University Erosion and Sediment Control Testing Facility, mainly to investigate the effects of staking patterns and filter fabric underlay. Seven wattle installations were tested to measure velocity reductions, impoundment length, and installation structural integrity. The main objective was to reduce the flow length of highly erosive supercritical flows. They examined staking on the downstream side of the wattle, which pierces the netting, to an alternative method of driving stakes into the ground on both upstream and downstream sides, which does not pierce the netting. They also examined the use of a stapled filter fabric underlay that protects the channel bottom from scour beneath the wattles. Three replicates were conducted for each installation option. They used a multiple regression method to identify the significant installation variables. They concluded that:

- Staking patterns did not significantly affect the subcritical flow length.
- Trenching the wattle had a significantly detrimental effect on performance.
- The filter fabric stapled underlay significantly improved performance by increasing the subcritical flow length.

Donald, *et al.* (2015) measured the impoundment depth upgradient of wattle check dams as the measure of performance. The data indicated an apparent similar trend within each material group for various flow conditions. During high flows, the excelsior and wheat straw wattles were similar when the wattle density to impoundment ratio was considered, while the synthetic wattle (composed of recycled carpet fibers) created a much greater impounding depth, even though it has a lower density in comparison with the other material groups. This was likely due to the synthetic wattle being able to absorb water and swell, causing a greater flow restriction. During low flows, the excelsior and wheat straw wattles did perform significantly differently because flow was not restricted by the high flow-through properties of the excelsior.

Garcia, *et al.* (2015) tested several types of channel check dams during controlled tests at the University of Illinois Erosion Control Research and Training Center. The upgradient total sediment average concentration was about 700 to 800 mg/L, while the downgradient average concentrations ranged from about 443 to 556 mg/L for the three products during three flow rates, although statistical tests did indicate significant differences between the three products. The Triangular Silt Dike performed better under all flow conditions, while the GeoRidge and the Sediment Log performed similarly. The GeoRidge was found to be able to retain more sediment upstream compared to the other two products.

Line and White (2001) evaluated the effectiveness of check dams at two different construction sites in North Carolina having different soil types and slopes. A washed stone and rock check dam was used at one site (43 storms) and a horseshoe-shaped berm, with the open side facing upstream, was used at the other site (13 storms). The overall sediment trapping efficiency at the two sites were about 60 to 70%. Construction control researchers also investigated the improved sediment retention performance of check dams by using polyacrylamide (PAM) additions. McLaughlin, *et al.* (2009a) studied erosion control test options at two roadway construction projects in North Carolina. The controls investigated included: standard narrow sediment traps in the ditch along with rock check dams; fiber check dams consisting of a mix of straw wattles and coir logs; or fiber check dams with granulated anionic PAM (Siltstop 705). The fiber check dams resulted in greater reductions in sediment losses compared to the standard rock check dams. The use of the PAM further increased the performance of the fiber check dams. McLaughlin, *et al.*

(2010) further reported on the turbidity reduction performance of three check dam types in combination with PAM (rock only, rock with PAM, rock wrapped with excelsior, rock wrapped with excelsior with PAM, excelsior wattle, and excelsior wattle with PAM). During three tests, the rock alone resulted in about 400, 1050, and 1300 effluent NTU levels (the highest for any control combination). PAM additions significantly reduced the effluent turbidity for all dam materials (by about 60 to 90% compared to tests without PAM). For the higher influent NTU experiments, the excelsior blankets (wrapped rocks or wattles) reduced the turbidities by about 60% without PAM.

Other check dam and PAM studies conducted at the lined channel test facility at North Carolina State University (Kang, *et al.* 2013) examined turbidity reductions through several types of check dams, both with and without polyacrylamide additions. The check dams investigated were: 1) rock check dam representing the standard installation in the state, 2) excelsior wattle representing a fiber check dam (FCD), and 3) rock check dam wrapped with excelsior erosion control blanket representing an alternative FCD. The check dams were installed in a lined, 24-m long channel on a 5 to 7% slope. Additional tests were conducted after manually sprinkling granular polyacrylamide (PAM) on the check dams. The granular PAM applied on the excelsior wattles was able to maintain effluent turbidity well below 280 NTU. The hydrated PAM on the surface of the excelsior formed a gelatinous pad, which still appeared to be active after the end of the repeated storm event tests. The PAM addition to the bare rock check dams was not as effective (washed out easier), but still reduced the turbidity significantly. Overall, the effluent turbidity in the ditch outlet was reduced by 78 to 93% when PAM was applied to any check dam type compared to identical tests with no PAM treatment. They also found that wrapping rocks with an erosion control blanket can achieve turbidity reductions comparable to the excelsior wattle in situations where rock check dams are used.

This following section is excerpted from the *Alabama Handbook* (ASWCC 2014) and describes example check-dam use for erosion controls, presented as a sidebar.

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Sidebar: “Practice Description

A check dam (also referred to as a “ditch check”) is a small barrier or dam constructed across a swale, drainage ditch or other area of concentrated flow for the purpose of reducing channel erosion. Channel erosion is reduced because check dams flatten the gradient of the flow channel and slow the velocity of channel flow. Check dams can be constructed of rock, wattles (sometimes referred to as tubes or rolls), sand bags, or other materials that may be acceptable to the design professional. Contrary to popular opinion, most check dams trap an insignificant volume of sediment, as check dams usually just trap the coarser grained material leaving the turbid water to flow downstream.

This practice applies in small open channels and drainageways, including temporary and permanent swales. Check dams are not to be used in a live stream. Situations of use include areas in need of protection during establishment of grass and areas that cannot receive a temporary or permanent non-erodible lining for an extended period of time.

Planning Considerations

Check dams are utilized in concentrated flow areas to provide temporary channel stabilization during the intense runoff periods associated with construction disturbances. Check dams may be constructed of rock, wattles, sand bags, or other suitable material, including manufactured products. Most check dams are constructed of rock. Rock may not be acceptable in some installations because of aesthetics and alternative types of check dams need to be considered. Rock check dams (Figures 5-36 and 5-37) are usually installed with backhoes or other suitable equipment but hand labor is likely needed to complete most installations to the quality needed. The rock is usually purchased and some locations in the state may not have rock readily available. The use of rock should be considered carefully in areas to be mowed. Some rock may be washed downstream and should be removed before each mowing operation. The use of small graded aggregate and geotextile can be used on the upstream face of the rock check dam to increase the sediment trapping efficiency of the rock check dam. Measures must be taken to prevent undermining of the check dam.

Water flowing over a check dam is very often super-critical and creates erosive forces on the down slope of the dam and immediately downstream of the dam. Some measures to prevent this erosion include placing larger rock on the downstream face of a rock dam, concrete grouting the downstream face of a rock dam, and providing erosion protection material just downstream of the dam.

Wattles have been found to be best installed without trenching and on top of stapled geotextile that extends up and downstream from the wattle. Wattles must be properly stapled and staked on top of the geotextile (see picture below).

Figure 5-35. Coir log check dam placement.

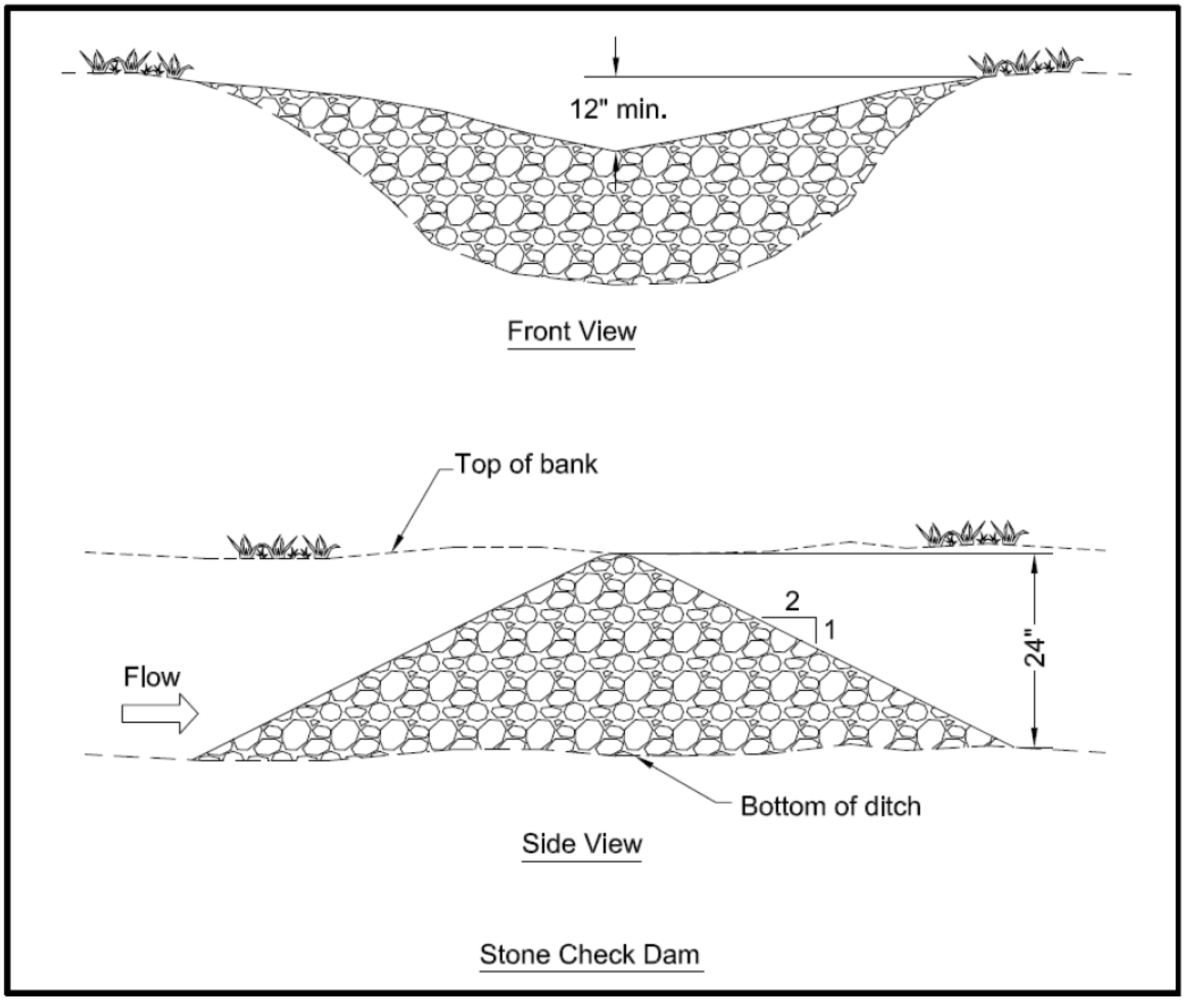

Figure 5-36. Profile and Cross-Section of Typical Rock Check Dams

Check dams should be planned to be compatible with the other features such as streets, walks, trails, sediment basins and rights-of-way or property lines. Check dams are installed with the center overflow area lower in elevation than the ends to ensure flow goes over the check dam and not around. Check dams are normally constructed in series and the dams should be located at a normal interval from other grade controls such as culverts or sediment basins.

The use of check dams are a temporary BMP and should be removed following construction to allow for final long term stabilization.

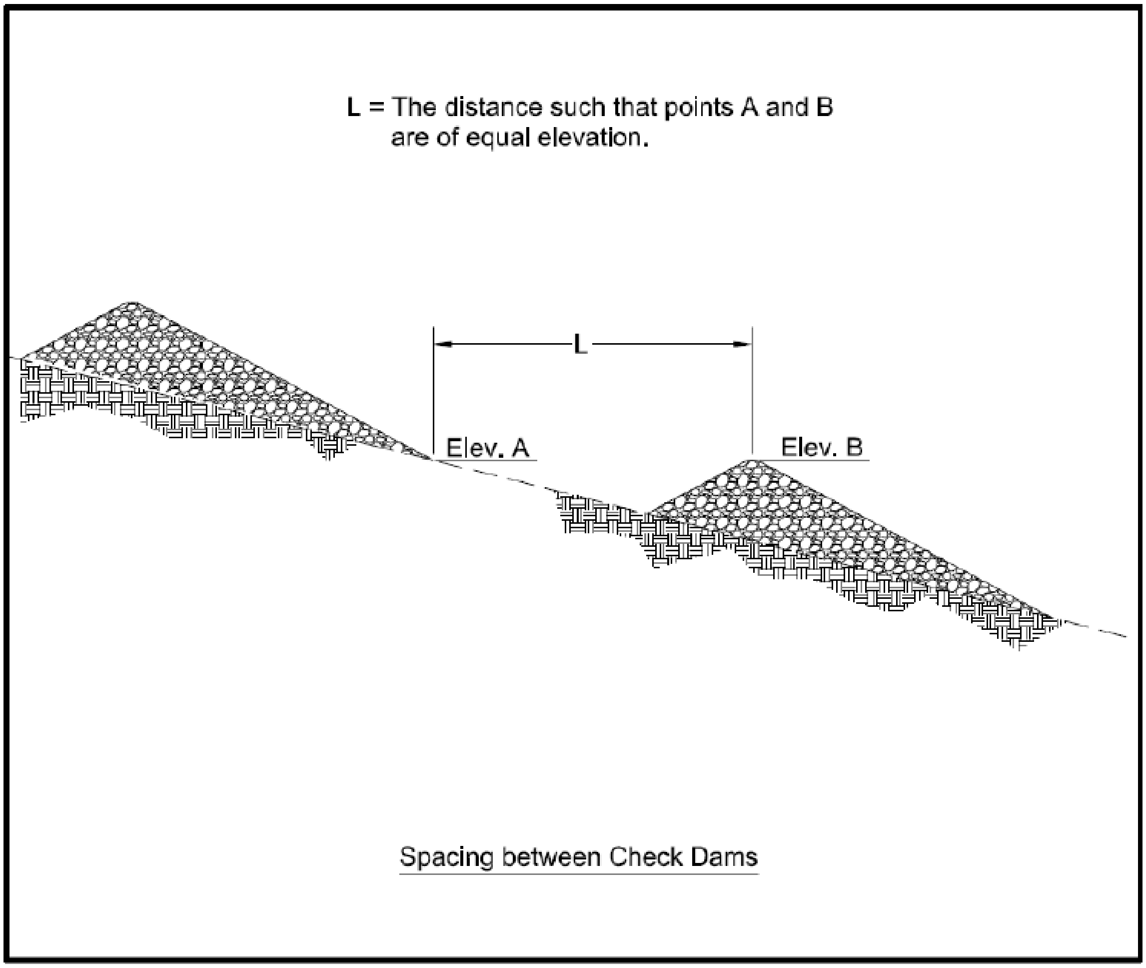

Figure 5-37. Profile of Typical Rock Check Dams

Design Criteria
Formal design is not required. The following limiting factors shall be adhered to when designing check dams:

Drainage Area: Ten acres or less (Rock)

Maximum Height: Two feet when drainage area is less than 5 acres

Three feet when drainage area is 5 to 10 acres

Depth of Flow: Six inches when drainage area is less than 5 acres

Twelve inches when drainage area is 5 to 10 acres

The top of dam, perpendicular to flow, should be parabolic. The center of the dam should be constructed lower than the ends. The elevation of the center of the dam should be lower than the ends by the depth of flow listed above.

Side Slopes: 2:1 or flatter

Spacing

The elevation of the toe of the upstream dam should be at or below the elevation of crest of the downstream dam (Figure 5-37).

For example, if the channel is 3% grade, and the drainage area is 3 acres:
The check dam height would be 2 feet.
The check dam spacing should be 67 feet:
Spacing (ft) = dam height (ft) / channel grade
Spacing = 2 ft / 0.03 = 67 feet

Keyway

Measures should be taken to ensure the flow does not cause erosion underneath the check dam. This is often accomplished using geotextile underneath the check dam or in highly erosive soils a keyway lined with geotextile and filled with rock. Keyways if used should be keyed into the channel bottom and abutments to a depth of 12 to 24”. The keyway width should be at least 12”.

Rock Check Dams

Rock check dams should be constructed of appropriately sized durable rock riprap. Riprap gradation should conform to the requirements of Alabama Highway Department, Standard Specification for Highway Construction.

In soils where failure by piping of soils into the rock is likely, a non-woven geotextile will be used as a filter to separate the soils from the rock. The geotextile shall be of the strength and durability required for the project to ensure the rock and soil base are stable. Generally, the non-woven geotextile should meet the requirements found in ASSHTO M288.”

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It should be noted that straw bale check dams are not recommended by the ASWCC (2018) and are frequently being removed from many erosion control guidance documents due to their poor performance and poor installation history. Rock check dams (for high flows) and wattle check dam logs, possibly with PAM additions, (for lower flows) are the preferred material choices in most current erosion control handbooks.

Flow Rates through Stone Check Dams
The flow through a stone check dam can be calculated using the following equation:

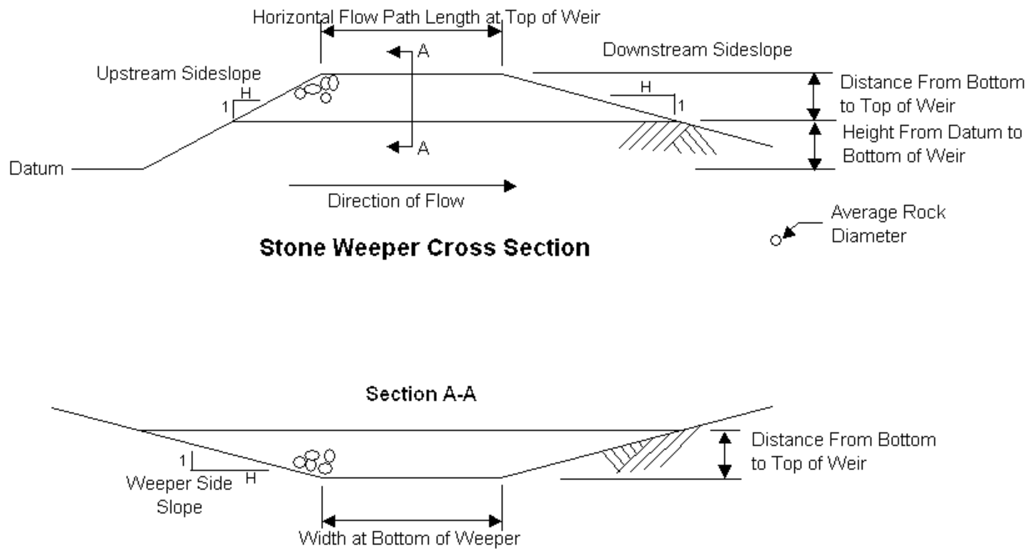


Figure 5-38. Cross-sections of check dams for flow calculations.

$$Q = \frac{h^{3/2} W}{\left[(L / D_{50}) + 2.5 + L^2 \right]^{0.5}}$$

where:

Q = Outflow through the stone check dam (cfs)
h = Ponding depth behind the check dam (ft)
W = Effective width of the check dam (ft), not to be confused with the horizontal flow path length through the check dam. The effective width is an average of the width at the channel bottom and the width at the depth of the flow (or the actual width if using a gabion structure).
L = Horizontal flow path effective length through the check dam (ft). Similarly, it is the average of the flow length at the channel bottom and the flow length at the flow depth.
D_{50} = Average rock diameter in the check dam (ft)

This equation is from *Analysis of Flow through Porous Media as Applied to Gabion Dams Regarding the Storage and Release of Storm Water Runoff*, NAHB/NRC Designated Housing Research Center at Penn State, Report No. 10, August 1992. This equation was developed to calculate the flow through a gabion dam, which is usually a vertical walled structure composed of large stones confined in wire baskets. In order to apply it to stone check dams that have sloped faces, WinSLAMM (www.WinSLAMM.com), a continuous hydraulic and particle routing model, calculates the flow by dividing the stone check dam into horizontal slices. The flow through each slice is calculated, and the flows from all slices are summed to determine the total flow for a given depth. Alternatively, the effective width and flow length can be used as an estimate, as described above.

Example: Calculation of Flows through Check Dams

The following examples assume uniform thickness (such as would apply in a gabion dam):

h = 3 ft
W = 15 ft
L = 3 ft
D = 9 inches = 0.75 ft

$$Q = \frac{h^{3/2}W}{\left[(L/D)+2.5+L^2\right]^{0.5}} = \frac{(3\,ft)^{3/2}(15\,ft)}{\left[(3\,ft/0.75\,ft)+2.5+(3\,ft)^2\right]^{0.5}} = 19.8\,ft^3/\sec$$

The same stone check dam, but with only a 1 ft depth of water:

h = 1 ft
W = 15 ft
L = 3 ft
D = 9 inches = 0.75 ft

$$Q = \frac{h^{3/2}W}{\left[(L/D)+2.5+L^2\right]^{0.5}} = \frac{(1\,ft)^{3/2}(15\,ft)}{\left[(3\,ft/0.75\,ft)+2.5+(3\,ft)^2\right]^{0.5}} = 3.8\,ft^3/\sec$$

This process can be repeated for an installation for different depths of water to create a stage-discharge curve for a stone check dam.

Example: Design for Reinforced Grass-Lined Channels with Check Dams and Level Spreader Pads
An industrial site in Huntsville, AL, has many 2-acre individual building sites. Each of the sites are served with a grass-lined channel that carries site water to a larger swale system. The slopes of the channels vary from about 1 to 6.5%. The calculated peak flow from each construction site was calculated to be 16 ft^3/sec (corresponding to the Huntsville, AL, 25-yr design storm of 6.3 inches for 24 hours). Grass-lined channels are designed for each site. The bare seed bed has a hydraulic roughness of about 0.016. The channels were built to be 10 ft wide on the bottom and have 3 to 1 (h:v) side slopes. The following table summarizes the results of these calculations:

Slope	Bare seed bed shear stress (lb/ft^2)	Unvegetated mat shear stress, effect on soil (lb/ft^2)	Safety factor (allowable shear stress of 0.05 lb/ft^2)	Maximum velocity with mature vegetation (ft/sec)
1%	0.14	0.012	4.2	3.1
3%	0.28	0.023	2.2	4.8
5%	0.42	0.035	1.4	5.5
6.5%	0.46	0.039	1.3	6.4

The seed bed has an allowable shear stress of about 0.05 lb/ft^2. The calculated values for unprotected conditions are all much larger than this allowable value. These values would be exceeded even with a much smaller 2-yr design storm (3.9 inches, 24 hrs). Therefore, an erosion control mat was needed to protect the seedbed until the grass can become established. A North American Green S75 mat was selected, having an allowable shear stress of 1.55 lb/ft^2 and a life of 12 months. The unvegetated mat has a roughness factor n of 0.055. The shear stress under the mat is calculated as follows (for the 6.5% slope condition), assuming a C_f = 0 for the unvegetated condition and a bare soil n of about 0.016.

$$\tau_e = 0.46(1-0)\left(\frac{0.016}{0.055}\right)^2 = 0.039\, ft^2 / \sec$$

The unvegetated mat is seen to be suitable protection of the seed bed, with safety factors ranging from 4.2 (for the 1% slopes) to 1.3 (for the 6.5% slopes).

The allowable velocity for mature bermudagrass for slopes <5% is 6 ft/sec for sandy silt soils to 8 ft/sec for silty clay soils. The 6-ft/sec maximum is expected to be most applicable for the site soils. The swales greater than 5% slopes may be a problem, as they exceed the maximum slope criterion for bermudagrass. In addition, the 6.5% slopes have maximum velocities of about 6.4 ft/sec, slightly greater than the maximum permissible velocity. Although these maximum flows are very infrequent (associated with the 25-year storms), rock check dams were specified for the 5 and 6.5% slopes to provide a suitable safety factor.

The check dams, in the 3-ft deep channels, are 2 ft high to the over-topping elevation. In channels with 5% slopes, the check dams would have to be about 40 ft apart (or less) to ensure that the toes of the upstream check dams were at the same, or lower, elevations as the overflows of the downstream dams. Similarly, the check dams in the 6.5% sloped channels would have to be no more than 30 ft apart (quite close for most channels). The *Alabama Handbook* specifies ALDOT class 1 riprap for check dams. This rock has the following size:

d_{10} = 10 lb
d_{100} = 100 lb (1.1 ft in diameter)
d_{50} = 50 lbs (0.8 ft in diameter)

The roughness coefficients for class 1 riprap is dependent on channel slope:

S of 1%, n = 0.033
S of 3%, n = 0.0393
S of 5%, n = 0.0423
S of 6.5%, n = 0.044

The flow rate through the check dam (2-ft high, 10-ft wide at the base, and 4-ft average flow length) in the grass channels is estimated to be about 5 ft^3/sec. This would leave about 11 ft^3/sec to overtop the check dams during peak flows. There is adequate capacity in the channels to accommodate this overtopping. The velocity through the check dams is reduced to about 0.5 ft/sec. The ponding between the check dams and the low velocity through the check dams will substantially reduce the peak flows to values well below the critical values for the grass-lined channels.

The last check dams for each channel are located at the end of the channels and discharge onto level-spreader pads. These are located at the end of the channels, even those at 1 and 3% slopes. These dissipate the energy of the flow from each building area and produce sheetflow until the flows collect in the large main swales. The level spreader pads handle a maximum flow of 16 ft^3/sec. The *Alabama*

Handbook provides design guidance for these pads. The pads need to be at least 15 feet long, and spread flow out to a width of 25 ft from the 10-ft wide channel. For this example, the rock size for the pad needs to be 0.7 ft in diameter (d_{50}) and be spread at least 15 inches thick.

Slope Stability Applied to Construction Site Erosion Control Design

Much of the above information on channel stability can also be applied to slope stability evaluations. Of course, this discussion assumes that the slopes have been designed by geotechnical engineers to prevent slippage, as this discussion only addresses sheet and rill erosion.

The following pictures illustrate track walking (or up-slope tracking) which compacts and roughens the bare soil to reduce erosion when other more permanent slope controls are not possible (such as temporary use during site grading).

Sheep's foot compactor.

Roughened slope after compaction by Sheep's foot compactor.

Roughened and compacted slope.

Up-slope compaction (J. Voorhees photo)

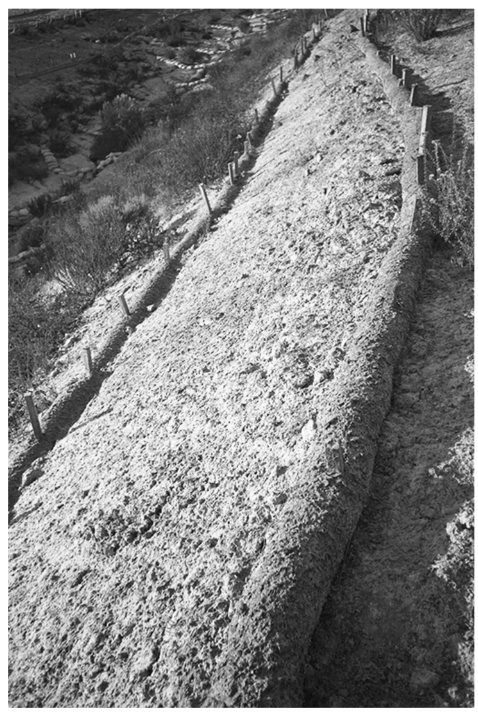
 Up-slope tracking prior to erosion control mat installation (J. Voorhees photo)	 Up-slope tracking (J. Voorhees photo)
 Up-slope tracking (N. Lipinski photo)	

Figure 5-39. Soil Roughening and Compaction to Protect Slope

 Asphaltic Slope Protection in Heavy Shade	 Geoweb installation to protect slope (M. Harding photo)

 Bio-technical slope protection on Whiteface Mtn. (NY) using old ski lift rubber bushings (D. Lake photo)	

Figure 5-40. Physical Covering to Protect Slopes

 Coir (cocoanut fiber) rolls/logs and soil adhesives for slope stabilization project at Newport Beach, CA, wildlife refuge.	 Tackifier mulch slope protection and coir log check dams on steep slope.

Slope stabilization using tracking, seeds and mulch, with coir logs (D. Lake photo)

Figure 5-41. Coir log slope checks

Figure 5-42. Topsoil Preparation before Seeding (J. Voorhees photos)

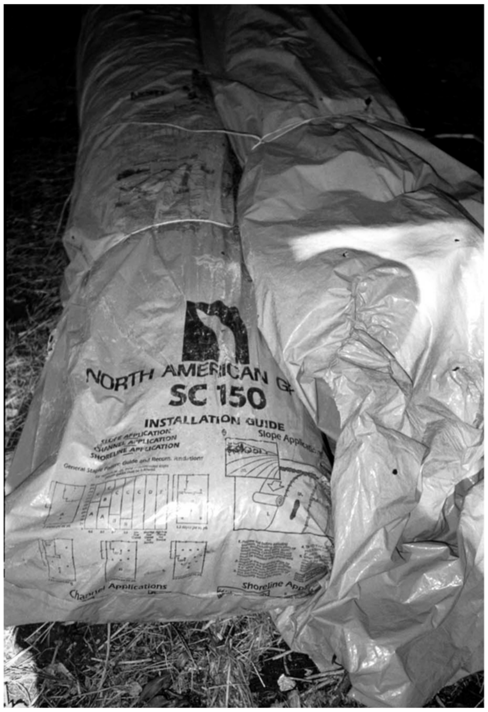
Reinforced slope netting and established vegetation at Birmingham, AL, highway project.

Slope being protected with netting after failure

Netting used in areas to repair bank failure

Figure 5-43. Slopes Protected by Erosion Control Netting and Vegetation

Figure 5-44. Installation of Erosion Control Matting (SCS photo)



Stockpile of Erosion Control Mats at Construction Site

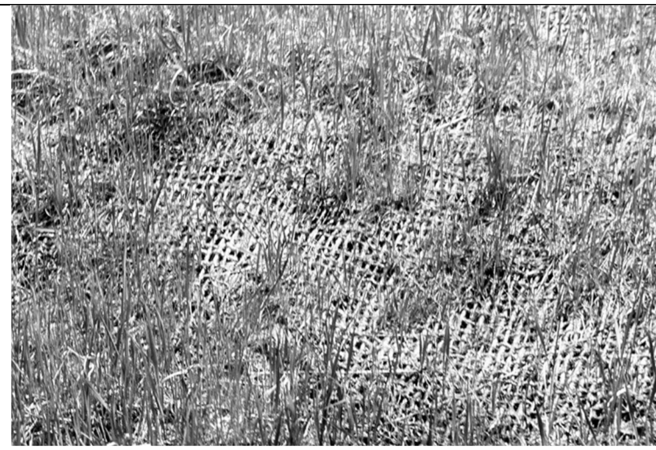

Netting over Mulch allowing Grass to Grow (Bill Morton photo)

Figure 5-45. Erosion control mats.


Figure 5-46. Failing Mulch on Slope above Rip Rap

Figure 5-47. Installation of Wire Netting over Mulch

Figure 5-48. Installation of Netting over Mulch

Figure 5-49. Various Slope Protection Treatments and Tree Conservation

As indicated in Chapter 4, it is possible to modify the Manning's formula to calculate the flow depth for the sheetflow conditions used for slope analyses:

$$y = \left(\frac{qn}{1.49 s^{0.5}} \right)^{\frac{3}{5}}$$

where: y is the flow depth (in feet),
q is the unit width flow rate (Q/W, the total flow rate, ft^3/sec, divided by the slope width, ft.)
n is the sheet flow roughness coefficient for the slope surface, and
s is the slope (as a fraction)

The basic shear stress equation can be used to calculate the maximum shear stress expected on a slope:

$$\tau_o = \gamma y S \quad \text{(lb/ft}^2\text{)}$$

where:

γ = specific weight of water (62.4 lbs/ft^3)
y = flow depth (ft)
S = slope (ft/ft)

Information in Chapter 3 can be used to calculate the unit width flow rate (q) for the slope in question. Assume the following conditions:

Design storm peak flow rate (Q) = 2.2 ft^3/sec (from Chapter 3 procedures)
Slope width (W) = 200 ft
Slope roughness for sheetflow (n) = 0.24 (vegetated with dense grass stand; would be only about 0.055 for an erosion control mat before vegetation, however, using the vegetated mat results in deeper water and a worst-case shear stress condition)
Steepness of slope (s) = 25% = 0.25

Therefore, the unit width peak flow = Q/W = 2.2 ft^3/sec/200 ft = 0.011ft^2/sec and the flow depth is:

$$y = \left(\frac{(0.011)0.24}{1.49(0.25)^{0.5}} \right)^{\frac{3}{5}} = 0.033 ft$$

This depth corresponds to a flow depth of about 0.4 inches. The corresponding maximum shear stress would be:

$$\tau_o = (62.4)(0.033)(0.25) = 0.51 lb / ft^2$$

For an ordinary firm loam soil, the Manning's roughness is 0.020 and the allowable shear stress is 0.15 lb/ft^2. Without a protective mat, the calculated maximum shear stress is substantially greater than the allowable shear stress for the soil. The effective shear stress impacting the soil underneath an erosion control mat can be calculated (using the previously calculated maximum shear stress). The following calculation indicates the effective shear stress underneath the mat:

$$\tau_e = \tau_o (1 - C_f)\left(\frac{n_s}{n}\right)^2$$

Where:

τ_e = effective shear stress exerted on soil beneath mat on slope
τ_o = maximum shear stress from the flowing water = 0.51 lb/ft^2
C_f = vegetal cover factor (this factor is 0 for an unlined channel) = 0 for critical unvegetated slope
n_s = roughness coefficient of underlying soil = 0.020
n = roughness coefficient of mat = assume 0.055 as a typical value for unvegetated mat on slope

Therefore:

$$\tau_e = \tau_o (1 - C_f)\left(\frac{n_s}{n}\right)^2 = 0.51(1-0)\left(\frac{0.020}{0.055}\right)^2 = 0.067 \text{ lb/ft}^2$$

The safety factor using these values is about: 0.15/0.067 = 2.2, so the slope should be adequately protected when an adequate mat is selected. In fact, any erosion mat with a Manning's roughness larger than 0.037 should be adequate for this example, shown by setting the effective shear stress equal to the allowable shear stress (0.15 lb/ft^2):

$$n = n_s \sqrt{\frac{\tau_o (1 - C_f)}{\tau_e}} = (0.020)\sqrt{\frac{(0.51)(1-0)}{0.15}} = 0.037$$

Final mat selection is usually based on calculating the erosion yield from the slope, using the RUSLE [A = RK(LS)CP]. Table 5-13 lists some representative conservation factors (C) for different North American Green erosion control mats, and the following lists other needed RUSLE values, for example:

R = 350 (Birmingham, AL conditions)
K = 0.28
LS for length of 300 ft and slope of 25% = 10.81 (from Chapter 3)

This is a 200 ft by 300 ft area, or about 1.4 acres.

Soil loss for bare slope (C = 1):

Soil loss = (350)(0.28)(10.81)(1) = 1,060 tons/acre/yr

Soil loss for protected slope (example using S75, with an n = 0.055, and C=0.19)

Soil loss = (350)(0.28)(10.81)(0.19) = 201 tons/acre/yr

The conversion factor for calculating the uniform inches lost per year from tons/acre is 0.00595 (for a typical loam soil). Therefore, for the unprotected bare slope, the soil loss would be about 6.3 inches, while it would be about 1.2 inches for the protected slope. Both these values are excessive. The USDA (1987) states that a reasonable tolerance limit to allow agricultural activity (plants to survive) would be about 0.5 inches. North American Green recommends that a tolerable soil loss value of 0.25 inches (at the bottom 10% of the slope length) be used for temporary erosion control blankets and new growth vegetation. This corresponds to a maximum soil loss of about 42 tons/acre/year (still about 10 times greater than the tolerable, T, value given for many soils in the USDA county soil maps for sustainable agriculture). Since these are for temporary controls while the vegetation is immature, it is expected that the soil losses would decrease substantially with time as the plants on the slope mature. The tolerable soil loss for permanent slope protection is given as 0.03 inches/year, or about 5 tons/acre/year (close to the USDA tolerable, T, values in the soil maps).

Therefore, an erosion control mat having a smaller C factor for these slope conditions is needed. The target maximum C value can be estimated by the ratio of the maximum allowable to the bare soil conditions:

$C_{maximum}$ = 42/1060 = 0.039
Manning's $n_{minimum}$ = 0.037

For the long slope length of 300 ft and the 25% (4:1) slope, the suitable erosion control mats shown on Table 5-13 would be: S150BN (C=0.020 and n=0.055) or SC150BN (C=0.010 and n=0.050). Both of these mats are much more substantial than the initial selection of S75 based on shear stress alone. If the slope length was shorter, the lower rated mats would be suitable (such as S75 for slope lengths less than 20 ft, and C125 if the slope lengths are up to 50 ft). None of these erosion control mats would provide the soil loss protection on this long slope example for permanent installations (5/1060 = 0.0047) without vegetation. Both the C350 or P300 mats would likely be suitable permanent solutions with partial to full vegetation.

It is possible to design slope protection having different erosion control mats at different sections on the slope. The free software available from North American Green, for example, can recommend composite slope protection schemes using different mats for different areas on a slope. Online design and evaluation software is available from most, if not all, mat manufacturers and all have comparable design features. However, there are many other factors involved in selecting the most appropriate erosion control mat, and the manufacturers' information must be reviewed for proper selection.

Table 5-13. North American Green Conservation Factors (C) for Different EroNet Erosion Control Mats, for Different Slopes and Slope Lengths

Slope length and gradient	S75	S150	SC150	C125	S75BN	S150BN	CS150BN	C125BN	C350	P300
Length ≤ 20 ft (6 m)										
S ≤ 3:1	0.029	0.004	0.001	0.001	0.029	0.00014	0.00009	0.00009	0.0005	0.001
S between 3:1 to 2:1	0.11	0.106	0.048	0.029	0.11	0.039	0.02	0.018	0.015	0.029
S≥ 2:1	0.23	0.13	0.10	0.082	0.23	0.086	0.063	0.05	0.043	0.082
Length between 20 and 50 ft (6 to 15 m)										
S ≤ 3:1	0.11	0.062	0.51	0.036	0.11	0.010	0.005	0.003	0.018	0.036
S between 3:1 to 2:1	0.21	0.118	0.79	0.060	0.21	0.07	0.055	0.04	0.031	0.06
S≥ 2:1	0.45	0.17	0.145	0.096	0.45	0.118	0.092	0.06	0.050	0.096
Length ≥ 50 ft (15 m)										
S ≤ 3:1	0.19	0.12	0.10	0.07	0.19	0.02	0.01	0.007	0.035	0.07
S between 3:1 to 2:1	0.30	0.18	0.11	0.09	0.30	0.10	0.08	0.07	0.047	0.09
S≥ 2:1	0.66	0.22	0.19	0.11	0.66	0.15	0.12	0.07	0.057	0.11

Field observations of slope stability indicate successful applications of grass and reinforced mats for erosion control, as indicated in the following case study summaries.

Xu, *et al.* (2006) studied a range of erosion control measures to reduce runoff and soil losses along the Qinghai–Tibet highway near the Tuotuo River in the summers of 2003 and 2004. The test locations were characterized by high elevations, low summer rainfall, and poor vegetation cover. They found that engineering erosion controls can be effective during short periods, but established vegetation on the steep slopes was the most effective for the long term. They found that a combination of lattice structures and establishing vegetation was the most effective erosion preventative measure overall.

Fulazzaky, *et al.* (2013) conducted a series of laboratory flume tests to investigate grass filter strip retention of synthetic construction site runoff particulates. The regression model developed relating runoff flow rate and sediment trapping efficiency was verified at a construction site in Kuala Lumpur. Typical laboratory inlet suspended solids concentrations were about 1,200 mg/L and the observed outlet suspended solids concentrations after grass filtering was reduced to about 200 to 400 mg/L. The outlet concentrations increased with increasing flow rates. Maximum sediment trapping efficiencies were about 75 to 85% for 2% slopes and reduced to about 55 to 65% for 8% slopes.

Hopkinson, *et al.* (2016) evaluated 29 vegetated roadside and median highway locations to compare the quality of grass establishment to site factors (soil type, elevation, vegetation establishment and cover, seed mixture, slope, aspect, time since planting, and climate). About half of the sites met the 70% cover criterion necessary to terminate the NPDES permit for the West Virginia Division of Highways. The sites having the worst cover had soils with high soluble salts or low organic matter. The salt content was associated with deicing operations, while organic matter content was associated with the native soil material. Neither of these factors were considered amenable to changes in management, as adding mulches to increase organic matter is not feasible for large projects and deicing chemical use was for safety considerations, and alternative chemical deicers were not considered warranted. Nitrogen soil levels was the only nutrient that had a positive correlation with vegetation cover. Soil tests to indicate needed fertilization were therefore recommended. They did not find any significant relationships between physical site characteristics and vegetation cover. The test location vegetation was mostly tall fescue (*Festuca arundinacea*) and crownvetch (*Coronilla varia L.*), which are considered invasive, although included in the seed mixtures used for highway projects. They conclude that site specific seed mixtures should be used at highway projects. Based on this study, these mixtures should be able to better withstand high salt exposures and soils with low organic matter. There are also concerns about using non-native plants in many areas of the country.

RUSLE Cover Factors (C) for Grasses

Table 5-14 lists reported RUSLE cover (C) factors for different grass-covered slopes, having varying mulch rates, and for different growing periods. The use of erosion control mats and blankets significantly increases the immediate protection available (compared to seeding) under most conditions. The use of mulch rates of 2 tons per acre for slopes less than 20% may result in comparable initial performance and only slightly less protection for longer periods, assuming the mulch is securely anchored. With mulches or protective mats or blankets, grasses can provide 85 to 98% erosion control during the initial year, increasing to 99+% control the second year. Without mulches or other protection, the level of erosion control is much less before establishment. In fact, in many cases, grasses planted on slopes and without protection would likely be so severely damaged that successful grass stands would never occur.

Table 5-14. RUSLE Cover C-Factors for Different Grass Growing Periods and Mulch Rates (Sprague 1999)

				C-Factor for Growing Period for Humid Climates			
Treatment	**Mulch rate (tons/acre)**	**Slope (%)**	**<6 weeks**	**1.5 to 6 months**	**6-12 months**	**First year weighted total C factor**	**Second year grass and fully vegetated mats**
No mulching or seeding	--	all	1.00	1.00	1.00	1.00	1.00
Seeded grass	none	all	0.70	0.10	0.05	0.15	0.01
	1	<10	0.20	0.07	0.03	0.07	0.01
	1.5	<10	0.12	0.05	0.02	0.05	0.01
	2	<10	0.06	0.05	0.02	0.04	0.01
	2	11 – 15	0.07	0.05	0.02	0.04	0.01
	2	16 – 20	0.11	0.05	0.02	0.04	0.01
	2	22 – 25	0.14	0.05	0.02	0.05	0.01
	2	26 – 33	0.17	0.05	0.02	0.05	0.01
	2	34 – 50	0.20	0.05	0.02	0.05	0.01
Organic and synthetic blankets and composite mats	--	all	0.07	0.07	0.005	0.02	0.005
Synthetic mats	--	all	0.14	0.14	0.005	0.03	0.005

It's important that the usefulness of native seeding, both for long term slope stability and for improved and deeper root structures that enhance infiltration capacity, be considered when selecting grasses for slope stability. Local agencies will recommend which native plants are most suitable for the site conditions.

Hydroseeding and Mulching

Monitoring Performance of Mulching at Construction Sites

These controls are included in most (mulching 91%) of the 95 erosion and sediment control guidance manuals reviewed.

Recent monitoring performance results for hydroseeding and mulches are shown in Tables 5-15 (no polymers) and 5-16 (with polymers).

Figure 5-50. Slope drains on terraces (Source: Tobiason, *et al.* 2000)

Figure 5-51. Laboratory erosion pans and rain simulator (Source: Wilson, *et al.* 2010)

Table 5-15. Reported Erosion Control Effectiveness of Mulches at Construction Sites

ref	control	type of tests and general location	number of events X locations per treatment	TSS influent (mg/L) avg	TSS effluent (mg/L) avg	% TSS reduc	Turbidity influent (NTU) avg	Turbidity effluent (NTU) avg	% Turbidity reduc
Soupir, et al. 2004 JAWRA	hydroseed	field plots - Virginia	6	6,537	3,257	50			
McLaughlin and Brown 2006 JAWRA	straw mulch	field fescue test plots - North Carolina	5	6,770	1,220	82	2,279	763	67
McLaughlin and Brown 2006 JAWRA	straw erosion control mat ECB	field fescue test plots - North Carolina	5	6,770	3,320	61	2,279	1,350	41
McLaughlin and Brown 2006 JAWRA	bonded fiber matrix MBFM	field fescue test plots - North Carolina	5	6,770	950	86	2,279	349	85
McLaughlin and Brown 2006 JAWRA	straw, with or without PAM	lab erosion tray	3				3,530	857	76
McLaughlin and Brown 2006 JAWRA	wood fiber, with or without PAM	lab erosion tray	3				3,530	664	81
McLaughlin and Brown 2006 JAWRA	bonded fiber matrix MBFM, with or without PAM	lab erosion tray	3				3,530	142	96
Soupir, et al. 2004 JAWRA	straw mulch	field plots - Virginia	6	6,537	527	92			
Tobiason, et al. 2000 IECA	hydromulch	full size - Seattle. WA	5						22 - 95
Wilson, et al. 2010 IECA	jute matting	lab erosion tray	4	n/a	n/a	98	3,500	900	74

		number	10	5	5	6	7	7	7
		average	4.5	6,677	1,855	78	2,990	718	74
		median	5	6,770	1,220	84	3,500	763	76
		min	3	6,537	527	50	2,279	142	41
		max	6	6,770	3,320	98	3,530	1,350	96
		COV	0.26	0.02	0.72	0.24	0.22	0.55	0.23

Table 5-16. Reported Erosion Control Effectiveness of Mulches with Polymers at Construction Sites

ref	control	type of tests and general location	number of events X locations per treatment	TSS influent (mg/L) avg	TSS effluent (mg/L) avg	% TSS reduc	Turbidity influent (NTU) avg	Turbidity effluent (NTU) avg	% Turbidity reduc
McLaughlin and Brown 2006 JAWRA	straw mulch with PAM	field fescue test plots - North Carolina	5	6,770	950	86	2,279	371	84
McLaughlin and Brown 2006 JAWRA	straw erosion control mat ECB wit PAM	field fescue test plots - North Carolina	5	6,770	750	89	2,279	570	75
McLaughlin and Brown 2006 JAWRA	bonded fiber matrix MBFM with PAM	field fescue test plots - North Carolina	5	6,770	2,170	68	2,279	142	94
Tobiason, et al. 2000 IECA	hydromulch and PAM	full size - Seattle. WA	5						94 - 99
Tobiason, et al. 2000 IECA	straw and PAM	full size - Seattle. WA	7						57 - 82
Wilson, et al. 2010 IECA	jute matting with PAM	lab erosion tray	4	n/a	n/a	100	3,500	0	100
		number	6	3	3	4	4	4	4
		average	5	6,770	1,290	86	2,584	271	88
		median	5	6,770	950	88	2,279	257	89
		min	4	6,770	750	68	2,279	0	75
		max	7	6,770	2,170	100	3,500	570	100
		COV	0.19	0	0.60	0.15	0.24	0.93	0.12

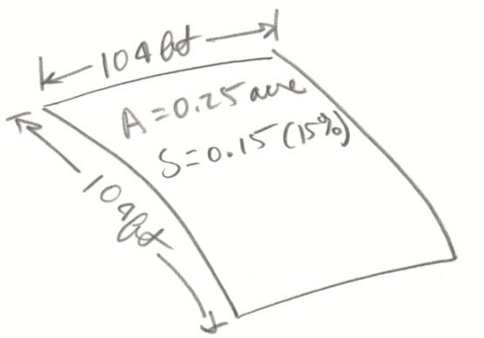
Hydroseeding and mulching provide a method of planting on moderate to steep slopes but require large amounts of water. Mulches include:

1. Long-stem wheat straw (preferred), clean prairie hay, and so forth. Straw or hay mulches are either broadcast and "punched" in (4 to 5 inches deep desired, but usually much less) on moderate slopes with a straight disk, or broadcast along with an adhesive or tacking agent on steep slopes. About 1.0 to 2 tons/acre of straw is desired. Mulches conserve surface moisture and reduce summer soil surface temperatures and crusting. The disadvantages of hay and straw mulches are that they can be a source of weed seed, and too much surface mulch, regardless of the type, can cause seedling disease problems. Also, if not properly installed (which is typical) they will blow away. Commercial wood fiber mulch materials are available for relatively level areas.

2. Soil retention blankets, or mats, made of various interlocking fabrics and plastic webbing can be used on moderate to steep slopes in areas with a high potential for runoff. These erosion blankets prevent seeds from being washed out by rain, and at the same time mulch and enhance germination and establishment.

Example: Slope Stability Calculation

The following simple example shows how it is possible to select the most appropriate erosion protection for a slope, based on allowable erosion rates. Assume a 0.25 acre hillside, as shown below, having a slope width of 104 ft and a slope length of 104 ft. The total critical flow rate off this hillside was previously calculated to be 1.2 ft^3/sec, and the steepest slope is 15%. The Manning's n of the soil (n_s) is 0.05.



The sheetflow depth can be calculated using Manning's equation:

$$y = \left(\frac{qn}{1.49 s^{0.5}} \right)^{\frac{3}{5}}$$

Where q is the unit width flow = 1.2 ft^3/sec/104 ft = 0.012 ft^2/sec. Therefore:

$$y = \left(\frac{(0.012)(0.05)}{1.49(0.15)^{0.5}} \right)^{\frac{3}{5}} = 0.02\,ft = 0.21\,in$$

$\tau_o = \gamma y S$ = (62.4 lb/ft^2)(0.02 ft)(0.15) = 0.18 lb/ft^2

The allowable shear stress for the soils on this hillside is only 0.11 lb/ft^2, and a vegetated mat will therefore be needed. Assuming the n for the mat to be 0.055, it is possible to calculate the resulting shear stress:

$$\tau_e = \tau_o (1 - C_f) \left(\frac{n_s}{n} \right)^2 = 0.18(1-0)\left(\frac{0.05}{0.055} \right)^2 = 0.15\, lb/ft^2$$

This mat selection is therefore not adequate. The mat needs to have an n of at least:

$$0.18(1-0)\left(\frac{0.05}{n} \right)^2 = 0.11\, lb/ft^2$$

Solving for $n_{minimum}$ = 0.067

The mat also needs a C factor to meet the maximum allowable erosion rate on the slope (0.25 inches, or less). Using RUSLE:

R = 350/yr
k = 0.28
LS = 2.5 (for 104 ft slope at 15%)

The base (unprotected) erosion rate is therefore: (350)(0.28)(2.5) = 245 tons/acre/year

This corresponds to 245 (0.00595) = 1.45 inches per year. With a maximum allowable erosion loss of 0.25 inches per year, the maximum C factor for the mat must be: 0.25/1.45 = 0.17. Table 5-13 shows many mats that have this C factor for this slope condition (all except S75). In this example, the selection of a mat having an n of 0.067 or greater will be difficult. Most mats are in the range of 0.022 to 0.055. It will therefore be necessary to use filter fences, coir logs, or other methods to provide additional flow resistance on this slope. Alternatively, the slope length can be shortened with a bench and diversion.

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Case Study: Erosion Control on Very Steep Slopes, the Millennium Pipeline Project

The Millennium Pipeline Project consisted of the construction of 182 miles of 30 inch high pressure gas main in the southern tier of New York State just north of the Pennsylvania border. The project spanned from western Allegany County to Ramapo in Rockland County near the Hudson River. Construction began in June of 2007 under regulatory oversight by the Interagency Compliance Commission which consisted of the Federal Energy Regulatory Commission, the US Army Corps of Engineers, and the New York State Department of Environmental Conservation.

This linear construction project was confined to a right-of-way width of approximately 110 feet and disturbed at total area of approximately 2,400 acres. Much of the area was cleared weeks in advance of the actual excavation operations. During the initial stages of construction, the owners utilized third party monitors and inspectors to assure compliance with the environmental construction standards that had been published by the company itself. The majority of the construction was carried out on very steep slopes within a narrow corridor.

On June 16, 2008 a mudslide from the work area at Peas Eddy, Town of Hancock, Delaware County, closed a town road which was reportedly covered with a mudflow 5 to 6 feet deep. The slide originated from a cleared very steep slope (about 56 degrees). This incident prompted an immediate investigation and response from the NYS DEC Division of Water. The entire project was shut down by the Assistant Commissioner of Water Resources until a full evaluation and appropriate remedies were implemented.

The post mortem of the slope failure at this site stated that the mudslide was attributed to excessive spacing of the slope breakers with no exits for water to get off the site right-of-way. In addition, the temporary slope breakers on the lower portion of the slope were shaped like a horseshoe causing water to dam up the hillside until it breached over the breaker washing out the hillside.

The DEC found that the project had violated the NYS Environmental Conservation Law and was not in compliance with the requirements of the state's General Permit for Stormwater Discharges from Construction Activities. Specifically, the stormwater pollution prevention plan (SWPPP) did not conform to the General Permit requirements, the environmental inspectors did not meet the standards for Qualified Inspectors, over 5 acres of disturbance at one time was occurring without DEC authorization, and the erosion and sediment control standards published by the company did not meet the New York standards and lead to a number of water quality violations.

Figure 5-52. View from the top of the Millennium Pipeline construction slope at Peas Eddy. Note the Town road cleared at the slope bottom and the west branch of the Delaware River just beyond (NYSDEC photo)

Figure 5-53. Slope repair work being done on the very steep slope. Note that the four pieces of equipment are tethered together with steel cables (Binghamton Press photo)

As a result of their investigation, DEC issued a notice of Hearing and Complaint which was held in November 2008. At this hearing the violations that had occurred in four NYS DEC regions were summarized. There were 182 documented water quality violations and 608 NY SPDES General Permit violations. There were 324 days that the project was without coverage under the General Permit. The project also incurred 61 days without adequate or proper inspection and 91 days of unauthorized construction beyond the 5-acre threshold.

Figure 5-54. Remediation work on the Millennium slope above Peas Eddy to control and dissipate runoff. (NYSDEC photo)

Based on these violations the project owners received the largest penalty to date for violations under the Construction General Permit – approximately 8.4 million dollars. The Order on Consent was signed in February 2009 which suspended about 7.2 million dollars for remediation and implementation of a proper SWPPP designed in accordance with NYS standards and implemented for full compliance with the regulations. The remainder of the penalty was divided with 200 thousand dollars paid to DEC and 1 million dispersed to 5 NYS Soil and Water Conservation Districts to hire stormwater program specialists to assist in the support of program efforts.

Figure 5-55. Peas Eddy slope stabilized with slope breakers and seeding with a double layer of jute mesh over straw mulch over the entire slope face (D. Lake photo)

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Case History on Steep Slopes, Lake Bluff Slope Stabilization

Lake Bluff is located on the southern shore of Lake Ontario, adjacent to Sodus Bay, halfway between Rochester and Syracuse, New York. Lake Bluff has been a popular recreation area and vacation spot since the late 1800's. Lake Bluff and Chimney Bluffs, just east, were formed over eons by the coastal erosion of drumlins from the last glacial period that extended into Lake Ontario. At present, the edge of Lake Bluff is over 80 feet above the lake surface and has been estimated to be receding at an average rate of four feet per year.

Figure 5-56. Lake Bluff above the south shore of Lake Ontario eroded to within 20 feet of existing camps (T. Cassel photo)

Development drawings for Lake Bluff dated 1882 depicted a camping ground that would be built around the Lake Bluff Hotel. Since those times, the top of the bluff has eroded so far back for its location in 1882 that some proposed streets and camps that were built no longer exist. A handful of camps survive today because they were relocated many years ago to available lots. It is estimated, from topographic projections, that 50 percent of the original drumlin deposit has eroded away.

The remaining property owners took action in the early seventies to protect the bluff and prevent its erosion. A breakwater was constructed in 1975, after Hurricane Agnes (1972), to prevent toe undermining at the base of the slope at the shoreline. A barge floated crane placed very large rock about 20 feet from the shore to dissipate wave energy. This effort was marginally effective. Over the next 15 years, the top of the bluff receded even further, jeopardizing structures that had already been relocated once and had no more room to move further away from the cliff's edge.

Figure 5-57. Precipice of Lake Bluff. Note drain pipes outlets at the top of the slope (O'Brien & Gere photo)

Stabilization of Lake Bluff depended on the recognition of and attention to a number of complex factors that were all working to unravel the slope. First was the erosion at the toe of the bluff. A properly designed revetment system was needed to stabilize the toe. Second, the extremely steep slopes created by the toe undermining and the surface weathering had to be stabilized. The drumlin soils were classified by the USCS system as SM. They had 45 percent by weight of particles that passed through a #200 sieve. Third, the groundwater and surface water had to be controlled to prevent saturating the slope and causing sloughs or washing off the fine-grained soil.

Figure 5-58. On-shore toe revetment at the bottom of the Lake Bluff slope to resist wave action (T. Cassel photo)

A detailed toe revetment was constructed that combined off-shore and on-shore components. The off-shore section was a sloping rock blanket of 3,000-pound stone with a 5 foot wide crest approximately 5 feet above mean water level. The on-shore section was built of stone weighing 2,500 to 3,000 pounds with a 4-foot-wide, 4-foot-thick berm just below the normal water line and running up the shoreline to an elevation 8 feet higher on the 2 to 1 constructed slope.

Figure 5-59. Slope construction taking place on Lake Bluff. Note the ramps for access to grade out the design slopes (T. Cassel photo)

The next step was to design a stable slope section that could be vegetated to reduce the rill erosion. Initially a compound slope of 2 horizontal to 1 vertical for the lower half and 1.25 horizontal to 1 vertical for the upper half was designed. The upper half was later re-designed to a 1:1 slope due to the addition of benches for stability, access, and drainage. The sequencing of the construction of this slope was critical. 1) Rough grading was done first, 2) then the drainage, 3) then, from east to west on the slope, finish grading, placing and anchoring jute matting, 4) the prepared section was in-filled with seed and a compost material.

Figure 5-60. Placing a filter wrapped perforated drain pipe in the slope (Abscope Construction photo)

Groundwater seeps on the face of the slope were controlled by rock slope drains tied to sub-surface outlets, while a trench drain at the top of the slope was constructed to intercept shallow groundwater and capture surface flows and divert them around the slope face to a rock lined waterway.

Initial results were very good. The entire slope face germinated a dense seeding. However, in the spring 2010, some surface sloughing did occur as a result of snow pack melt water and additional seeps on the slope. Slope repair commenced as soon as the slope was dry enough for access. Sloughed areas were excavated, and stone weep drains were installed. The linear sloughs were re-graded, seeded and mulched with anchor netting placed over the top.

Further stabilization was provided by placing live willow stakes driven into the damp slope areas. As these root, the plants will provide a reinforcement to the soil while its transpiration will help keep the slope drier.


Figure 5-61. Finished grading on the slope. 2:1 on the lower slope and 1:1 on the upper slope. Note the jute mat on slope in foreground (Abscope Construction photo)

There were no public funds or grants to help pay for this project. The cost was born solely by the landowners. Although exact figures for the cost of the project are not known, it is estimate that the total investment to preserve this unique area and property exceeds $750,000.

The slope is currently stable with no toe erosion and a good stand of vegetation. Close monitoring continues to assure any problems that might occur are immediately addressed.

Figure 5-62. The sequencing of the slope construction can be seen in this photo. Rough grading and drainage installation has been completed with some still evident at the top of the picture. Finish grading is occurring in the middle while below that the jute matting is being placed on the slope and anchored. The dark area at the bottom of the picture is the seed and compost mix that has been pumped onto the slope (T. Cassel photo)

Figure 5-63. Initial germination at Lake Bluff from the seed/compost mix (T. Cassel photo)

Figure 5-64. Surface sloughs at Lake Bluff, spring 2010 (T. Cassel photo)


Figure 5-65. Slope drain and rill repair on Lake Bluff (T. Cassel photo)


Figure 5-66. Additional stabilization methods included the use of willow live stakes as a biotechnical slope stabilization measure (T. Cassel photo)

Figure 5-67. Final slope stabilization of Lake Bluff (D. Lake photo)

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Winter Stabilization

Although the majority of land disturbing activities take place during warmer spring, summer and fall months in northern states, a significant and, it seems, an ever-increasing amount of construction continues throughout the colder winter months. Protecting New York's water resources is a year-round job and the challenges to protect these resources are greater during the winter months. Saturated and frozen soils combined with rains in late fall, thaws throughout the winter, and spring melt with rains can produce significant flows increasing the potential for erosion. In addition, the contractor's ability to maintain existing practices during these events is limited by poor access and unstable ground conditions.

New York State is a very large geographical area and the "winter season" is recognized over a varied schedule. For example, the "winter season" on Long Island will be different (and shorter) than the "winter season" at Lake Placid. Contractors, however, need to be aware of the risks associated with changing weather patterns since they may dramatically affect their job site. Generally, if construction activities involving land disturbance is ongoing between late fall and early spring (such as December 1 and April 1 in New York), the following actions should be taken:

1. Enlarge and stabilize access points to provide for snow management and stockpiling. Snow management activities must not destroy or degrade installed erosion and sediment control practices.
2. Prepare a snow management plan with adequate storage and control of meltwater, requiring cleared snow to be stored in a manner not affecting ongoing construction activities.
3. A minimum 25-foot buffer shall be maintained from all perimeter controls such as silt fences.
4. In areas of disturbance that drain to a waterbody within 100 feet, two rows of silt fence need to be installed on the contour.
5. Drainage structures must be kept open and free of snow and ice dams.
6. Sediment barriers must be installed at all appropriate perimeter and sensitive locations. Silt fence and other practices requiring earth disturbance must be installed ahead of frozen ground.
7. Soil stockpiles must be protected by using established vegetation, anchored straw mulch, rolled erosion control product, or other durable covering. A barrier must be installed around the stockpile to prevent soil migration.
8. All slopes must be stabilized as soon as practicable but in no case left unprotected for more than 3 days. Rolled erosion control blankets must be used on all slopes 3 horizontal to 1 vertical and steeper.
9. If straw mulch alone is to be used for temporary stabilization, it needs to be applied at double the standard rate from 2 tons per acre increased to 4 tons per acre. Other manufactured mulch products should be applied at double the manufacturer's recommended rates.
10. To ensure cover of disturbed soil in advance of a melt event, areas of disturbed soil must be stabilized at the end of each work day unless:
    a. work will resume within 24 hours in the same area and no precipitation is forecast or,
    b. the work is in disturbed areas that collect and retain runoff, such as open utility trenches, foundation excavations, or water management areas.
11. Use stone to stabilize perimeters of building under construction and areas where construction vehicle traffic is anticipated. Stone paths should be a minimum 10 feet in width but wider as necessary to accommodate equipment.

The Contractor should inspect the site regularly to ensure that the erosion and sediment control plan is performing its winter stabilization function. If the site will not have earth disturbing activities ongoing during the "winter season," all bare exposed soil must be stabilized by an established vegetation, straw or other acceptable mulch, matting, rock or other approved material such as rolled erosion control products. Seeding of areas with mulch cover is preferred. Seeding alone is not acceptable for proper stabilization.

Figure 5-68. Winter stabilization at New York site (D. Lake photo)

Use of Newly Developed Erosion Controls

The following presents some brief information concerning new products for controlling soil erosion at construction sites. This is a rapidly expanding area with chemical products to bind soil particles seem to have the most products being developed and marketed. Few of these products have been evaluated in comprehensive field tests, but it is hoped they will offer additional tools to the erosion-control professional. The following are only examples of a few of these alternatives. Many more exist and this listing is not intended to be comprehensive, or an endorsement.

Chemical Treatment of Exposed Soils

Anionic PAM is a non-toxic chemical material that is the most commonly used polymer in the U.S. It is used for enhanced control of soil erosion and sedimentation performance on construction sites. Water-based or pellet/tablet versions of PAM have been tested and found to be non-toxic at the concentrations of interest in erosion applications; however, oil-based anionic PAM formulations do appear to result in toxicity to fish, likely due to the surfactants and/or emulsifiers in the oil-based PAM formulations (Weston, *et al.* 2009). PAM can be combined with conventional mulching and seeding practices, as part of coir log perimeter barriers, added to sediment ponds, and as an enhanced soft armoring polymer on bare soil, for enhanced performance. Anionic PAM increases aggregation of the small particles to improve soil stability and prevent soil detachment and decreases the settling time of particles that become suspended. Anionic PAM is applied on site via two dosing methods (direct or passive), and is available in four media types (granular, powder, powder dissolved in water, emulsion, gel block). The powder and the wet and emulsion material can be directly applied to short, steep slopes, and other exposed soil surfaces for soil stabilization, while gel blocks are passively used within a channel. PAM is intended for use on areas that contain high amounts of fine silt, clay or colloidal solids, and requires site-specific testing. It is generally not effective on sandy soils. The effectiveness of PAM to reduce turbidity in stormwater runoff can be influenced by a variety of PAM and soil properties. Misuse or over usage of PAM can clog soils which reduces infiltration.

The EPA (2013) prepared a factsheet on polymer flocculation. The following is a summary from that factsheet. Flocculation is the process where a flocculant is used to reduce the turbidity by binding suspended particles in the liquid together to form larger particles. The sizes of these flocs are very large but have low densities. However, their settling rates are much greater than the individual suspended particles and therefore cause faster settlement. This particle binding and settling process reduces soil erosion and the runoff's turbidity, as well as the aquatic life toxicity associated with turbidity. Polymers are long chain-like macromolecules and vary in their ability to act as good flocculants. Polymers are long chain-like macromolecules. The two wavy ribbons in Figure 5-69 represent polymer molecules dissolved in water, and the brown circles represent suspended soil particles. Cationic polymer molecules have positive charges, and many soil particles (particularly clays) have negative charges. The negatively charged soil particles are attracted to the positively charged polymer molecules, and this causes the soil particles to bind with the polymer chains. Many of the soil particles form ionic bridges between the polymer chains, and some bind to the outside of the polymer chains. This binding process continues until many thousands of polymer chains and soil particles combine to form a floc having sufficient mass to settle to the bottom, thereby reducing the water's turbidity. Cationic polymers are effective flocculants and reduce turbidity, but their positive charges make them toxic to aquatic organisms. Anionic polymers have negative charges and are not toxic, if they are in water or solid phase. They can be added to runoff in a mixture with some positive ions. The soil particles bind onto these anionic polymer molecules and form the ionic bridges show in Figure 5-70. Adding positive calcium ions (Ca^{++}) to the anionic polymer enables anionic polymer flocculation that can reduce the turbidity without harming the aquatic life (EPA 2013).

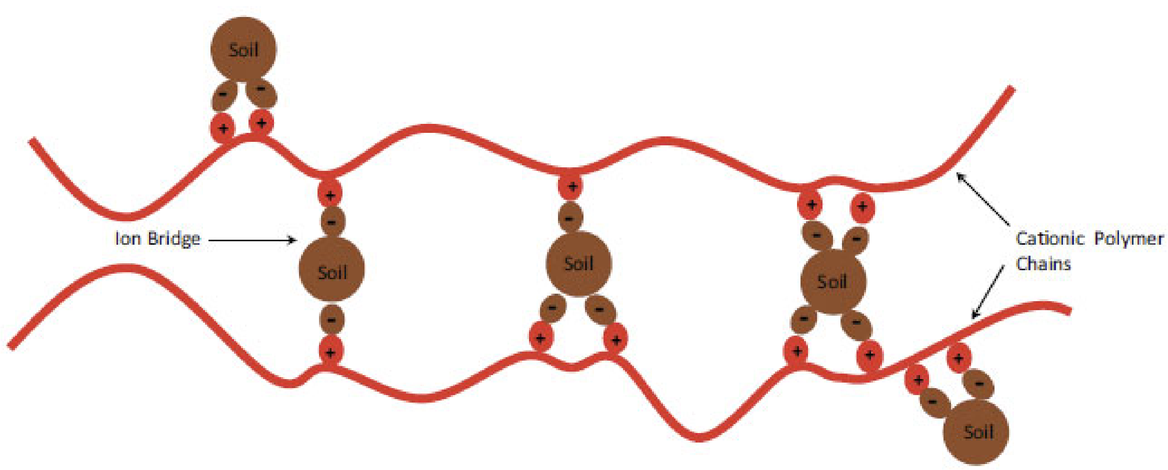

Figure 5-69. Cationic polymer flocculation (EPA 2013)

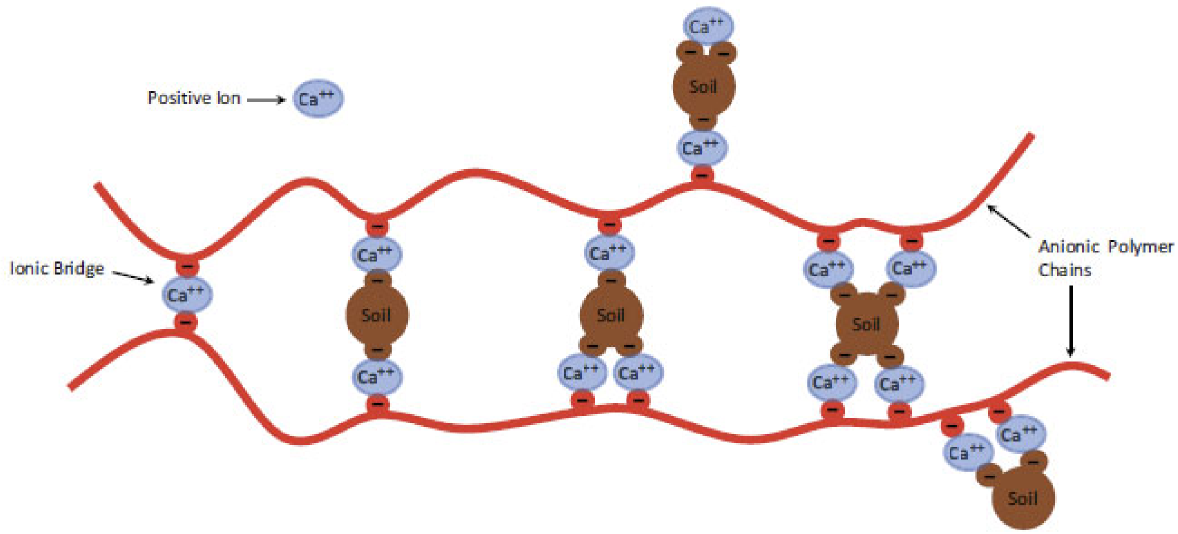

Figure 5-70. Anionic polymer flocculation (EPA 2013)

Monitored Performance of Polymer Applications to Soils at Construction Sites

Chemical stabilization: land and water applications (19%), soil binders (23%) treated with polymers. Table 5-17 summarizes available data reflected applying polymers directly to the soil (as in agricultural practice).

Figure 5-71. Applying polymers to soil (Source: http://www.soilnetllc.com/dust.html).


Figure 5-72. Applying hydromulch mixture to channel (Source: http://www.crwp.org/files/RD_Mulch_FactSheet_July2012.pdf).

Table 5-17. Reported Erosion Control Effectiveness of PAM Directly Applied to Soil at Construction Sites

ref	control	type of tests and general location	number of events X locations per treatment	TSS influent (mg/L) avg	TSS effluent (mg/L) avg	% TSS reduc	Turbidity influent (NTU) avg	Turbidity effluent (NTU) avg	% Turbidity reduc
McLaughlin and Brown 2006 JAWRA	bare soil with PAM	field fescue test plots - North Carolina	5	6,770	3,520	48	2,279	1,950	14
McLaughlin and Brown 2006 JAWRA	bare soil with PAM	lab erosion tray	3				3,530	2,400	32
Roa-Espinosa. Et al. 2000 Chicago conf	dry PAM mix dry soil	field test trays - Wisconsin	3	6,596	2,537	62			
Roa-Espinosa. Et al. 2000 Chicago conf	solution PAM dry soil	field test trays - Wisconsin	3	6,596	2,072	69			
Roa-Espinosa. Et al. 2000 Chicago conf	solution PAM moist soil	field test trays - Wisconsin	3	6,596	2,366	64			
Roa-Espinosa. Et al. 2000 Chicago conf	solution PAM mulch dry soil	field test trays - Wisconsin	3	6,596	859	87			
Soupir, et al. 2004 JAWRA	dry PAM	field plots - Virginia	6	6,537	3,293	50			
Soupir, et al. 2004 JAWRA	low PAM	field plots - Virginia	6	6,537	5,322	19			
Soupir, et al. 2004 JAWRA	Rec. PAM	field plots - Virginia	6	6,537	4,857	26			
Soupir, et al. 2004 JAWRA	High PAM	field plots - Virginia	6	6,537	4,556	30			
		number of studies	11	9	9	9	2	2	2
		average	4.5	6,589	3,265	51	2,905	2,175	23
		median	5	6,596	3,293	50	2,905	2,175	23
		min	3	6,537	859	19	2,279	1,950	14
		max	6	6,770	5,322	87	3,530	2,400	32
		COV	0.32	0.01	0.45	0.44	0.30	0.15	0.56

A number of projects investigated the use of chemicals (mostly the polymer flocculant polyacrylamide, PAM, or chitosan) applied directly to construction site soils or mixed with mulch or seeding mixtures for slope protection. Some of these are summarized below.

Sidhu, *et al.* (2015) investigated runoff volume and sediment delivery reductions associated with different surface treatments. Pilot-scale 1.2 m × 0.6 m test plots were used with 2-year 15 minute and 2-year 30-minute rain intensities at the Turfgrass Research Unit at Auburn University, AL. The test plots used sandy clay soils. The ground covers tested were bare soil with polyacrylamide (EnviroPAM® distributed by Innovative Turf Solutions, Cincinnati, OH), wheat straw and PAM with and without seed; and engineered fiber matrix with and without seed. The fiber mat with the seed was found to be the most effective treatment for turbidity and suspended solids reductions (>98% reductions). The runoff volume reductions ranged from about 16% for the bare soil plus PAM to about 68% for the fiber mat plus seed. The wheat straw plus PAM and seed was recommended as the most cost-effective method for sediment erosion reductions.

Roa-Espinosa, *et al.* (2000) conducted erosion tests at 15 test plots at a construction site in Madison, WI. They applied a simulated 6.3 cm/hr rain after the plots were treated with a PAM mixture (CFM 2000) applied at a rate of 22.5 kg/ha. The PAM treatments resulted in sediment reductions of 63% to 81% when applied to dry soil, and 36% to 97% when applied to moist soil.

Tobiason, *et al.* (2000) investigated different PAM application rates at three sites in the state of Washington. At the first site, slopes of test boxes were 3.5H to 1V. Chemco™ 9836A granular anionic polyacrylamide was used in these tests, along with Vanson™ Chitosan (at a single concentration). Construction sites of 0.4 to 13.5 acres with slopes ranging from 6H to 3H to 1V were also investigated at a second location. The third location was a large construction project where hydroseeding was used along with geotextile-lined interceptor ditches that drained to a sedimentation pond. A polymer batch treatment system was used at this location as an experimental control for post treatment. The sediment pond effluent was dosed with Catfloc 2953, a poly-aluminum-based conventional water treatment polymer. Observation from the first test facility indicated that a PAM dosage in the range of 40-80 mg/L was more effective for the soils and slopes. At the second site, turbidity reductions were high (up to > 90%) with PAM alone and in combinations with hydromulch. At the third site, turbidity reductions of >90% in the pond effluent were obtained with a 2-hour contact time.

McLaughlin, *et al.* (2002) tested 11 different types of PAM on 13 different sediment sources from North Carolina highway construction sites in the laboratory. Field tests were also performed using two PAMs (Soilfix and Silt Stop 705) at two rates, with and without straw much and seeding, on a 2:1 fill slope, applied at the recommended rate and at half of the recommended rate. These field tests were conducted with and without straw mulch seeding, straw mulch and seed only, and bare soil. Eight rain events were recorded during the 5-week testing period with total rainfall for each event varying from 0.08 to 2.24 cm. Turbidity reductions of 80%, or more, were achieved at higher doses for all the flocculants. Turbidity reductions of 95% or more were achieved for many PAM and soil combinations, showing that PAM is effective in the right combinations. PAM only had marginal effects on severe 2:1 slopes.

Twenty-one test plots were studied at a Virginia Tech construction site. All were fertilized and PAM was applied at three rates on different plots by Soupir, *et al.* (2004). A hydromulch-cellulose-seed mixture was applied with the fertilizer. Rainfall simulations were used one month apart to test the short- and long-term effects of the different combinations. They found that the most effective treatments in reducing TSS concentrations were straw mulch, then the hydroseed, and then the dry PAM. The straw mulch, followed by dry PAM, were the most effective treatments in reducing TP concentrations, while the low PAM application rate was most effective in reducing TN concentrations.

McLaughlin, *et al.* (2006) evaluated the use of anionic PAM on bare soil and in combinations with different ground covers (straw, straw erosion control blanket, wood fiber, and mechanically bonded fiber matrix). Natural rainfall and vegetation (fescue) were tested on a 4% slope and other tests were conducted with a rainfall simulator on 10 and 20% slopes. The ground covers were applied with and without PAM (Siltstop 705 at 19 kg/ha) after seeding. Table 5-18 shows the average turbidity levels for the four treatments, with and without PAM. The ground covers significantly reduced runoff volume, turbidity losses and sediment losses compared to bare soil at the 4% slope test site, as shown in the table above. Straw produced better vegetative cover than either bare soil or the fiber matrix on the steeper slopes. PAM with straw was effective in reducing turbidity during the 20% slope tests.

Table 5-18. Average Turbidities on Fescue Plots over Five Rainfall Events on 4% Slopes (McLaughlin, *et al.* 2006)

	No PAM (NTU and % reduction compared to bare soil, all no PAM)	With PAM (NTU and % reduction compared to bare soil with PAM and compared to bare soil without PAM)
Bare soil	2,279 (n/a)	1,950 (n/a, 14%)
Erosion control blanket	1,350 (41%	570 (71, 75%
Straw	763 (67%)	371 (81, 84%)
Mechanically bonded fiber matrix	349 (85%)	142 (93, 94%)

McLaughlin, *et al.* (2007) also reported on their study of 18 erosion control treatment plots at four locations in North Carolina. The plots were treated with fertilizer and lime and a fescue, a Bermuda, and a centipede seed mixture. Straw and asphalt tackifiers and Polymer Systems 705 PAM powder were also applied at some test plots. They found that the runoff turbidity from straw treated plots was substantially reduced, while the Excelsior matting had a smaller reduction in runoff turbidity. A large turbidity reduction with PAM was noted for one site, but not at another. They concluded that PAM applications of 20 kg/ha were needed on slopes from 5 to 45% for consistent turbidity reductions.

Wilson, *et al.* (2010) tested soil from a construction site in Auburn, AL, under controlled rainfall simulations at 4.4 in/hr (the local 2-yr, 24-hr rainfall intensity). Dry PAM (Silt Stop^{TM} 712) was applied at a rate of 31.2 kg/ha with an open weave jute matting installed on bare soil. The jute matting was found to be effective in reducing soil losses, while the addition of the dry PAM resulted in further reductions in soil losses and turbidity levels.

Babcock and McLaughlin (2013) tested several hydromulches and straw applications, with and without polyacrylamide, during small-scale controlled tests. Soil was packed to a depth of 0.06 m (0.2 ft) into 1 by 2 m (3.3 by 6.6 ft) boxes, which were placed under a rainfall simulator at a slope of 18° and tested for several artificial rainfall applications. The straw had the highest effluent turbidity (about 1,000 to 1,500 NTU), while the lowest effluent turbidity was observed with the hydromulch plus PAM (about 60 to 150 NTU). No tests were conducted on bare soil. Adding PAM to the straw mulch was less expensive and had similar turbidity results as the hydromulch without PAM. However, the hydromulch with PAM was found to provide the lowest turbidity and best erosion protection. Adding PAM would cost about $600 per ha ($250/ac), which is about 10% of the typical costs of the total application of seed, fertilizer, lime, and straw, based on local erosion control bids. During these controlled tests with a relatively high rain intensity (1.5 in/hr), the dissolved forms of PAM provided the best initial protection, as the granular forms required some time to dissolve. The granular forms performed best during later tests. During earlier field tests, the researchers did not find any significant differences between dissolved and granular PAM applications, probably due to lower natural rain intensities allowed the granular forms to dissolve more completely before runoff was initiated.

Zhang, *et al.* (2016) noted that PAM is adsorbed by soil through cationic bridges between soil and polymer anionic groups, and multivalent cations in the soil solution would bridge the negatively charged soil particles and polymers together. Nine types of anionic polyacrylamide (PAM) were studied during twenty-seven simulated rainfall events in a greenhouse. They found that:

- PAM reduced total nitrogen and total phosphorus losses from the 3 mm test aggregate by about 35% to 50% compared to the control group.

- The losses of total nitrogen and total phosphorus were significantly correlated with the molecular weight of the PAM.

There are a number of new products being developed and sold for the control of erosion and sediment at construction sites. One emerging area is the use of chemical polymers and coagulant agents, as described above. Older chemical products were mostly soil binding agents, including light asphalts. These newly developed materials act by chemically combining small soil particles into larger discrete particles that are more effective in settling in ponds and in channels. Polyacrylamide (PAM) is the most common chemical being sold now. The following information is from the Internet sites of several distributors or manufacturers of some of these chemicals. This list is very short and is not intended to include all products.

JRM Chemicals, Inc.
(http://www.soilmoist.com/agerosion.html)

Products:

1) FI-1000 Soil Erosion Polymer: FI-1000 is an anionic high molecular weight polymer designed to reduce soil loss and silt loss in furrow irrigation applications. FI-1000 will increase water infiltration and reduce fertilizer and other chemical runoff. The anionic polymer bonds the suspended particles in the water and they fall to the bottom of the water. Its application rate is one pound per acre (into 12,000 gallons of water).

2) FI-2000: FI-2000 is an anionic high molecular weight water-soluble polymer designed to reduce soil loss and silt loss in all aspects of agricultural irrigation. FI-2000 is an emulsion that can be applied to furrow, gated pipe, sprinkler and pivotal irrigation systems. Its application rate is 30 ppm.

Polyacrylamide (PAM)
The University of Nebraska Cooperative Extension service provides the following information on PAM:

> "Polyacrylamide (PAM) is a long-chain synthetic polymer that acts as a strengthening agent, binding soil particles together. It is harder for water to move these larger, heavier particles of soil. USDA researchers in Kimberley, Idaho began working with PAM in the early 1990s as a method to reduce erosion in furrow irrigation. Their tests indicated PAM applied in the irrigation water reduced soil erosion in furrows by over 95 percent, when compared to irrigation without the polymer.
>
> Polyacrylamide used for erosion control should have a negative (anionic) molecular charge. Historically, similar compounds have been used in other industries like potable water treatment, food processing, paper manufacturing and wastewater treatment. Research conducted in Idaho showed that less than 5 percent of PAM applied during an irrigation left fields in the runoff water. This research also showed that after leaving the field, the PAM concentration in the runoff quickly fell below detectable limits (>1,500 yards). There is no indication of any adverse impact on soil, plant or aquatic systems when anionic PAM is used to control soil erosion. Because PAM limits soil erosion, using it can prevent attached pollutants from also leaving the area.
>
> Many companies distribute PAM. HYDROSORB (1390 N. Manzanita St., Orange, CA 92867) presents the following information for their products. SOILFLOC™ is a water-soluble, linear polyacrylamide (PAM) polymer that was designed to be used for erosion control, soil structure improvement and dust abatement. SOILFLOC™ works by aggregating soil particles, increasing pore space and infiltration capacity, resulting in soils that are less susceptible to raindrop and scour erosion. SOILFLOC™ is environmentally safe and non-toxic. A variety of PAM products have been approved by NSF International for potable water clarification. They will naturally degrade with UV light and are consumed by microbiological attack. This product is compatible with almost all irrigation systems. PAM products are now registered throughout the western United States. MSDS and TDS available upon request. SOILFLOC™ is available in a dry granule form, liquid emulsion, and tablets."

HydroGrass Technologies also supplies PAM. The following describes their products:

APS 600 Series Silt Stop®
Polyacrylamide Erosion Control Emulsion
A soil specific tailored polyacrylamide copolymer liquid emulsion for erosion control. It reduces and prevents erosion of fine particles and colloidal clays from water. Applied with a water truck of hydroseeder or other spraying devices at a rate of 1 1/2 gallons per acre.

APS 700 Series Silt Stop®
Polyacrylamide Erosion Control Powder
A soil specific tailored polyacrylamide copolymer powder for erosion control. Used to reduce and prevent erosion of fine particles. Settles our suspended particles of sediment and colloidal clays from

water. Applied with a hand spreader, mechanical disc or can be mixed with water and applied with a spraying device at a rate of approximately 10 pounds per acre.

APS Floc Log®
Polyacrylamide Semi-hydrated Gel Block
A soil and water chemistry tailored gel block, that when placed within stormwater or construction site damages will remove fine colloidal particles and reduce NTU values. Floc Logs are staked in place in a location close to active earth moving activities and can also be used in drop inlets, storm drains, retrofits and slope drains. The APS Floc Log will treat a flow rate of 60 to 75 gallons per minute.

The *Alabama Handbook* (ASWCC 2014) provides the following guidance for use of PAM, shown as a sidebar.

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Sidebar: "Chemical Stabilization (CHS)
Practice Description
Chemical Stabilization erosion control involves the use of products, including soil binders that help to hold the soil in place, thereby reducing soil particle detachment and short-term erosion caused by water and wind. Water-soluble polyacrylamide (PAM) is often used for this purpose. Other products may also provide this benefit. The products are typically applied with temporary seeding and or mulching on areas where the timely establishment of temporary erosion control is so critical that seeding and mulching need additional reinforcement.

Planning Considerations
Chemical Stabilization products for surface stabilization are available in different formulations should be used in combination with other Best Management Practices. The use of seed and mulch should be considered for providing erosion protection beyond the life of the chemical or soil binder. If the area where Chemical Stabilization products have been applied is disturbed, the application will need to be repeated. Following are additional considerations to enhance the use of or avoid problems:

- Use recommended setbacks (Buffer Zone) when applying near natural water bodies.
- Application delays between product mixing and application as well as ultraviolent light exposure may decrease the performance of some products.
- Products are generally not effective in concentrated flow areas.
- Seeded areas will also need mulch.
- It is important to closely follow manufacturer's recommendations on application procedures.
- Do not use products in a way that will be toxic to aquatic organisms.

- Requests to use products not approved for Chemical Stabilization on permitted sites should be made to the state environmental agency.

Design Criteria
Application rates shall conform to manufacturer's guidelines for application.

The following specific criteria shall be followed:

- Chemical mixtures shall be environmentally benign, harmless to fish, wildlife, and plants, and shall be non-combustible.

- Users of chemical stabilization products shall follow all Material Safety Data Sheet requirements and manufacturer's recommendations. In the case of PAM, the use of a specific product should be based on the jar test with soil from the site and there should be appropriate measures at the site to ensure that PAM is not carried in stormwater emptying directly into natural waterbodies. This means that runoff should be flowing to settling sites such as sediment basins or sediment traps or be flowing over sites such as filter strips, straw or matting that serves as a collection site for the sediments.

- Additives such as fertilizers, solubility promoters or inhibitors, etc. to chemical stabilization products shall be non-toxic.

- The manufacturer or supplier shall provide written application methods. The application method shall ensure uniform coverage to the target and avoid drift to non-target areas including waters of the state. The manufacturer or supplier shall also provide written instructions to ensure proper safety, storage, and mixing of the product."

===

Other products are available for slope stability applications that go beyond simply hydromulching or PAM. Examples include various fiber mixtures that have soil binders, often called bonded fiber matrices. There are also organic fiber matrices with biological topsoil enhancements that are applied by hydroseeding, which enhance and speed up seed growth.

Summary

This chapter reviewed several techniques for preventing erosion at construction sites, including the design of stable channels and slopes at construction sites. The shear stress method was shown to be generally necessary for channel design, compared to only using an allowable velocity approach. However, liner vegetation in erosion resistant soils may still fail due to vegetation damage, thus requiring careful plant selection. For slopes, tolerable soil loss calculations may also be needed to verify the selection of slope protection solutions; the use of shear stress alone may not be suitable, especially in highly erosive locations.

Anionic PAM is a non-toxic chemical material that is increasingly being used in the US to reduce erosion losses and enhance sediment control at construction sites. PAM has been combined with other practices, such as conventional mulching and seeding practices, as part of coir log perimeter barriers, and when added to sediment ponds, and as an enhanced soft armoring polymer on bare soil, for enhanced, but variable, performance. PAM works best in areas that contain high amounts of fine silt, clay or colloidal solids, and requires site-specific testing for to determine the optimal dosages.

It is critical that a construction site use suitable procedures to prevent erosion on site, instead of relying on sediment removal from the flowing water after erosion occurs. These techniques must be used, in conjunction with good construction planning, to minimize the amount of land exposed to erosion, and to decrease the amount of sediment erosion produced. The next chapter describes sediment control measures, and their design, for construction sites.

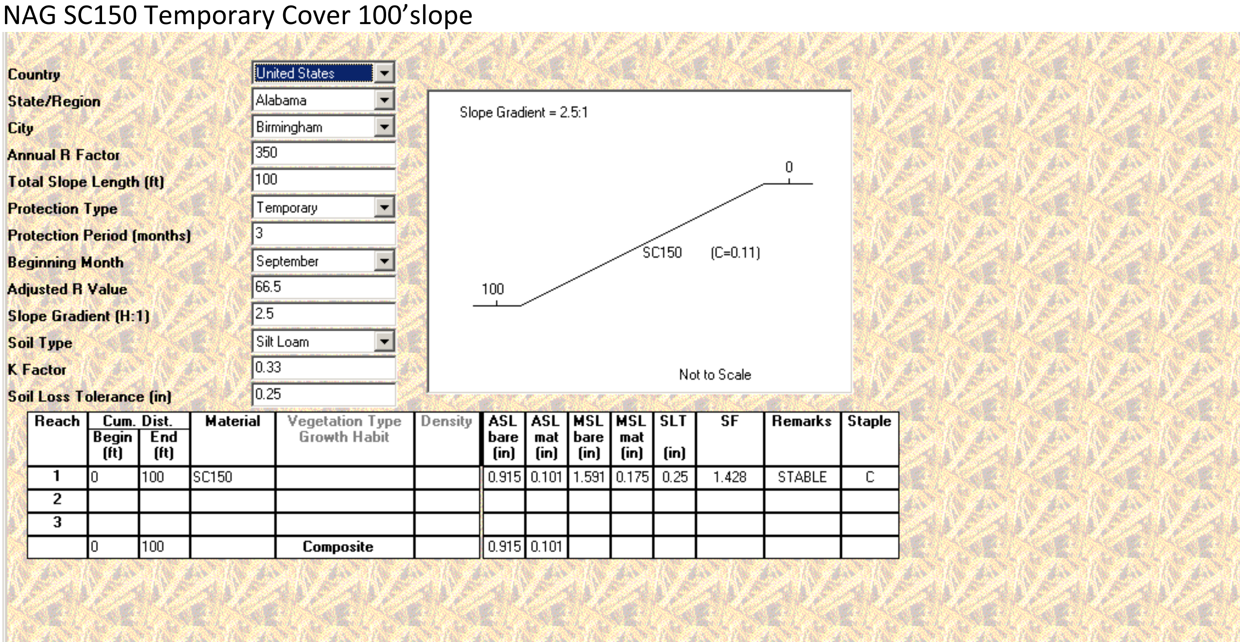
Example Project Assignment on Slope and Swale Design

The following is excerpted from a homework assignment prepared by Heather Hill, a student at the University of Alabama at Birmingham, as part of the Construction Site Erosion and Sediment Control Class taken during the summer of 2005. The assignment was given as follows:

1) **Identify several different slope categories on your construction evaluation site and propose suitable control practices for each type. Justify your selections with appropriate calculations.**

The following is an example output screen from the North American Green software to assist in the selection of turf reinforcement mats for slopes.

NAG SC150 Temporary Cover 100'slope



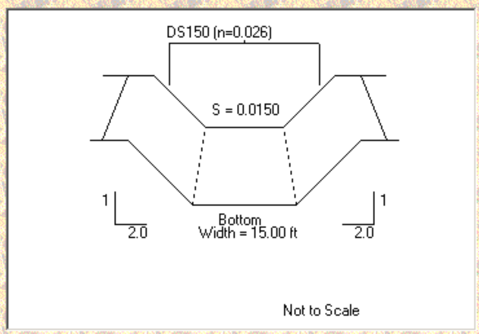
Reach	Cum. Dist. Begin (ft)	Cum. Dist. End (ft)	Material	Vegetation Type Growth Habit	Density	ASL bare (in)	ASL mat (in)	MSL bare (in)	MSL mat (in)	SLT (in)	SF	Remarks	Staple
1	0	100	SC150			0.915	0.101	1.591	0.175	0.25	1.428	STABLE	C
2													
3													
	0	100		Composite		0.915	0.101						

2) Design an appropriate diversion swale for your evaluation site. Using the previously calculated flow rates, select a suitable channel lining, including the consideration of check dams. Justify your selections with appropriate calculations.

There is not a diversion swale at this construction site. The creek that runs through the site will actually be rerouted through a 15’ culvert pipe and covered to level out the site. In order to reroute the stream and install the culvert, an impermeable diversion dam was installed where the stream entered the site. A bypass pump was set up at this location to pump the water to the end of the site where it naturally releases. The average daily flow of this stream is approximately 2600 gpm. The following is an example of applying the North American Green software to evaluate a channel lining material to this channel, assuming that an open channel was an optional method.

HYDRAULIC RESULTS

Discharge (cfs)	Peak Flow Period (hrs)	Velocity (fps)	Area (sq.ft)	Hydraulic Radius(ft)	Normal Depth (ft)
295.0	24.0	8.93	33.04	1.44	1.78



LINER RESULTS

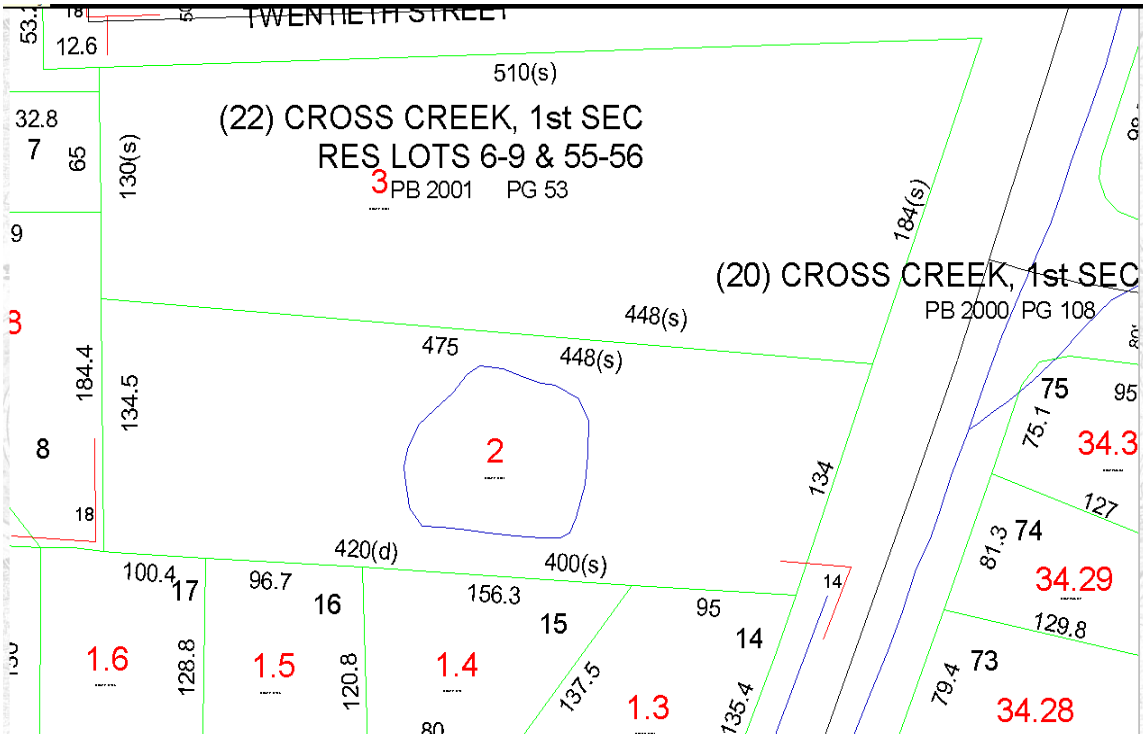
Reach	Matting Type / Staple Pattern	Stability Analysis	Vegetation Characteristics				Permissible Shear Stress (psf)	Calculated Shear Stress (psf)	Safety Factor	Remarks
			Phase	Class	Type	Density				
Straight	DS150	Unvegetated					1.75	1.67	1.05	STABLE
	Staple D									

Example Project Assignment on Slope and Swale Design

The following is modified from a homework assignment prepared by Regan Johnson, a student at the University of Alabama, as part of the Construction Site Erosion and Sediment Control Class taken during the summer of 2005.

1) **Identify several different slope categories on your construction evaluation site and propose suitable control practices for each type. Justify your selections with appropriate calculations.**

The City of Tuscaloosa has granted permission to develop St. Charles Place, a townhouse residential development located. The following is the detailed site topographic map donated by the site developer, and a USGS aerial photograph of the surrounding area.



This site was separated into the following slope categories: 0-2%, 2-5%, 5-20%, and 20% and greater. One critical slope is examined in the following calculations for slope stability requirements, having the following characteristics:

Slope = 0.5 = 50%
Width of slope = 175ft
Manning's "n" = 0.02

The modified Manning's equation was used to calculate the nominal depth for sheetflow on this particular slope, using the previously calculated peak flow rate of 6.4 ft^3/sec.

$$y = \left(\frac{qn}{1.49 s^{0.5}} \right)^{\frac{3}{5}}$$

Where: y is the flow depth (in feet),
q is the unit width flow rate (Q/W)
n is the sheet flow roughness coefficient for the slope surface

s is the slope (as a fraction)

q= Q/W= 6.39/175= 0.0365 cfs
n= 0.02 for sandy loam soils
s= 0.50 ft/ft

y= ((0.0365)(0.02) /(1.49/ 0.50$^{0.5}$))$^{3/5}$ = 0.051 ft, or about a half an inch

Therefore, the basic shear stress equation can be used to calculate the maximum shear stress expected on a slope:

$$\tau_o = \gamma y S \quad (\text{lb/ft}^2)$$

where:

γ = specific weight of water (62.4 lbs/ft^3)
y = flow depth (ft)
S = slope (ft/ft)

Thus, τ_o = (62.4)(0.051)(0.50)= 1.58 lb/ft^2

Since the allowable shear stress for the soils on this hillside is only 0.15 lb/ft^2, a vegetated mat will be needed. The next step is to check the shear stress under the mat.

We can solve for the needed roughness factor "n" of the mat to find a mat that will work given the following equation:

$$\tau_e = \tau_o(1 - C_f)\left(\frac{n_s}{n}\right)^2$$

τ_e = 0.15 = 1.58(1-0)[0.02/n_{mat}]^2 n_{mat} = 0.065

Therefore, a mat is needed having an "n" value of at least 0.065 to provide proper soil protection. Additionally, the mat also needs a C factor to meet the maximum allowable erosion rate on the slope (0.25 inches, or less). Using RUSLE:

R = 350/yr (Tuscaloosa)
k = 0.21
LS = 12.75 (for 150 ft slope at 50%)

The base (unprotected) erosion rate is therefore: (350)(0.21)(12.75) = 643 tons/acre/year

This corresponds to 643(0.00595) = 3.8 inches per year. With a maximum allowable erosion loss of 0.25 to 0.5 inches per year, the C factor for the mat should therefore be: 0.5 to 3.8 = 0.13; or 0.25/3.8 = 0.065, or less

A NAG P300 mat has a C of 0.09 (intermediate in the above range) and an n of 0.02 for this slope and unvegetated condition.

The shear stress is too large, as the mat n is only 0.02, and not the desired 0.065, or larger. Therefore, the only reasonable solution for this steep and long slope is to use terraces to divide the slope into several segments, and to use diversion down-slope drains to collect the water from each terrace bench and safely carry it to the bottom of the slope.

If the slope was divided into 50 ft segments, 1/3 of the original slope length, the Q would also be 1/3, or 2.1 ft^3/sec, and the q would be 0.012 cfs. The resulting flow depth would therefore be:

$y= ((0.012)(0.02) /(1.49/ 0.50^{0.5}))^{3/5}$ = 0.0125 ft, or 0.15 inch

The resulting shear stress is therefore: $\tau_o = (62.4)(0.0125)(0.50)= 0.39$ lb/ft^2
The needed value for n (unvegetated) is therefore: $\tau_e = 0.15 = 0.39(1-0)[0.02/n_{mat}]^2$ $n_{mat} = 0.032$ at least

The NAG P300 still is not “rough” enough.

If the slope was divided into 25 ft length segments, 1/6 of the original slope length, the Q would also be 1/6, or 1.1 ft^3/sec, and the q would be 0.006 cfs. The resulting flow depth would therefore be:

$y= ((0.006)(0.02) /(1.49/ 0.50^{0.5}))^{3/5}$ = 0.0043 ft, or 0.052 inch

The resulting shear stress is therefore: $\tau_o = (62.4)(0.0043)(0.50)= 0.13$ lb/ft^2
The needed value for n (unvegetated) is therefore: $\tau_e = 0.15 = 0.13(1-0)[0.02/n_{mat}]^2$ $n_{mat} = 0.019$ at least

Therefore, this slope length is suitable, as the n for the mat is 0.02.

As an alternative, it may be suitable to re-examine the slope itself and consider reducing it from 50% to 40%, and with terraces at 50 ft spacing:

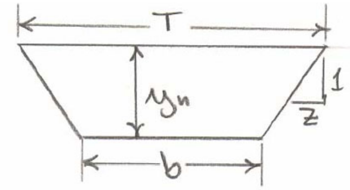
$y= ((0.012)(0.02) /(1.49/ 0.40^{0.5}))^{3/5}$ = 0.007 ft, or 0.08 inch

The resulting shear stress is therefore: $\tau_o = (62.4)(0.007)(0.40)= 0.17$ lb/ft^2
The needed value for n (unvegetated) is therefore: $\tau_e = 0.15 = 0.17(1-0)[0.02/n_{mat}]^2$ $n_{mat} = 0.021$ at least

This is close to the available n of 0.2 and is also a likely a suitable solution. Either of these solutions to modify the slope would also reduce the resulting erosion rate.

2) Design an appropriate diversion swale for your evaluation site. Using the previously calculated flow rates, select a suitable channel lining, including the consideration of check dams. Justify your selections with appropriate calculations.

This site consists of one channel that diverts water from the upper portion of the watershed. This channel is located in the back of the site and it will be designed to handle the flow rates that were calculated through an earlier analysis. The cross section of the channel will be a trapezoidal in shape.



Other factors such as slope, Manning's "n", and soil type also affect the channel's performance as well. There are two important parameters involved when designing a diversion swale (1) Allowable velocity (V_0) and (2) Allowable shear stress (τ_0). The first step of the design is to determine the applicable values associated with site specific soil conditions. The site soil is sandy loam. The following parameters should therefore be meet for this design:

Maximum permissible velocity (V_0): 2.5 ft/sec
Allowable shear stress (τ_0): 0.075 lb/ft^2

For this particular swale design, the Manning's equation for open channel flow will be used with the Chow shape factor relationship:

$$AR^{\frac{2}{3}} = \frac{nQ}{1.49S^{0.5}}$$

Where: Q= 16.3 cfs
S= 0.055 ft/ft
n= 0.02

It is therefore possible to calculate the nominal depth of channel flow within the swale for different swale cross sections, using an Excel spreadsheet. The spreadsheet allowed an examination of various base widths (b) and side slopes (z) of the channel. The selected alternative for the channel dimension is one with a 3ft base and 2:1 side slope. The resulting shear stress and channel velocity are also shown on this table.

Channel Design Option

b (ft)	z (ft)	Top (ft)	$AR^{2/3}$	$b^{8/3}$	$AR^{2/3}/b^{8/3}$	y_n/b (From Chow's figure)	y_n	τ (lb/ft^2)	R	V (ft/s)
3	2	15	8.01	18.72	0.43	0.35	1.05	3.60	0.70	2.50
4	2	20	8.01	40.32	0.20	0.3	1.20	4.12	0.83	1.94
5	2	25	8.01	73.10	0.11	0.27	1.35	4.63	0.96	1.48
6	2	30	8.01	118.87	0.07	0.153	0.92	3.15	0.71	1.91
3	3	21	8.01	18.72	0.43	0.32	0.96	3.29	0.62	2.43
4	3	28	8.01	40.32	0.20	0.27	1.08	3.71	0.73	1.85
5	3	35	8.01	73.10	0.11	0.24	1.20	4.12	0.84	1.46
6	3	42	8.01	118.87	0.07	0.142	0.85	2.92	0.63	1.83

Note: Highlighted areas indicate the best option for the channel design.

Since the shear stress is higher than permissible, the channel will be fitted with a liner or vegetation mat. Installing a channel liner will cause the effective shear stress to decrease, thus, reducing the potential of excessive sediment erosion. Moreover, the vegetation mat will provide adequate support for the channel's exposed sediment surface.

The North American Green website provides a list of suitable of potential mats to be used for erosion control for construction sites. For this channel, a EroNet P300 polypropylene fiber erosion control blanket was selected. The following calculations show that this liner meets the permissible shear stress criteria.

$$\tau_e = \gamma DS(1 - C_f)\left(\frac{n_s}{n}\right)^2$$

Where:
τ_e = effective shear stress exerted on soil beneath vegetation
γ = 62.4 lbs/ft^3
D = the maximum flow depth in the cross section=1.05 ft
S = hydraulic slope = 0.055 ft/ft
C_f = vegetation cover factor =0.90 (Bermuda grass)
n_s = roughness coefficient of underlying soil = 0.02
n = roughness coefficient of erosion control blanket = 0.44

τ_e= 62.4*1.05'*0.055(1-0.90)[0.02/0.044]2 = 0.074

Therefore, $\tau_e < \tau_o$ and the NAG EroNet P300 mat will be an acceptable solution to the for this the channel.

Problems

1. Explain the influence of each of the following on the tractive force or shear stress along a channel bottom. (a) The shape of the soil particles; (b) The specific weight of the fluid; (c) The specific weight of the soil particles; (d) The particle diameter.

2. Using the allowable shear stress method, design an upslope diversion channel to carry a discharge of 10 ft^3/sec, a maximum velocity of 2 ft/sec, a channel slope of 0.5%, and that is located on loam soil. Is this channel stable if no protective mat or liner is installed?

3. An existing trapezoidal canal has a slope of 0.01 ft/ft, a base of 12 ft, a Manning's roughness coefficient of 0.035, and side slopes of 3.5H:1V. Determine the permissible velocity.

4. A new roadway is being cut through your area. The side slope (1H:1V) of 500 ft in width and 50 ft in slope length needs to be stabilized. Assuming the design storm for side-slope stabilization is the 25-yr storm (to prevent washout of roadway support). Design a slope stabilization scheme. Does this slope require protection above mulching while awaiting seed cover?

5. A stone check dam is to be designed in a swale whose bottom width is 2 feet and side slopes are 2H:1V. The check dam is 2 feet high. The maximum allowable discharge through the check dam is 1.6 cubic feet per second. What should the average rock size be for the dam assuming a 2:1 slope on both the upstream and downstream faces of the dam?

6. A stone weeper is being proposed to discharge concentrated highway runoff onto a vegetated filter area as sheet flow. The weeper is 2 feet high to its crest and is 20 feet long with a 2 foot top width and 2H:1V side slopes. The D50 stone size is 4 inches. What is the flow capacity through the weeper with the flow at the crest? Assume vertical abutments.

7. Develop the stage discharge curve for this stone weeper for each 0.5 feet of head beginning at the channel bottom. If the water quality peak discharge is 1.5 cubic feet per second, what is the depth of water behind the stone weeper?

8. A field check shows that the stone weeper was not constructed as designed. It was built with steeper side slopes; they are 1H:1V. What is the impact on the stage discharge curve flow rates and the depth of water quality storm flow?

9. Project Questions:
   a. Identify several different slope categories on your construction evaluation site and propose suitable control practices for each type. Justify your selections with appropriate calculations.

   b. Design an appropriate diversion swale, or a main drainage swale for your evaluation site. Using the previously calculated flow rates, select a suitable channel lining, including the consideration of check dams. Justify your selections with appropriate calculations.

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Appendix 5A: Commercial Sources for Channel Liners

The following lists various commercial sources for channel liners and turf-reinforcing mats for protecting channels. Obviously, this is not a comprehensive listing and their inclusion here does not imply any endorsement. These are included as examples of the types of products, and supporting information, currently available.

Rock Baskets (Gabions)

Maccaferri www.maccaferri-usa.com
Terra Aqua www.terraaqua.com

IECA photo

Gabion Wall Channel Protection

Concrete Flexible Grids (Revetment)

Armortec www.armortec.com
Hydropace info@hydropve.com

Plastic Grids

Invisible Structures, Inc, (Slope Tamer^2) www.invisiblestructures.com
Presto (Geoweb) 1-800-548-3424 http://www.prestogeo.com/

Fabric Blankets and Channel Mat Liners

Synthetic Industries (Landlok erosion control blankets and Pyramat) www.fixsoil.com
Construction Products, Inc. (Contech) Middleton, Ohio
Amoco Fabrics and Fibers Co. (Super Gro) 1-800-445-7732

Akzo Nobel (Enkamat) 1-800-365-7391
North American Green www.nagreen.com
RoLanks Erosion Control Blankets 1-800-760-3215

Turf Grass

Gardner Turfgrass, Inc. (sod farms, also Stay Turf live matting) www.Gardnerturf.com

Hydroseeding and Chemicals

Conwed fibers (mulch and blankets) www.conwedfibers.com 1-800-366-1180
Soil Guard (bonded fiber matrix mulch) www.soilguard.com
Soil Moist (soil erosion polymer) www.soilmoist.com
Terra Mulch www.terra-mulch.com
Applied Polymer Systems lwinskis@aol.com

Appendix 5B: Kansas Department of Transportation Bureau of Materials and Research

The following is an example list containing the pre-approved products listed by the Kansas Department of Transportation, Bureau of Materials and Research, for different types of construction site erosion control applications.

This list is an example of pre-approved erosion control products and shows the variety of products now available for slope protection. Other states' have similar lists, but may have differing standards and testing procedures. This is included here as an example of what is being developed. Obviously, it is important to select materials that will meet local, site-specific conditions, and that are also approved by the local regulatory agency.

"Approved Erosion Control Products for Slope Protection (revised 12/01/2008)

KANSAS DEPARTMENT OF TRANSPORTATION
BUREAU OF MATERIALS AND RESEARCH
PQL-34B-Revised 12/01/08

CLASS 1 "SLOPE PROTECTION"
Type A - Slopes 1:3 or Flatter - Clay Soils:
AEC Premier Straw
AEC Premier Straw Double Net
AEC Premier Straw/Coconut
AEC Premier Coconut
Airtrol - Hydromulch
Anti-Wash/Geojute
BioD-Mesh 60
Carthage Mills Veg Net
C-Jute
CocoFlex ET-FGM
Contech Standard
Contech Standard Plus
Contech Straw/Coconut Fiber
Mat w/Kraft Net
Contech C-35
Curlex™ 1
Curlex™-LT
Earth Bound - Hydromulch
EcoAegis™ - Hydromulch
Econo-Jute
ECB S31 Single Net Straw
ECB S32 Double Net Straw
ECS-1

ECS Excelsior Blanket Standard
ECS High Velocity Straw Mat
ECS Standard Straw
EnviroGuard Plus - Hydromulch
Enviro-Matrix - Hydromulch
Enviro-Shield - Hydromulch
Excel CC-4
Excel CS-3 All Natural
Excel Lc-1
Excel PP5-10
Excel R-1
Excel Rc-1
Excel SR-1
Excel SR-1 All Natural
Excel SS-2
Flexterra FGM - Hydromulch
Futerra®
Grass Mat
Greenfix CFS072R
Greenfix WS05
Greenfix WSO72
Green Solutions DNS2
Green Solutions SNS1
Green Triangle Regular
Green Triangle Superior
Greenstreak Pec-Mat
Hydra CX2 - Hydromulch
Multimat 100
North American Green® S75
North American Green® S75 BN
North American Green® S150
North American Green® S150 BN
North American Green® SC150
Hydro Blanket - Hydromulch
Landlok® S1
Landlok® S2
Landlok® CS2
Landlok® 407
Landlok® TRM 435
Miramat TM8
Landlok® SuperGro
Pennzsuppress® - Hydromulch
Poplar Erosion Blanket
Rhino Erosion King Single Net
Rhino Erosion King Double Net

SEC-S2
Soil Guard - Hydromulch
Soil Saver
SprayMat - Hydromulch
Terra-Control® - Hydromulch
TerraJute
Terra-Mulch - Hydromulch
Verdyol Ero-Mat
Verdyol Excelsior High Velocity
Verdyol Excelsior Standard
Webtec Terraguard 44P
WintersChoice
WintersCoir
WinterStraw HV

CLASS 1 “SLOPE PROTECTION”

Type B - 1:3 or Flatter - Sandy Soils:
AEC Premier Straw
AEC Premier Straw Double Net
AEC Premier Straw/Coconut
AEC Premier Coconut
C-Jute
Carthage Mills Veg Net
CocoFlex ET-FGM
Contech Standard
Contech Standard Plus
Contech Straw/Coconut Fiber Mat w/Kraft Net
Contech C-35
Cotton Fiber Matrix (CFM)
Curlex™ 1
Curlex™ II - CL
Curlex™ LT
Curlex NetFree
Earth Bound - Hydromulch
EarthGuard Fiber Matrix *(Conweb 1000 wood fiber and Tascon Pro Mat paper mulch)*Hydromulch
ECB S31 Single Net Straw
ECB S32 Double Net Straw
ECS-1
ECS Standard Straw
ECS Excelsior Blanket Standard
ECS High Velocity Straw Mat
EnviroGuard Plus - Hydromulch
Excel CC-4

Excel CS-3 All Natural
Excel CS-3
Excel Lc-1
Excel PP5-8
Excel PP5-10
Excel PP5-12
Excel R-1
Excel Rc-1
Excel SR-1 All Natural
Excel SS-2
Flexterra FGM - Hydromulch
Futerra®
Geojute Plus 1
Greenfix CFS072R
Greenfix WS05
Greenfix WSO72
Green Solutions SNS1
Green Triangle Regular
Green Triangle Superior
Hydra CX2 - Hydromulch
Landlok® S1
Landlok® S2
Landlok® CS2
Landlok® 407
Landlok® TRM 435
Miramat 1000
Miramat TM8
Multimat 100
North American Green® S75
North American Green® S75 BN
North American Green® S150
North American Green® SC150
North American Green® S150 BN
Poplar Erosion Blanket
Rhino Erosion King Single Net
SEC-S2
Soil Guard - Hydromulch
Terra-Control® - Hydromulch
TerraJute
Verdyol Ero-Mat
Verdyol Excelsior Standard
Webtec Terraguard 44P
WintersChoice
WintersCoir
WinterStraw HV
WinterStraw SN

CLASS 1 "SLOPE PROTECTION"

Type C - Slopes Steeper than 1:3 - Clay Soils:

AEC Premier Straw Double Net
AEC Premier Straw/Coconut
AEC Premier Coconut
Airtrol - Hydromulch
Anti-Wash/Geojute
Carthage Mills Veg Net
C-Jute
CocoFlex ET-FGM
Contech Standard Plus
Contech Straw/Coconut Fiber Mat w/Kraft Net
Contech C-35
Curlex™ 1
Earth Bound - Hydromulch
Eco-Aegis - Hydromulch
Econo Jute
ECB S32 Double Net Straw
ECS-1
ECS High Velocity Straw Mat
ECS Standard Straw
EnviroGuard Plus - Hydromulch
Enviro-Matrix
Enviro-Shield
Excel CC-4
Excel CS-3 All Natural
Excel Lc-1
Excel PP5-10
Excel R-1
ExcelRc-1
Excel SS-2
Excel SR-1
Excel SR-1 All Natural
Flexterra FGM - Hydromulch
Futerra®
Greenfix CFS072R
Greenfix WS05
Greenfix WSO72
Greenstreak Pec-Mat
Green Solutions DNS2
Green Triangle Superior
Hydra CX2 - Hydromulch
Hydro Blanket - Hydromulch
Landlok® S2

Landlok® CS2
Landlok® 407
Landlok® SuperGro
Landlok® TRM 435
Miramat TM8
Multimat 100
North American Green® S75
North American Green® S150
North American Green® S150 BN
North American Green® SC150
Pennzsuppress® - Hydromulch
Poplar Erosion Blanket
Rhino Erosion King Single Net
Rhino Erosion King Double Net
SEC-S2
SprayMat - Hydromulch
SprayMatt®
Soil Guard - Hydromulch
Soil Saver
TerraJute
Verdyol Excelsior High Velocity
Webtec Terraguard 44P
WintersChoice
WintersCoir
WinterStraw HV

CLASS 1 "SLOPE PROTECTION"

Type D – Slopes Steeper than 1:3 - Sandy Soils:
AEC Premier Straw Double Net
AEC Premier Straw/Coconut
AEC Premier Coconut
C-Jute
Carghage Mills Veg Net
CocoFlex ET-FGM
Contech Standard Plus
Contech Straw/Coconut Fiber Mat w/Kraft Net
Cotton Fiber Matrix (CFM)
Contech C-35
Curlex™ 1
Curlex™ II CL
Curlex™ NetFree
EarthGuard Fiber Matrix *(Conweb 1000 wood fiber and Tascon Pro Mat paper mulch)*Hydromulch
ECB S32 Double Net Straw

ECS-1
ECS High Velocity Straw Mat
ECS Standard Straw
EnviroGuard Plus - Hydromulch
Excel CC-4
Excel CS-3 All Natural
Excel CS-3
Excel Lc-1
Excel PP5-10
Excel PP5-12
Excel R-1
Excel Rc-1
Excel SR-1 All Natural
Excel SS-2
Flexterra FGM
Futerra®
Geojute Plus 1
Greenfix CFS072R
Greenfix WS05
Greenfix WSO72
Green Triangle Superior
HydraCX2
Landlok® S2
Landlok® CS2
Landlok® 407
Landlok® TRM 435
Miramat 1000
Miramat TM8
North American Green® S150
North American Green® SC150
North American Green® S150 BN
Rhino Erosion King Single Net
SEC-S2
Soil Guard - Hydromulch
TerraJute
Webtec Terraguard 44P
WintersChoice
WintersCoir
WinterStraw HV

APPROVED PRODUCT LIST: ITEM 169 "SOIL RETENTION BLANKET" CLASS 2 - "FLEXIBLE CHANNEL LINER

"Type E - Shear Stress Range 0 - 96 Pascal (Up to 2 Pounds Per Square Foot):
Channel Soxx
Contech Coconut/Poly Fiber Mat

Contech Coconut Mat w/Kraft Net
Contech TRM C-35
Contech TRM C-45
Contech TRM C-50
Curlex® II Stitched
Curlex® III Stitched
Curlex® Channel Enforcer I
Curlex® Channel Enforcer II
Earth-Lock
Earth-Lock II
ECB P 42 TRM
ECB SC 32 Double Net Extended Term
ECS High Impact Excelsior
ECS Standard Excelsior
Enkamat 7018
Enkamat 7020
Enviromat
Excel CC-4
Excel CS-3
Excel CS-3 All Natural
Excel PP5-8
Excel PP-5-10
Excel PP5-12
Excel R-1
Excel S-2
Excel SD-3
Greenfix CFG 2000
Greenstreak Pec-Mat
Koirmat™ 700
Landlok CS2
Landlok C2
Landlok® TRM 435
Landlok® TRM 450
Landlok® TRM 1051
Miramat TM8
Multimat 100
North American Green® C125BN
North American Green® C350
North American Green® SC150BN
North American Green® SC250
North American Green® P550
Pyramat®
Recyclex TRM
SEC P2
SEC XL2
StayTurf® ~ *A fully vegetative product that*

requires an establishment period
Webtec Terraguard 44P
Webtec Terraguard 45P

CLASS 2 - "FLEXIBLE CHANNEL LINER

Type F - Shear Stress Range 0 - 192 Pascal (Up to 4 Pounds Per Square Foot):
Channel Soxx
Contech TRM C-35
Contech TRM C-45
Contech TRM C-50
Contech Coconut/Poly Fiber Mat
Contech Coconut Mat w/Kraft Net
Curlex® II Stitched
Curlex® III Stitched
Curlex® Channel Enforcer I
Curlex® Channel Enforcer II
Earth-Lock
Earth-Lock II
ECB P 42 TRM
ECB SC 32 Double Net Extended Term
ECS High Impact Excelsior
ECS Standard Excelsior
Enkamat 7018
Enviromat
Excel CC-4
Excel PP5-8
Excel PP5-10
Excel PP5-12
Excel R-1
Excel S-2
Excel SD-3
Greenfix CFG 2000
Greenfix CFO 72RR
Greenstreak Pec-Mat
Koirmat™ 700
Landlok® CS2
Landlok® C2
Landlok®TRM 435
Landlok®TRM 450
Landlok® TRM 1051
Miramat TM8
Multimat 100
North American Green® C125BN
North American Green® C350
North American Green® SC150BN

North American Green® SC250
North American Green® P550
Pyramat®
Recyclex TRM
SEC P2
StayTurf® ~ *A fully vegetative product that requires an establishment period*
Webtec Terraguard 44P
Webtec Terraguard 45P

CLASS 2 - "FLEXIBLE CHANNEL LINER

Type G - Shear Stress Range 0 - 287 Pascal (Up to 6 Pounds Per Square Foot):
Channel Soxx
Contech TRM C-35
Contech TRM C-45
Contech TRM C-50
Contech Coconut/Poly Fiber Mat
Curlex® Channel Enforcer II
Earth-Lock
Earth-Lock II
ECB P 42 TRM
Enkamat 7018
Excel PP5-8
Excel PP5-10
Excel PP5-12
Greenfix CFG 2000
Greenstreak Pec-Mat
Koirmat ™ 700
Landlok® TRM 435
Landlok® TRM 450
Landlok® TRM 1051
Landlok®TRM 1060
Multimat 100
North American Green® C350
North American Green® P350
North American Green® S350
North American Green® P550
Pyramat®
Recyclex TRM
SEC P2
StayTurf® ~ *A fully vegetative product that requires an establishment period*
Webtec Terraguard 44P
Webtec Terraguard 45P

CLASS 2 - "FLEXIBLE CHANNEL LINER

Type H - Shear Stress Range 0 - 383 Pascal (Up to 8 Pounds Per Square Foot):
Channel Soxx
Contech TRM C-35
Contech TRM C-45
Contech TRM C-50
Contech Coconut/Poly Fiber Mat
ECB P 42 TRM
Excel PP5-8
Excel PP5-10
Excel PP5-12
Landlok® TRM 435
Landlok® TRM 450
Landlok® TRM 1051
Multimat 100
North American Green® C350
North American Green® P350
North American Green® S350
North American Green® P550
Pyramat®
Recyclex TRM
SEC P2
StayTurf® ~ *A fully vegetative product that requires an establishment period*
Webtec Terraguard 44P
Webtec Terraguard 45P

CLASS 2 - "FLEXIBLE CHANNEL LINER

Type I - Shear Stress Range 0 - 479 Pascal (Up to 10 Pounds Per Square Foot):
Channel Soxx
ECB P 42 TRM
Excel PP5-8
Excel PP5-10
Excel PP5-12
Landlok® TRM 450
North American Green® C350
North American Green® P550
Recyclex TRM
StayTurf® ~ *A fully vegetative product that requires an establishment period*

CLASS 2 - "FLEXIBLE CHANNEL LINER

Type J - Shear Stress Range 0 - 575 Pascal (Up to 12 Pounds Per Square Foot):
Channel Soxx

Excel PP5-12
Landlok® TRM 450
North American Green® P550
Recyclex TRM
StayTurf® ~ *A fully vegetative product that requires an establishment period*

CELLULOSE FIBER MULCHES

Clay or Tight Soils:
Agri-Fiber
American Fiber Mulch
American Fiber Mulch (with Hydro-Stick)
Conwed Hydro Mulch
Enviro-Gro
Enviro-Gro Fiber Mulch
Evercycle™ Hydro-Mulch
Excel Fibermulch II (with Exact-Tac)
Hydro-Lok
Hydro Straw
Lay-Low Mulch
Lonestar Hydro-Grass
Oasis Fiber Mulch
Pennzsuppress®
Pro Mat
Pro Mat (with RMBplus)
Pro Mat X
Pro Mat XL
Second Nature Regenerated Paper Fiber Mulch
Second Nature Regenerated Wood Fiber Mulch
Second Nature Wood Fiber Blend
Second Nature Recycled Paper Fiber
Second Nature Recycled Straw Tack
Silva Fiber Plus

CELLULOSE FIBER MULCHES

Sandy or Loose Soils:
American Fiber Mulch
American Fiber Mulch (with Hydro-Stick)
American Fiber Mulch with Stick Plus
Conwed Hydro Mulch
Enviro-Gro Fiber Mulch
Evercycle™ Hydro-Mulch
Excel Fibermulch II
Excel Fibermulch II (with Exact-Tac)
Hydro-Lok

Hydro Straw
Lay-Low Mulch
Lonestar Hydro-Grass
Oasis Fiber Mulch
Pennzsuppress®
Pro Mat
Pro Mat (with RMBplus)
Pro Mat X
Pro Mat XL
Second Nature Regenerated Paper Fiber Mulch
Second Nature Regenerated Wood Fiber Mulch
Second Nature Wood Fiber Blend
Second Nature Recycled Paper Fiber
Second Nature Recycled Straw Tack"

Chapter 6: Temporary Ponds and Filter Fabric Silt Barriers for Construction Site Sediment Control

Contents

Introduction

The use of temporary ponds for sediment control is a common practice at many construction sites. In some cases, these ponds are re-built after the construction period and used as permanent ponds for stormwater control. However, often they are filled in and their area used as part of the land development. Because sediment ponds at construction sites have relatively short lives, their design criteria and construction methods differ from more permanent stormwater control ponds. The particle trapping mechanisms are the same for both types of ponds, but the influent hydrology and particle size distributions can be substantially different. The following discussion therefore stresses the special features of temporary sediment control ponds for construction sites. Also discussed are silt fences for two reasons: 1) small drainage areas are usually controlled using silt fences, while large areas require sediment ponds (they are therefore complementary practices with similar objectives), and 2) silt fences remove sediment from the flowing water in much the same way as sediment ponds, by sedimentation (not by "filtration").

Temporary construction site sediment ponds have sediment loads that are very large while the particulates in that load may be very small. Large accumulations of sediment can therefore occur in short periods of time. Due to the lack of protection from scour, dry detention ponds have much smaller removal benefits than wet ponds (which have at least 3 ft. of standing water). If well designed and properly maintained, suspended solids removals of 70 to 90% can be obtained in wet ponds, while dry ponds seldom provide more than 30% suspended solids reductions.

There are a number of basic design guidelines needed to maximize sediment removal and to minimize potential problems in ponds, including the following:

- At least three feet of permanent standing water is needed over most of the pond to protect sediments from scouring. Additional depth is also needed for sediment storage between cleanout operations. Wet ponds (retaining water between storms) have much better sediment trapping ability than dry ponds that drain completely due to much reduced scour of captured fine material.

- Ideally, the pond length should be about three to five times the width for maximum detention efficiency.
- The inlets and outlets need to be widely spaced to minimize short-circuiting.
- Correct pond side slopes are very important to improve safety and to minimize mosquito problems. An underwater shelf near the pond edge needs to be planted with rooted aquatic plants to hinder access to deep water if the pond will be in place for several years. The temporary ponds commonly used at construction sites receive large sediment loads and their time is short that vegetation cannot easily become established. Temporary ponds in urban areas may therefore need fencing to prevent access by neighborhood children due to the general lack of vegetation barriers.
- Outlet structures should be designed for low flows during low pond water depths to maximize particulate retention. Place underwater dams or deeper sediment trapping forebays near pond inlets to decrease required dredging areas.
- Protect the inlet and outlet areas from scour erosion and cover the inlets and outlets with appropriate safety gratings. Provide an adequate emergency spillway.

Basic pond design guidelines must also be followed to provide the expected level of sediment removal. The following list is a typical example of these guidelines for proper design, installation and operation.

- Engineering design guidelines (covering such things as foundations, fill materials, embankments, gratings, anti-seep collars, and emergency spillway construction), such as published by the U.S. Natural Resources Conservation Service and the Corps of Engineers (SCS 1982).
- Desired particle control and water outflow rate. As an example, for construction sites, if the pond water surface is about 1.5% of the watershed area draining to the pond, it could achieve about 90% suspended solids reductions. If the pond area is reduced to only about 0.5% of the drainage area, the resulting removal could be reduced to about 65% (or less) of suspended solids. The use of chemical coagulants can increase the removal of sediment in ponds. In an early example, Colston (1974) used alum to increase suspended solids and turbidity removals up to about 85 to 97%. More recent examples show similar removal benefits when using chemical-assisted sedimentation.

Ponds can be classified according to their size and design objectives. Table 6-1 from the older *Alabama Handbook* (ASWCC 2003) is one way to classify ponds based on their size and spillway designs. The maximum water surfaces shown here are all very large for temporary ponds at construction sites, compared to ponds installed at other locations with different objectives than construction erosion control.

Table 6-1 Stormwater Detention Basin Classification (*Alabama Handbook*, ASWCC 2003)

Type	Maximum sediment pond water surface area (acre)	Maximum dam height[2] (feet)	Emergency spillway design storm frequency[3]	Freeboard[4] (feet)
1[1]	20	7	10-yr 24-hr	0.5
2	20	10	10-yr 24-hr	0.5
3	50	15	25-yr 24-hr	1.0

[1] Type 1 basins may be used where site conditions prevent the construction of an emergency spillway on residual earth.
[2] Height is measured from the top of the dam to the low point on the original centerline survey of the dam.
[3] Runoff should be determined by NRCS methods or other methods accepted by local ordinances. Soil and cover conditions used should be based on those expected during the construction period.

[4] Vertical distance between basin water surface at maximum design stage and top of dam.

Sediment pond at construction site needing dredging and slope stabilization

Construction site wet pond after de-watered and dredging

Sediment pond and newly stabilized adjacent slopes

Pond with mature vegetation on surrounding slopes

Figure 6-1. Different phases of a wet pond at a construction site converted to a permanent stormwater pond (J. Voorhees photos).

Monitoring Results of the Performance of Construction Site Sediment Ponds

Construction site sediment ponds are included in most of the 95 erosion and sediment control guidance manuals reviewed (sediment basin/trap 91%, but these two should be examined as separate categories).

Figure 6-2. Monitoring sediment retention performance at a dry pond (Source: Bharadwaj and McLaughlin 2008).

Figure 6-3. Dry pond at construction site with baffles (Source: McCaleb, *et al.* 2008).

Table 6-2. Reported Sediment Control Effectiveness of Sediment Traps and Dry Ponds at Construction Sites

ref	control	type of tests and general location	number of events X locations per treatment	TSS influent (mg/L) avg	TSS effluent (mg/L) avg	% TSS reduc	Turbidity influent (NTU) avg	Turbidity effluent (NTU) avg	% Turbidity reduc
Bharadwaj and McLaughlin 2008 ASABE	dry standard pond	field controlled tests - Raleigh, NC	2	230	220	5	150	140	8
Bharadwaj and McLaughlin 2008 ASABE	dry standard pond with coir porous baffles	field controlled tests - Raleigh, NC	2	360	301	17	250	215	14
Line and White 2001 ASAE	sed trap with rock outlet	full size - North Carolina	34	2,145	665	69			
Line and White 2001 ASAE	U-shaped sed trap with rock outlet	full size - North Carolina	42	4,685	1,921	59			
McCaleb, et al. 2008 ASABE	Dry standard 10-yr trap 10ST	full size - Piedmont North Carolina	18	1,665	1,080	35	n/a	2,090	n/a
McCaleb, et al. 2008 ASABE	Dry pond standard 25-yr trap 25ST	full size - Piedmont North Carolina	29	6,927	3,810	45	n/a	4,410	n/a
McCaleb, et al. 2008 ASABE	Dry standard trap with silt fence baffles STSFB	full size - Piedmont North Carolina	11	12,200	8,420	31	n/a	12,640	n/a
McLaughlin, et al. 2009 ASABE	Dry standard sediment trap wth rock dam outlets ST	large construction site - Charlotte, NC	26	n/a	3,950	n/a	n/a	4,320	n/a
		number	8	7	8	7	2	6	2
		average	21	4,030	2,546	37	200	3,969	11
		median	22	2,145	1,501	35	200	3,205	11
		min	2	230	220	5	150	140	8

		max	42	12,200	8,420	69	250	12,640	14
		COV	0.72	1.1	1.1	0.60	0.35	1.2	0.39

Table 6-3. Reported Sediment Control Effectiveness of Sediment Traps and Dry Ponds with Polymers at Construction Sites

ref	control	type of tests and general location	number of events X locations per treatment	TSS influent (mg/L) avg	TSS effluent (mg/L) avg	% TSS reduc	Turbidity influent (NTU) avg	Turbidity effluent (NTU) avg	% Turbidity reduc
Bharadwaj and McLaughlin 2008 ASABE	dry standard pond with pumped PAM	field controlled tests - Raleigh, NC	2	270*	68	75	260	30	88
Bharadwaj and McLaughlin 2008 ASABE	dry standard pond with coir porous baffles and pumped PAM	field controlled tests - Raleigh, NC	2	200*	40	80	150	50	66
Bharadwaj and McLaughlin 2008 ASABE	dry standard pond with passive block PAM	field controlled tests - Raleigh, NC	2	190*	66	65	150	30	78
Bharadwaj and McLaughlin 2008 ASABE	dry standard pond with coir porous baffles and passive block PAM	field controlled tests - Raleigh, NC	2	200*	111	45	260	30	88
McLaughlin, et al. 2009 ASABE	standard sediment trap with forebay, rock dam outlet and block PAM STFBPam	large construction site - Charlotte, NC	31	n/a	740	n/a	n/a	740	n/a
McLaughlin, et al. 2009 ASABE	sediment trap with surface skimmer outlet, forebay, and block PAM SkFBPam	large construction site - Charlotte, NC	17	n/a	820	n/a	n/a	1,560	n/a
		number	6	4	6	4	4	6	4
		average	9	215	308	6	205	407	80
		median	2	200	90	70	205	40	83

		min	2	190	40	45	150	30	66
		max	31	270	820	80	260	1,560	88
		COV	1.3	0.17	1.2	0.23	0.31	1.6	0.13

* these low influent TSS concentrations were likely partially treated before the pond

Table 6-4. Reported Sediment Control Effectiveness of Wet Ponds at Construction Sites

ref	control	type of tests and general location	number of events X locations per treatment	TSS influent (mg/L) avg	TSS effluent (mg/L) avg	% TSS reduc	Turbidity influent (NTU) avg	Turbidity effluent (NTU) avg	% Turbidity reduc
Gharabaghi, et al. 2006 CJCE	wet pond (L:W 8:1; 48 hr drawdown time)	full size - Toronto	14	about 3,500	177	>90			
Gharabaghi, et al. 2006 CJCE	wet pond (L:W 2:1; 83 hr drawdown time)	full size - Toronto	12	n/a (much less than 3,500)	37	>90			
McCaleb, et al. 2008 ASABE	Wet pond standard 10-yr trap with standing pool STSP	full size - Piedmont North Carolina	17	120 (?)	79	34	n/a	130	n/a
		number	3	3	3	1	0	1	
		average	14	n/a	98	n/a	n/a	130	
		median	14	n/a	79	>90	n/a	130	
		min	12	n/a	37	34	n/a	130	
		max	17	n/a	177	>90	n/a	130	
		COV	0.18	n/a	0.74	n/a	n/a	n/a!	

Table 6-5. Reported Sediment Control Effectiveness of Wet Ponds with Polymers at Construction Sites

ref	control	type of tests and general location	number of events X locations per treatment	TSS influent (mg/L) avg	TSS effluent (mg/L) avg	% TSS reduc	Turbidity influent (NTU) avg	Turbidity effluent (NTU) avg	% Turbidity reduc
Tobiason, et al. 2000 IECA	wet pond outlet after polymers	full size - Seattle. WA	225				226	7	97

Gharabaghi, *et al.* (2006) evaluated sediment pond performance at two construction sites in the Toronto area. A numerical model was used to calculate the sediment removal efficiencies based on various pond geometries. The ponds were also monitored to verify the calculations. The pond's effluent median particle size was less than 3.7 µm, showing good removal of fine-grain particles. Although both ponds were designed based on the same design criteria, significant differences in pond performance were observed, although both ponds showed more than 90% removal of total suspended solids. The main difference between the two ponds was thought to be associated with the length-to-width ratio: the better performing pond had a length-to-width ratio of 8:1, while the "poorer" operating pond had a length-to-width ratio of 2:1.

McCaleb and McLaughlin (2008) monitored several sediment trapping devices on construction sites in North Carolina. Three were sediment ponds with outlets designed for the 10-year recurrence storm with the following differences: one had a 1m standing pool depth (wet pond), one had silt fence baffles with weirs, and one was open and fully drained (dry pond). The fourth sediment pond had a rock outlet and was fully open and drained (dry pond) but was sized for the 25-year recurrence storm. The fifth sediment pond had a floating surface outlet and solid riser spillways plus porous baffles within the pond and was designed for a 25-year recurrence storm. The three sediment ponds with rock dam outlets retained less than 45% of the sediment entering the sediment ponds over the monitoring period. The sediment pond having the skimmer outlet with surface outlets, stable sides and inlet areas, and porous baffles, retained more than 99% of the sediment, but the sediment trapping efficiency dropped when the floating outlet became mired in the sediment when fully drained.

Fang, *et al.* (2015) studied the performance at a shallow sediment pond at a highway construction site that used skimmer outlets and baffles. The skimmer was the primary water quality outlet and drained the effluent water from the surface of the pond. The sediment pond also had three coir baffles, along with polyacrylamide flocculant blocks and check dams on the inflow channel. During two monitored events, the average influent turbidity was reduced from 6,830 and 2,024 NTU to 478 and 793 NTU, indicating turbidity removals of 93 and 61%, respectively. The sediment load reductions were 98 and 84%. Resuspension of deposited sediments from previous rainfall events resulted in higher turbidity in the sediment basin and reduced its effectiveness.

In addition to the above pond evaluations, researchers evaluated sediment pond performance enhancements by using chemical polymer additions.

Tobiason, *et al.* (2000) investigated different PAM application rates at three sites in the state of Washington. One of the locations was a large construction project where hydroseeding was used along with geotextile-lined interceptor ditches that drained to a sedimentation pond. A polymer batch treatment system was used at this location as an experimental control for post treatment of sediment pond effluent. The effluent water was dosed with Catfloc 2953, a poly-aluminum-based conventional water treatment polymer. The turbidity at this location was reduced by more than 90% in the pond effluent with a 2-hour contact time.

McLaughlin, *et al.* (2007) conducted laboratory tests to determine the effects of soil physical and chemical properties on flocculation by PAMs. Soil samples were collected from 13 construction sites in North Carolina. Eleven different PAM products were tested, having varying molecular weights (14 to 28 $Mgmol^{-1}$) and charge densities (0 to 50%). The flocculation tests used 5 g of subsoil mixed with 100 mL of distilled water. The PAM was then added to bring the PAM concentrations from 0 to 2 mg PAM/L. They concluded: “Three patterns of turbidity response to increases in PAM dosage were observed in this study: steady decline to 1 to 2 mg/L, steady decline with a stabilization (increased turbidity) response initiating at or below 1 mg/L, and low or erratic changes. The optimal dose appeared to be between 1 and 2 mg/L. Subsoils that demonstrated the greatest turbidity reduction with PAM has several common properties. They all were greater than 14% clay and 22% silt content. The most responsive subsoils had the highest CBD-extractable Fe. Anionic PAM flocculated the kaolinite-dominated soils more readily than subsoils with significant smectite or vermiculite. The relationships between PAM effectiveness and subsoil properties were found to be strong for particle size distribution, with increasing sand content having a negative effect on turbidity reduction.”

Bharadwaj and McLaughlin (2008) evaluated different PAM dosing methods along with the use of porous baffles in pilot-scale dry sediment ponds constructed at the Sediment and Erosion Control Research and Evaluation Facility at North Carolina State University. The passive PAM dosage method used a solid block of PAM (APS Floc Log 706b) which dissolved in water as the water flowed over the block. The active dosage PAM system pumped a concentrated PAM solution (made from a powder of APS Silt Stop 705) into the sediment pond influent flow. Turbidity and TSS concentrations were not reduced in the basic dry sediment pond having no baffles with 1.5- and 24-hour detention times. Porous baffles which were installed to reduce turbulence had little benefit on performance. However, both the active and the passive PAM dosing methods reduced the turbidity by up to 88%, with the active dosing system being slightly more effective.

McLaughlin, *et al.* (2009b) evaluated three different sediment pond alternatives (standard sediment trap, modified standard sediment trap with forebay and PAM, and skimmer basin with forebay and PAM) on a large construction site in North Carolina, during 11 rains. The skimmer pond had the largest turbidity improvement. The influent turbidities ranged from about 110 to 4,400 NTU while the surface outlet turbidities from the skimmer discharge ranged from about 30 to 780 NTU. The other changes (forebays and use of PAM) did not result in obvious turbidity reductions.

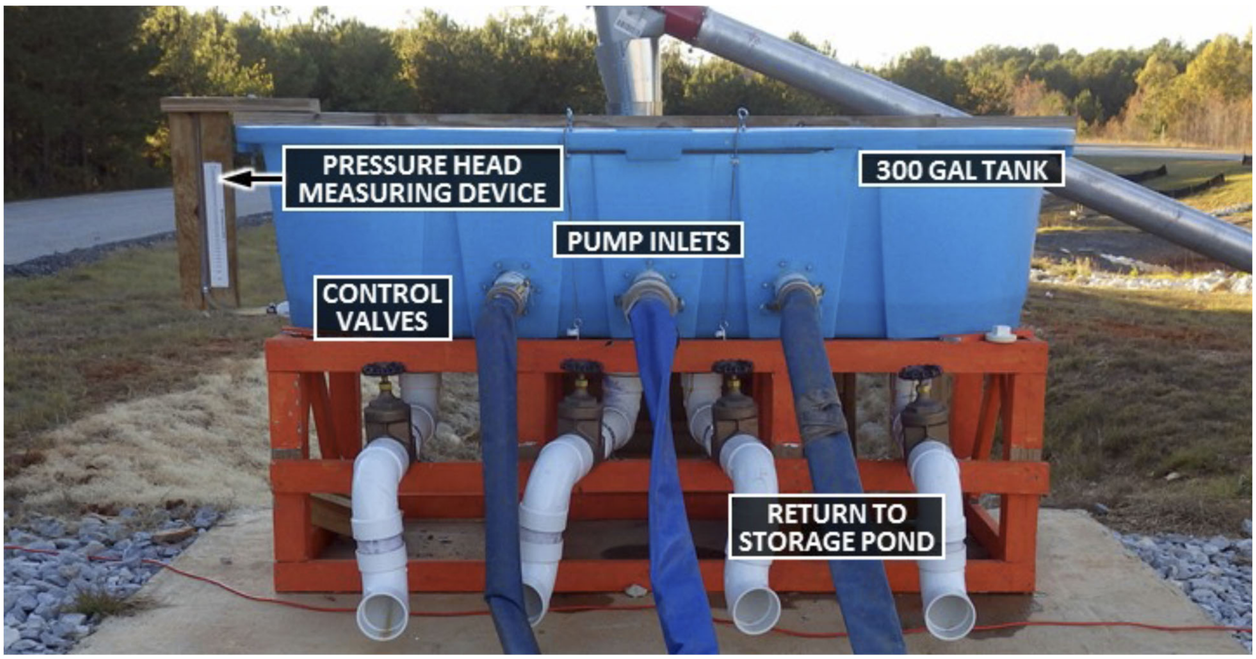
King and McLaughlin (2016) conducted controlled tests to investigate the benefits of adding a biopolymer (chitosan) or polyacrylamide (PAM) to simulated construction site runoff water (about 3,000 NTU) before discharging through a conventional bag filter. The dewatering bag resulted in relatively high removals, but the effluent water turbidity was still higher than desired (about 1,000 NTU). Additions of the chitosan or PAM reduced the effluent turbidity to much lower levels (<100 NTU). The chemical additions did not adversely affect clogging of the dewatering bag during the short duration of the experiments.

Vacconcelos, *et al.* (2017) describe a series of controlled erosion control evaluations conducted at the Auburn University Erosion and Sediment Control Testing Facility, AL, to enhance sediment pond performance. Their goal, using a 17 by 9 m pilot-scale pond, was to examine the benefits of the following on sediment pond performance:

- Having a forebay prior to a sediment pond;
- Changing thickness of coir fiber baffles;
- Adding high-rate lamella settlers in the sediment pond; and

- Adding a small-scale high-rate lamella settler to treat skimmer outflow from the sediment ponds.

Automatic water samplers were located at several locations in the pond between the porous baffles to measure the turbidity gradients along the water flow path in the pond. A surface skimmer was used to withdraw the water from the surface of the pond to minimize bottom scour. The pond was designed based on the Alabama Department of Transportation (ALDOT) pond sizing criterion of 250 m^3/ha (3,600 ft^3/acre). Another ALDOT sizing option is to completely contain the runoff from a 2-yr, 24-hr rain event. The test flows were 0.042 m^3/sec (1.5 ft^3/sec), corresponding to the average flow rate over 30 min of the design storm. The influent sediment concentration was estimated to be about 8,000 mg/L.



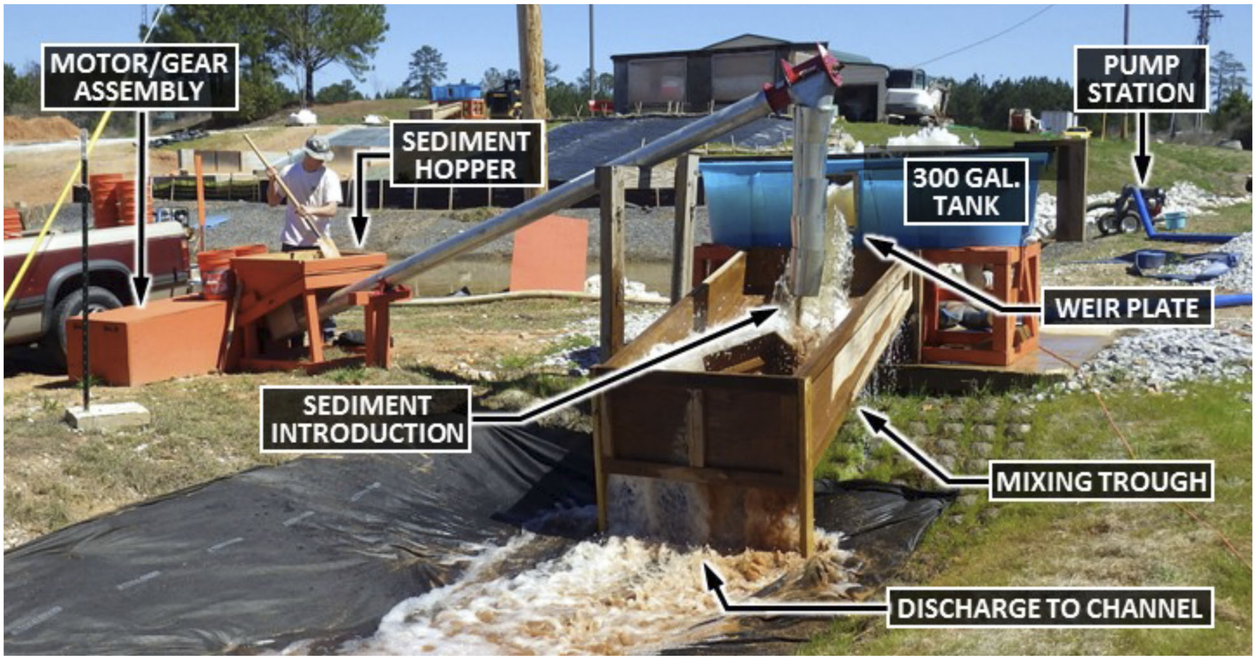


Figure 6-4. Water and sediment inlets at Auburn University Erosion and Sediment Control Testing Facility, AL (Vacconcelos, *et al.* 2017).

The porous baffle tests resulted in average effluent turbidity levels of about 770 NTU during the pond filling period. The initial turbidity levels in the other bays were about the same but decreased to about 300 NTU at the end of the filling period of the pond. During one-hour quiescent settling, lower turbidity levels (about 220 and 270 NTU) occurred in the different bays between the baffles. After 12 hours, the turbidity levels were the same in all three bays (at 113 NTU). The baffles were therefore found to only be important during the initial filling period, when scour would be the greatest. Tests were also conducted using an excavated sump forebay. However, no turbidity reduction was observed with the sump. In fact, sediment from the forebay became resuspended during the later tests. In contrast, the use of the lamella plate systems resulted in decreased turbidity levels. The lamella plates resulted in effluent median particle sizes of about 7 µm, compared to about 20 µm without using the plates.

Vacconcelos, *et al.* (2017) also tested the use of polyacrylamide (PAM) flocculants to further reduce the effluent turbidity. They tested the use of small blocks of PAM at the pond outlet as a polishing treatment of small particles after most of the sediment had been captured in the pond. The observed outlet turbidity levels were all less than 100 NTU with the use of the PAM, four times less than the untreated skimmer flows. Other observations during the tests found that the pond had greater removal rates with deeper water, indicating scour protection through dissipation of the energy of the flowing water. They also observed significant reductions in settling rates (and increased effluent concentrations) during cold weather due to the increase in viscosity of the water in cold weather versus warm weather (3.2×10^{-5} lb-s/ft^2 at 40^{o}F versus 2.0×10^{-5} lb-s/ft^2 at 70^{o}F).

Safety of Wet Detention Ponds

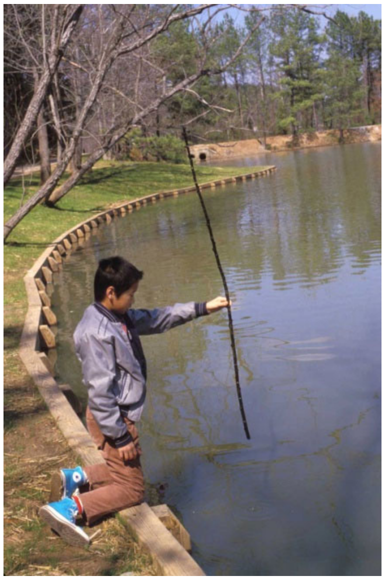
The most important wet detention pond design guidelines are those that maintain public safety. The following discussion briefly summarizes common suggestions to maintain and improve safety at wet detention facilities. Death by drowning is the most common safety concern associated with wet detention ponds. Marcy and Flack (1981) state that, in general, drownings most often occur because of slips and falls into water, unexpected depths, cold water temperatures, and fast currents. Four methods to minimize these problems include the following: (1) eliminating or minimizing the hazard; (2) keeping people away; (3) making the onset of the hazard gradual; and (4) providing escape routes. Many of the design suggestions and specifications contained in this discussion are intended to accomplish these methods.

Jones and Jones (1982) consider safety and landscaping together because landscaping can be an effective safety element. They feel that appropriate slope grading and landscaping can provide a more desirable approach than wide-spread fencing around a wet detention pond. Unfortunately, landscaping is not very effective for temporary pond installations, so pond side slopes are most critical. Fences are expensive to install and maintain and usually produce unsightly pond edges. They collect trash and litter, challenge some individuals who like to defy barriers, and impede emergency access if needed. Marcy and Flack (1981) state that limited fencing may be appropriate in special areas. When the pond side slopes cannot be made gradual (such as when the pond is located against a railroad right-of-way or close to a roadway), steep sides having submerged retaining walls may be needed. A chain link fence located directly on the top of the retaining wall very close to the water's edge would be needed (to prevent human occupancy of the narrow ledge on the water side of the fence). Another area where fencing may be needed is at the inlet or outlet structures. However, fencing usually gives a false sense of security, as most fences can be crossed easily (Eccher 1991). Current practice is for temporary sediment ponds in urban areas to include fencing as neighborhood children are likely to be attracted to the pool and the temporary nature of the sediment pond likely precludes the vegetative barriers recommended for permanent wet ponds.

Gradual slopes near the water edge and a submerged ledge close to shore are usually together the best solution to maximize safety. Aquatic plants on the ledge decreases the chance of continued movement to deeper water and thick vegetation on-shore near the water's edge would discourage access to the water edge and decrease the possibility of falling into the water accidentally, but vegetation is not practical at temporary construction site ponds. Pathways should not be located close to the water's edge or turn abruptly near the water. Again, construction site ponds will not have nearby pathways, but if converted to permanent stormwater ponds, these design features must be considered.

Steep walkway leading to water (unknown Internet source)

Winter ice skating dangers near pond edges (Steve Auger photo)



Deep drop-off at pond edge

Figure 6-5. Safety issues with wet detention ponds.

Marcy and Flack (1981) also encourage the placement of escape routes in the water whenever possible. These could be floats on cables, ladders, hand-holds, safety nets, or ramps. They should not be placed to encourage entrance into the water.

Public Safety Hazards Associated with Urban Drainage Systems

The *National Vital Statistics Report* (Vol. 50, No. 15, Sept 16, 2002) published leading causes of accidental deaths in the US. These were reported by age groups and by accident types. The categories and the percentage of the 97,900 annual accidental deaths reported for the US, included: motor vehicles (44.3%), unspecified accidents (17.8%), falls (13.6%), poisoning (13.0%), drowning (3.9%), fire (3.4%), other land transport accidents (1.5%), complications of medical procedures (3.1%), and firearms (0.8%). Therefore, about 3,800 deaths per year were associated with accidental drowning in the US. The breakdown of these deaths by age of the victims indicates that many of the drowning victims were young children, with very few older adults, as shown in Table 6-6.

Table 6-6. Drownings by Age Groups

Age	% accidental drowning deaths by age group
<1 yr	8.5%
1 to 4 yrs	27.0%
5 to 14 yrs	12.6%
15 to 24 yrs	4.6%
25 to 34 yrs	3.6%
35 to 44 yrs	3.1%
45 to 54 yrs	2.9%

55 to 64 yrs	2.9%
65 to 74 yrs	2.3%
75 to 84 yrs	1.3%
> 85 yrs	0.6%
not stated	28.2%

Drowning is the second largest cause of accidental deaths for toddlers from 1 to 4 years old, while it is the 5th leading cause of accidental deaths for all ages combined. Motor vehicles are the leading cause of death for all age groups up to 75 years of age.

Few mortality statistical reports break down the drowning deaths by situation (such as by swimming pools, ponds, rivers, lakes, etc.). However, a report from Florida and one from North Carolina indicated some further details for these southern states.

Patetta and Biddinger (1988) did a retrospective study of 1,052 accidental drowning deaths that occurred in North Carolina between 1980 and 1984. Their main purpose was to show the relationship between alcohol consumption and the settings of the accidents, but they did present some information about where the accidents occurred. The drowning rate for North Carolina residents during this period was 3.2 per 100,000 persons. Swimming and wading were involved in 41% of the deaths and was the most frequently reported activity leading to drowning. Fishing was next at 15% and motor vehicle accidents at 8%. Most of the deaths occurred in freshwater environments, with 39% occurring in lakes and ponds and 29% in rivers and creeks. Drowning victims 15 years of age and older tested positive for alcohol in more than half of the cases, with 38% having very high blood alcohol levels (>100 mg per deciliter). Most of the drowning victims in North Carolina were between 5 and 34 years of age and male during the period of this study. They reported that 37% of the drownings were in "incidental" waters which temporarily held water, such as drainage ditches. In addition, 24% of the drownings were in rock quarries. The overall categories of drowning locations were: lake or pond (39.1%), river or creek (29.4%), ocean of bay (10.6%), private pool (3.8%), bathtub (4%), other pool (4.4%), and all other (8.7%). Of the 74 children younger than 5 years of age that drowned, 80% were unattended. Of the 59 unattended children drowning victims, 29 fell into a body of water (such as a swimming pool or lake), 8 were bathing, and 7 were swimming or wading in a swimming pool.

Lo, *et al*. (2010) examined residential swimming pool drowning deaths in Florida between 2005 and 2007. They found that for every 10,000 residential pools in a county, an additional 2.4 additional drowning deaths can be expected every three years. During this 3-year period, 262 accidental drowning deaths occurred in swimming pool accidents. More people drown in Florida than in any other state, except for California. The number of drowning victims aged 1 to 4 is the greatest in Florida compared to any other state. They found that while both natural and man-made bodies of water are abundant in Florida, single family residential swimming pools are a particular problem. Of the accidental pool drowning deaths of older children and adults (age 5 and above), 55% deaths occurred in single family residential swimming pools, 10% in public or private community pools, 9% in hotel or motel pools, 8% in condominium pools, 7% in apartment pools, 1% in and above-ground home pools, and 0.5% in a duplex pool. Of the young children victims (<5 years old), 55% of the drownings occurred in single family pools. Of the 19 drownings that occurred in non-pool settings during this same period, 14 occurred in bathtubs or hot tubs, and one each drowned in a bucket, a washing machine, and a septic tank. The remaining 5 drowned in unspecified bodies of water (although swimming pools were located at the addresses).

Instances of drownings, and near drownings, in urban drainage infrastructure components can be found reported in local newspapers. As an example, in the 1999 to 2010 period, there have been several instances reported in the local Birmingham, AL, newspaper (*The Birmingham News*). One especially disturbing incident occurred on January 29, 1999, when 4-year old Jasmine Moore drowned after falling into an Ensley storm drain inlet (which had a 9 by 38-inch opening with no safety grate) while trying to get into an automobile parked at the curb during a heavy rain. The gutter was flooded and the inlet was submerged. Rapidly flowing water swept her five miles down Valley Creek where her body was found 2 days later. This incident resulted in an initial review of storm drain inlet structures in the Birmingham area. *The Birmingham News* surveyed 133 Birmingham storm drain inlets in the region and found that 11 had cracked, broken, or misplaced concrete lids, 10 metal lids were cracked, unstable, or partially removed, one was completely broken with an exposed pipe. Only 11 inlets were found to be too small for a child to enter, and only one had a grating and metal bar. Further surveys found that cities and counties in the area have thousands of storm drains that are in a variety of shapes, sizes and materials, even within a single city. Most cities don't use safety gratings or bars across the opening to prevent children from entering. Curbside openings in the cities surveyed ranged from 2 to 8 inches high.

Drowning accidents at locations having incidental water (periodic ponding) have also been reported. Another tragedy that occurred in the Birmingham area, was reported in the May 20, 2006 edition of *The Birmingham News*. George Little, an 8-year-old, rode his bike through a construction site in the evening in an area where many of the neighborhood children played. Site clearing was on-going, and a large tree stump was recently removed, leaving a four-foot-deep hole. Recent heavy rains had flooded much of the site, including ponding in the hole. When George rode his bike across the pond, he apparently did not realize how deep it was. The mucky water and muddy soil hindered locating the child and when finally found, revival was unsuccessful.

Awareness of these types of hazards is increasing, but it is very disturbing when children still lose their lives. As an example, local communities are now condemning property as public nuisances. The September 16, 2008 edition of *The Birmingham News* reported that the Hoover City Council declared that a house that was torn down after a fire, but with the foundation and swimming pool remaining, was a hazard. The tarp-covered pool was found to pose a drowning hazard and the city started the process to correct the site problems.

The Birmingham News of July 12, 2000 also reported two workers drowned in a manhole that contained 2 ft of standing water. An engineer and a utility worker both drowned after passing out due to lack of oxygen and an excess of carbon dioxide in the storm drain manhole. Proper confined space entry precautions were not followed, which resulted in their drownings in the storm drainage system. The article quoted a US Bureau of Labor Statistics report that indicated 75 workplace drownings, plus another 7 who died from oxygen depletion in enclosed spaces, nationwide in 1998.

The February 19, 2000 *Birmingham News* edition reported that a 5-year old drowned in a rain-swollen drainage ditch outside of her home. The victim, Ashley Church, and another child snuck out of their babysitters' home and wandered into a drainage ditch that was flowing full after 4 inches of rain. The mother sued the developers who built recent developments above their home but did "not make proper provisions for the runoff and drainage" in the lower elevations.

A story in the May 14, 1999 *Birmingham News* edition described how a Homewood street and sanitation employee was swept through an underground drainage pipe for more than a quarter mile but survived with minor cuts and bruises. Grant McCord was working with two others to clean debris from an open drainage ditch near a road intersection but was knocked into the rapidly flowing water by a flow surge. He hit his head on the pipe as he was being sucked under but stayed conscious. He shielded his face with his hands from rushing water, mud and rocks. "It knocked me down like a feather," he said. "I just stayed close to the walls and rode the water."

The above news stories indicate that every several years there has been a tragic drowning or near drowning in the Birmingham, AL, area associated with the storm drainage infrastructure, including ponded water at construction sites. These examples are not intended to imply that conditions are unusually hazardous in this area. It is likely that any review of local news stories throughout the country would identify similar tragedies. While the number of deaths associated with these drownings is not large, especially compared to other accidents, including drownings in swimming pools, any preventable death is tragic, and they do illustrate that improvements in safety are warranted in the design, construction, and maintenance of urban drainage infrastructure components and at construction sites.

Outlet Designs

The use of inlet and outlet trash racks and antivortex baffles are needed to prevent access to locations having dangerous water velocities. Several types are recommended by the NRCS (SCS 1982) and are shown below. Racks need to have openings smaller than about six inches to prevent people from passing through them and need to be placed where water velocities are less than three feet per second to allow people to escape (Marcy and Flack 1981). Besides maintaining safe conditions, racks also help keep trash from interfering with the outlet structures operation.

The Natural Resources Conservation Service (SCS 1982) guidelines for designing runoff control measures must be followed when designing emergency spillways for wet detention ponds. In addition, if the detention pond is large, special state regulations and the Army Corps of Engineers must be followed. As an extreme example of maintenance, it may be best to re-build a pond that was not originally designed for water quality benefits. As an example, the 30-year-old Expo Park regional stormwater detention facility in Aurora, Colorado, needed renewal (Hamilton, *et al*. 2001). Improvements to the multi-use 60-acre park facility were made to provide water quality benefits, improve site drainage, increase flood control detention, improve recreational usefulness and aesthetics, and upgrade the facility to meet jurisdictional State dam safety requirements. Dam safety related improvements included new outlet works, spillway improvements, and acceptance by the Engineer's Office for using irrigated turf grass as overtopping erosion protection for the emergency spillway.

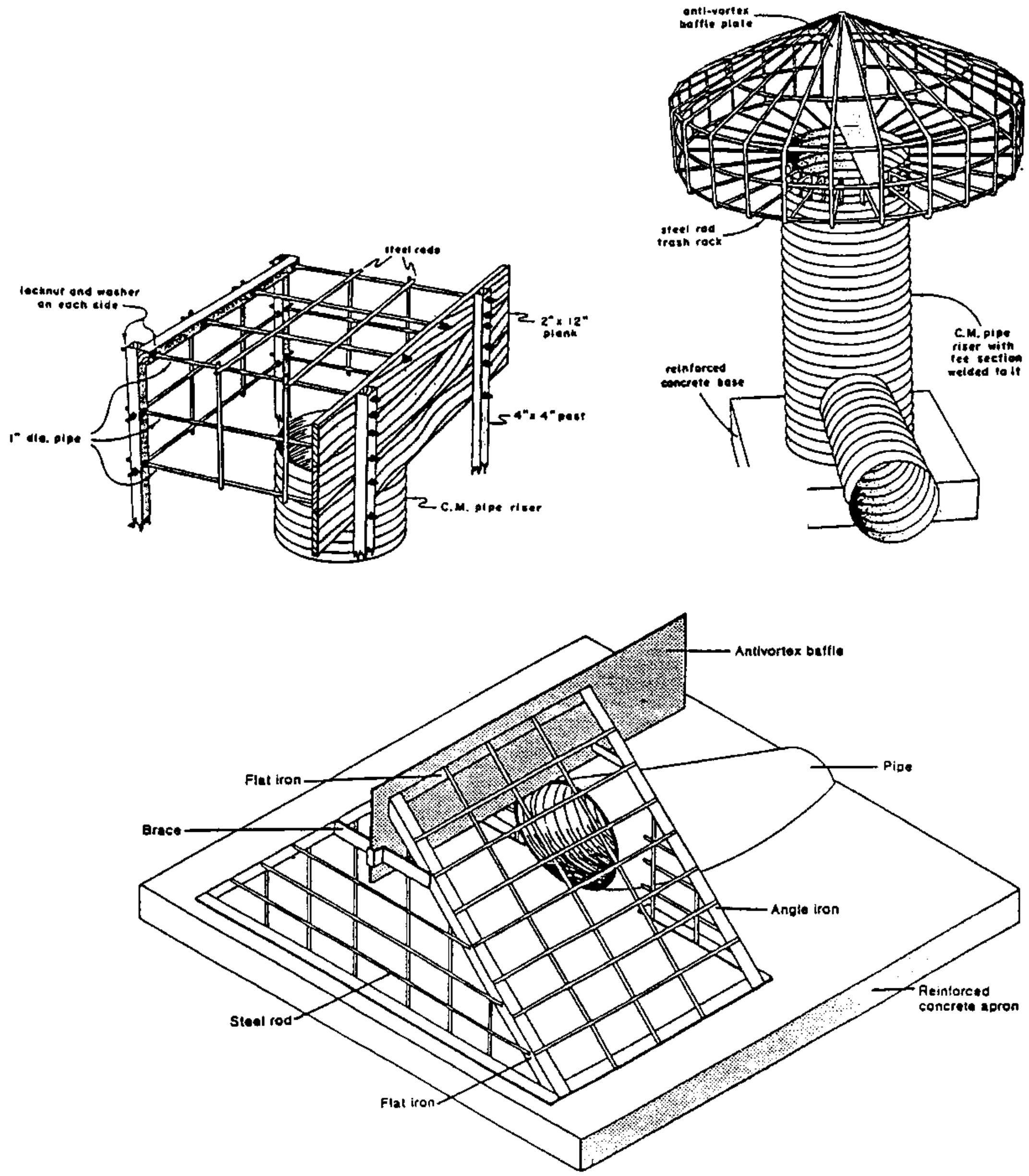


Figure 6-6. Various trash racks and baffles used by the SCS (NRCS) (SCS 1982).

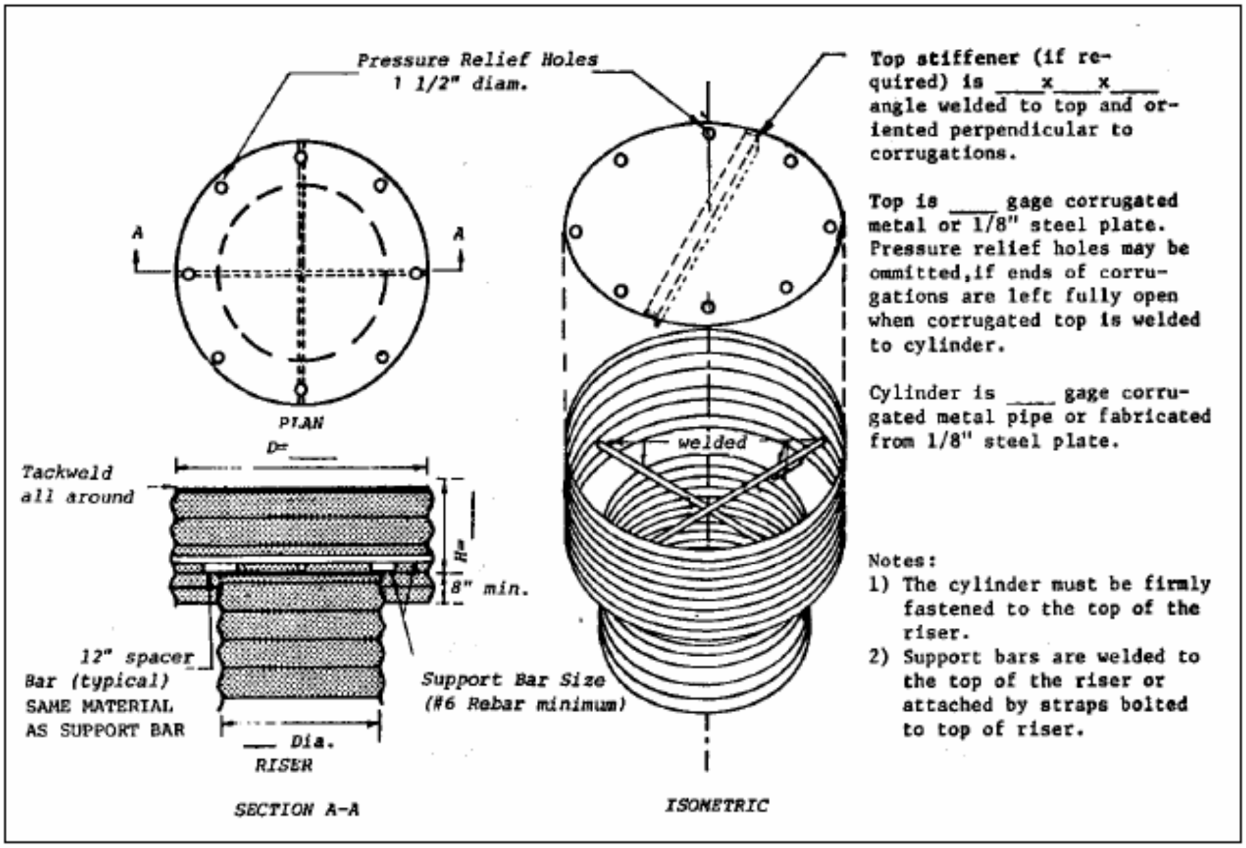


Figure 6-7. Anti-vortex design on riser outlet (*Alabama Handbook*, ASWCC 2003)

Eccher (1991) lists the following pond attributes to ensure maximum safety:

1. There should be no major abrupt changes in water depth in areas of uncontrolled access,
2. Slopes should be controlled to insure good footing,
3. All sloped areas should be designed and constructed to prevent or restrict weed and insect growth (generally requiring some form of hardened surface on the slopes), and
4. Shoreline erosion needs to be controlled.

As noted above, public safety should be the most important factor in the design, construction, and operation of any water infrastructure structure, especially in urban areas where children are in close proximity (such as construction sites). Recognizing these issues, the ASCE (ASCE UWRRC 2014) prepared a report titled: *Public Safety Guidance for Urban Stormwater Facilities.* The ASCE describes this report as: “This guidance, developed under the auspices of seven professional associations, provides a framework for integrating protection of the public into the planning, design, operation, and maintenance of stormwater facilities. It describes factors that should be considered in selecting measures and recommends practices than can be used generally or in specific cases. Guidance is provided on such topics as safety evaluations, prioritizing hazards, safeguarding children, fencing, and mosquito control.”

Maintenance Requirements of Wet Detention Ponds

The most important maintenance for temporary construction-site erosion ponds is to conduct periodic inspections and to make sure that the sediment accumulation is not excessive and prematurely filling the pond.

Temporary sediment ponds at construction sites need to be inspected after each major storm. The inspection should include checking the pond embankments for subsidence and erosion. The conditions of the emergency spillway and inlets and outlets also need to be determined during the inspection. The adequacy of any channel erosion protection measures near the pond also should be investigated. Sediment accumulation in the pond (especially near, and in, the inlets and outlets) also needs to be examined and removed as necessary.

Large sediment accumulations in detention ponds can have significantly adverse effects on pond performance. Bedner and Fluke (1980) reported on the long-term effects of detention ponds that received little maintenance. Lack of dredging caused the silted-in ponds to become a major sediment source to downstream areas. Poorly-maintained ponds only delayed the eventual delivery of the sediment downstream; they did not prevent it.

During major storms, construction-site erosion ponds can fill up during a single storm. Most of the sedimentation would occur near the inlet and the resulting sediment accumulation would be very uneven throughout the pond. Normally, sediment removal in a permanent wet pond may be needed about every five to ten years, but it may be needed every few months at construction sites. It is therefore necessary to plan for required maintenance during the design and construction of sediment ponds. Ease of access of heavy equipment and the possible paving of a sediment trap near the inlet would ease maintenance problems. Dredged sediment is usually placed directly onto trucks, or on the pond banks for dewatering before hauling to the disposal location. One common practice is to keep an area adjacent to the detention pond available for on-site sediment disposal. Small mounds can be created of the dried sediment and covered with top soil and planted.

Poertner (1974) reviewed various sediment removal procedures. An underwater scoop dragline can be pulled across the pond bottom and returned to the opposite side with guiding cables. If drains and underwater roads were built during the initial pond construction, the pond can be drained and front-end-loaders, draglines, and trucks can directly enter the pond area. Small hydraulic dredges can also be towed on trailers to ponds. The dredge pumps sediment through a floating line to the shore where the sediment then is dewatered and loaded into trucks or piled on site. A sediment trap (forebay) also can be constructed near the inlet of the pond. The pond entrances then are widened, and submerged dams are used to retain the heavier materials in a restricted area near the inlets. This smaller area can then be cleaned much easier and with less expense than the complete pond.

Guidelines to Enhance Pond Performance

The NRCS (SCS 1982) prepared a design manual that addressed specific requirements for such things as anti-seep collars around outlet pipes, embankment widths, types of fill required, foundations, emergency spillways, etc., for a variety of wet detention pond sizes and locations. The manual includes detailed engineering requirements. The *Alabama Handbook for Erosion Control* (ASWCC 2018) describes the construction and maintenance of sediment basins, and many other sediment and slope-control practices, as do other regional guidance documments.

Pond Surface Area and Shape
The pond surface area is one of the most important design considerations for particle removal. Hittman (1976) reports that pond length-to-width ratios of about five to one have produced maximum pond efficiencies (decreased short-circuiting) during dye tests. If a long and narrow pond cannot be constructed, Schueler (1986) suggests that baffles or gabions be placed within the pond to lengthen the flow path between the inlets and outlets. Bondurat, *et al*. (1975) has also suggested that the idealized pond shape would be triangular: narrow near the inlet and wider near the outlet. This triangular configuration would allow more efficient particle settling by having a continually decreasing forward velocity. Short-circuiting in adequately-sized ponds has little detrimental effect on pond performance. Very irregular pond shapes may decrease circulation and cause localized nuisance problems. Permanent pond shapes should be irregular for aesthetic considerations, but with minimal opportunities for water stagnation. Short-circuiting in adequately-sized ponds has little detrimental effect on pond performance, which can be serious in under-sized ponds. Stagnation can be a much more serious problem degrading pond water quality than short-circuiting.

Pond Water Depth
The storage volume above the permanent pool elevation of the pond affects the pond's ability to absorb excess flows for flood control. Harrington (1986) found that increasing the wet pool depth increases sedimentation efficiency (due to flocculation), but that surface area increases were much more effective in enhancing the water quality performance of wet ponds. A minimum wet pool depth is very critical in wet ponds to decrease scour losses of previously-settled material. Without an adequate permanent pool depth, reduced water quality benefits can be expected from wet ponds.

Extra pond depth needs to be considered for sediment storage between removal operations (Schimmenti 1980). Wiegand, *et al.* (1986) state that it costs about five times as much to remove sediment during pond dredging operations as it does to provide extra sediment storage capacity (sacrificial volume) during initial pond construction. This sacrificial storage should be provided as deeper forebays near the pond inlets (Driscoll 1986). These forebays, or the use of underwater dams, need to be designed as pre-sedimentation traps to encourage the deposition of sediment in a relatively restricted area. This would result in more frequent sediment removal operations, but at a much lower cost than dredging the entire pond.

Sufficient water depth (at least three feet over the maximum deposited sediment thickness) is also needed to decrease the potential of sediment scour caused by increased flows during large storms (EPA 1983). Hey and Schaefer (1983) found that a depth of five feet was sufficient to protect the unconsolidated sediment from resuspension in Lake Ellyn.

Pond Side Slopes
Reported recommended side slopes of detention ponds have ranged from 1:4 (one vertical unit to four horizontal units) to 1:10. Steeper slopes will cause problems with grass cutting and may erode. Steep slopes are not as aesthetically pleasing and are more dangerous than gentle slopes (Chambers and Tottle 1980). Sclueler (1986) also recommends a minimum slope of 1:20 for land near the pond to provide for adequate drainage.

The slope near the waterline, and for about one foot below, should be relatively steep (1:4) to provide relatively fast pond drawdown after common storms. However, a flat underwater shelf several feet wide and about one foot below the normal pond surface is needed as a safety measure to make it easier for anyone who accidentally falls into the pond to regain their footing and climb out. This shelf should also be planted with native rooted aquatic plants (macrophytes) to create a barrier making unauthorized access to deep water difficult for permanent ponds. If the installation is a temporary pond, a mild slope, without the planted safety ledge, is more common.

Outlet Structures

Most of the effort given to alternative outlet structure designs has been for dry detention ponds. Wet ponds at construction sites usually only have a surface weir, outlet pipe, or other simple overflow device to allow the passage of displaced pond water during rains. With the use of a more sophisticated outlet device (such as a floating weir), located at the normal wet pond surface elevation, more efficient particulate removals and flood control benefits occur.

Hittman (1976) recommends that wide outflow (and inflow) channels be used to decrease erosion. If wide flow channels are not possible, then energy dissipaters to reduce the water velocity should be used. The NRCS (SCS 1982) has prepared design guidelines for wet-pond outlet structures. These guidelines include a turf-covered embankment having a trapezoidal cross section, a pipe with a metal riser and passing through the embankment as the major outlet, an upstream trash rack at the outlet, and an emergency spillway.

Controlled emptying of a detention pond at low outlet flow rates is desirable for effective sediment removal and flood control. A small diameter outlet pipe, or a small orifice on a plate, typically is used to achieve low outflows. The rate of discharge varies for these outlets because the elevation above the orifice controls the outflow rate. High flow rates occur with higher water levels, and the outlet flow rates decrease with falling water levels. Selecting an appropriate outlet structure has significant effects on pond performance. To have a constant pond performance for all events (if desired), the shape of the outlet must allow a constant upflow velocity (pond outflow rate divided by pond surface area for all pond stages).

All outlets from a sediment pond (and inlets into the pond) need to be protected to prevent erosion and scour in those areas having high water velocities.

Figure 6-8. Rock outlet and inlet protection (E. Hahn photos).

The following sidebar discussion is from the *Alabama Handbook* (ASWCC 2018) and is an example of the guidance provided for outlet devices in many regional erosion control guidance documents.

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Sidebar: "Outlet Protection

Practice Description

This practice is designed to prevent erosion at the outlet of a channel or conduit by reducing the velocity of flow and dissipating the energy. Outlet protection measures usually consist of a riprap-lined apron, a reinforced concrete flume with concrete baffles, a reinforced concrete box with chambers or baffles and possibly pre-manufactured products. This practice applies wherever high velocity discharge must be released on erodible material.

Planning Considerations

The outlets of pipes and structurally lined channels are points of critical erosion potential. Stormwater which is transported through man-made conveyance systems at design capacity generally reaches a velocity which exceeds the ability of the receiving channel or area to resist erosion. To prevent scour at stormwater outlets, a flow transition structure is required which will absorb the initial impact of the flow and reduce the flow velocity to a level which will not erode the receiving channel or area of discharge.

The most commonly used structure for outlet protection is an erosion resistant lined apron. These aprons are generally lined with loose rock riprap, grouted riprap or concrete. They are constructed at zero grade for a distance which is related to the outlet flow rate and the tailwater level. Criteria for designing these structures are contained in this practice. Several outlet conditions are shown in Figure 6-9. Example design problems for outlet protection are found at the end of this practice.

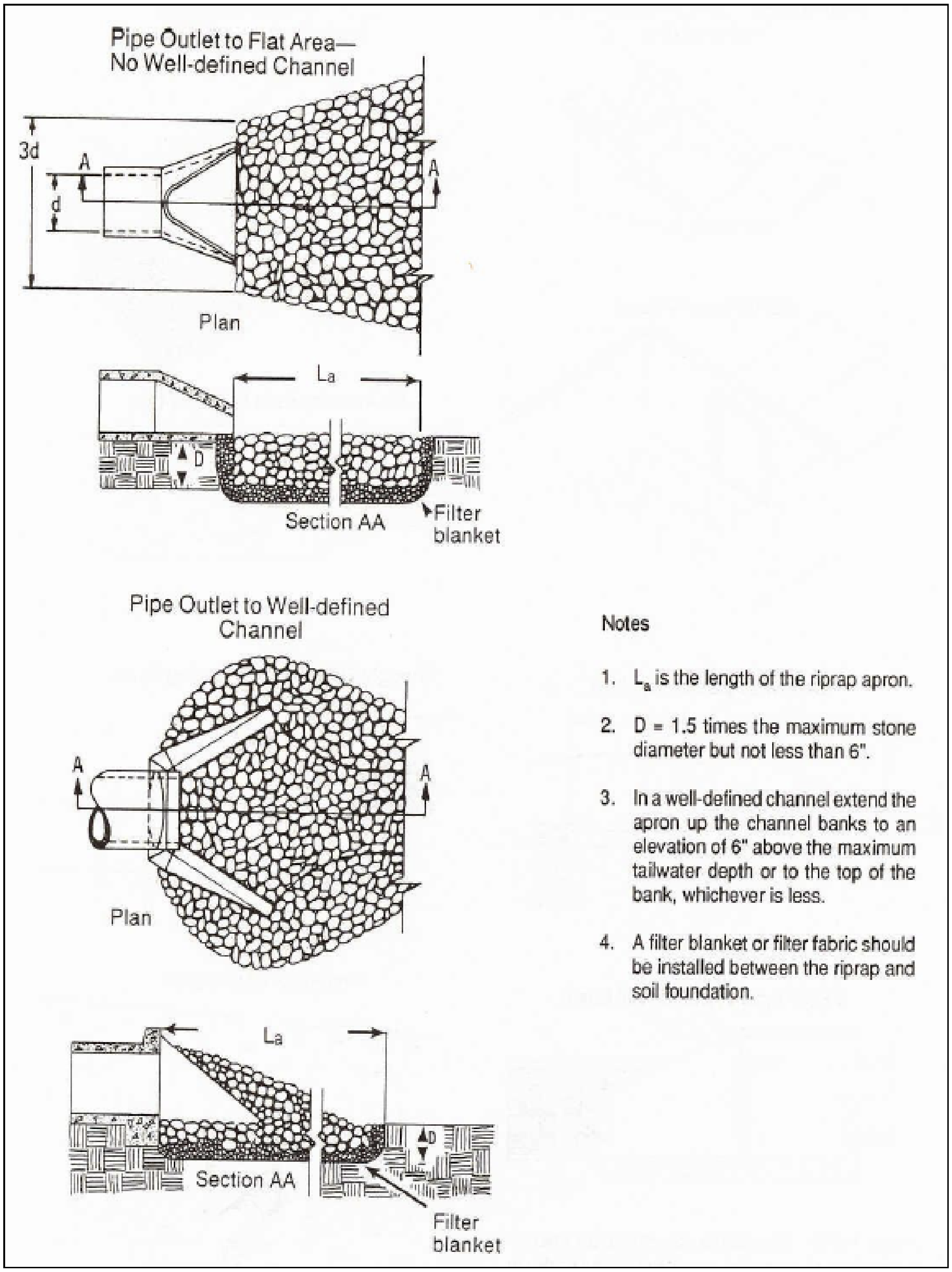

Figure 6-9. Pipe Outlet Conditions

Where the flow is excessive for the economical use of an apron, excavated stilling basins may be used. Acceptable designs for stilling basins may be found in the following documents available from the U. S. Government Printing Office.

Hydraulic Design of Energy Dissipaters for Culverts and Channels, Hydraulics Engineering Circular No. 14, U. S. Department of Transportation, Federal Highway Administration.

Hydraulic Design of Stilling Basins and Energy Dissipaters, Engineering monograph No. 25 U. S. Department of Interior - Bureau of Reclamation.

<u>Design Criteria</u>
Structurally lined aprons at the outlets of pipes and paved channel sections shall be designed according to the following criteria:

Pipe Outlets

Capacity

The structurally lined apron should have the capacity to carry the peak stormflow from the 25-year 24-hour frequency storm or the storm specified in state laws or local ordinances or the design discharge of the water conveyance structure, whichever is greatest.

Tailwater

The depth of tailwater immediately below the pipe outlet must be determined for the design capacity of the pipe. Manning's Equation may be used to determine tailwater depth. Manning's Equation may be found in the practice Grass Swales. If the tailwater depth is less than half the diameter of the outlet pipe, it shall be classified as a Minimum Tailwater Condition. If the tailwater depth is greater than half the pipe diameter, it shall be classified as a Maximum Tailwater Condition. Pipes which outlet to flat areas, with no defined channel, may be assumed to have a Minimum Tailwater Condition.

Apron Length

The apron length shall be determined from Figure 6-10 or 6-11 according to the tailwater condition.

Apron Thickness

The apron thickness should be determined by the maximum stone size (dmax), when the apron is lined with riprap. The maximum stone size shall be 1.5 x d_{50} (median stone size), as determined from Figure 6-10 or 6-11. The apron thickness shall be 1.5 x dmax.

When the apron is lined with concrete, the minimum thickness of the concrete shall be 4".

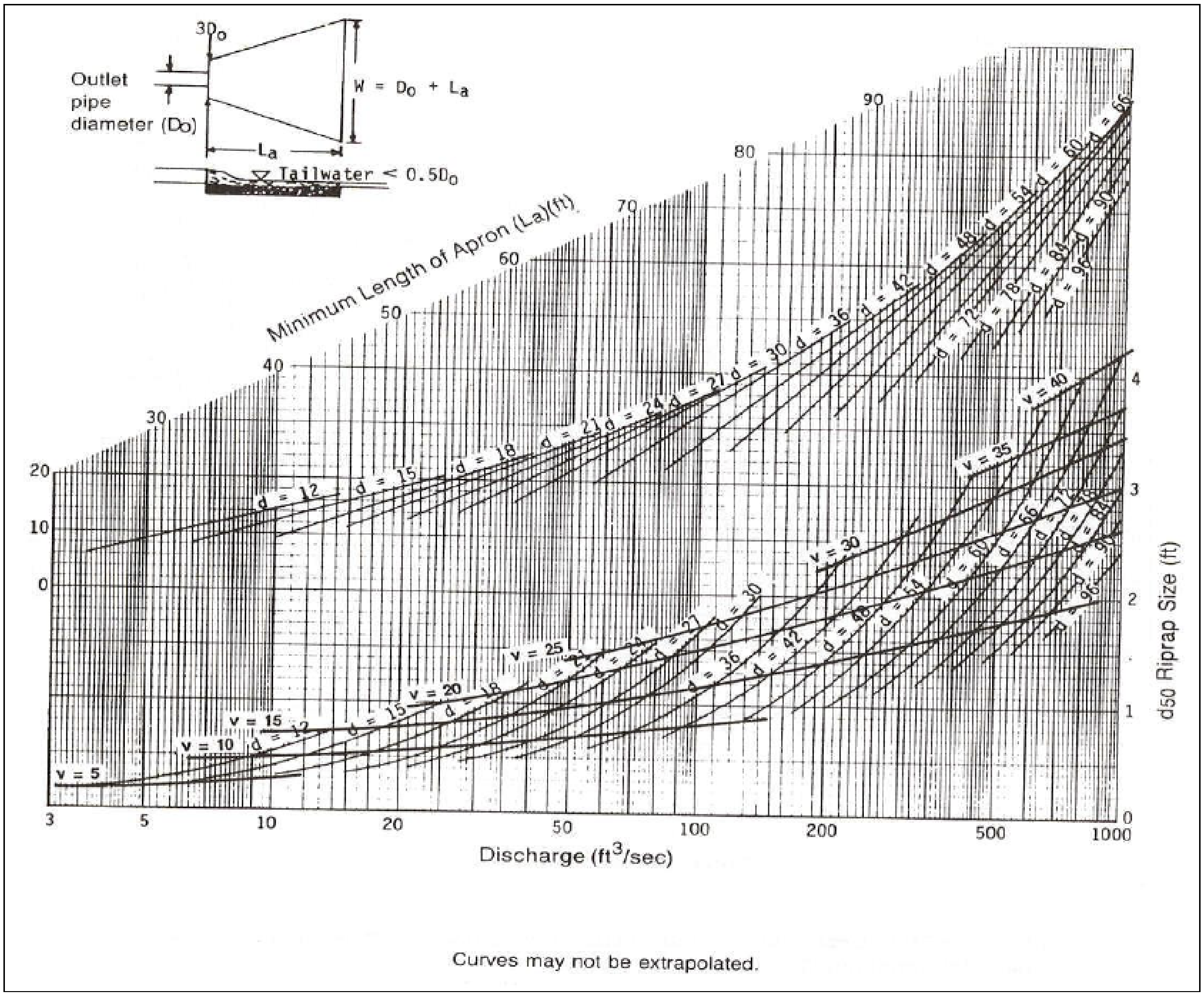

Figure 6-10. Outlet protection design for tailwater < 0.5 diameter.

Apron Width

If the pipe discharges directly into a well-defined channel, the apron should extend across the channel bottom and up the channel banks to an elevation 1foot above the maximum tailwater depth or to the top of the bank, whichever is the least.

If the pipe discharges onto a flat area with no defined channel, the width of the apron should be determined as follows:

- The upstream end of the apron, adjacent to the pipe, should have a width 3 times the diameter of the outlet pipe.
- For a Minimum Tailwater Condition, the downstream end of the apron should have a width equal to the pipe diameter plus the length of the apron obtained from the figures.

- For a Maximum Tailwater Condition, the downstream end shall have a width equal to the pipe diameter plus 0.4 times the length of the apron from Figures 6-10 or 6-11.

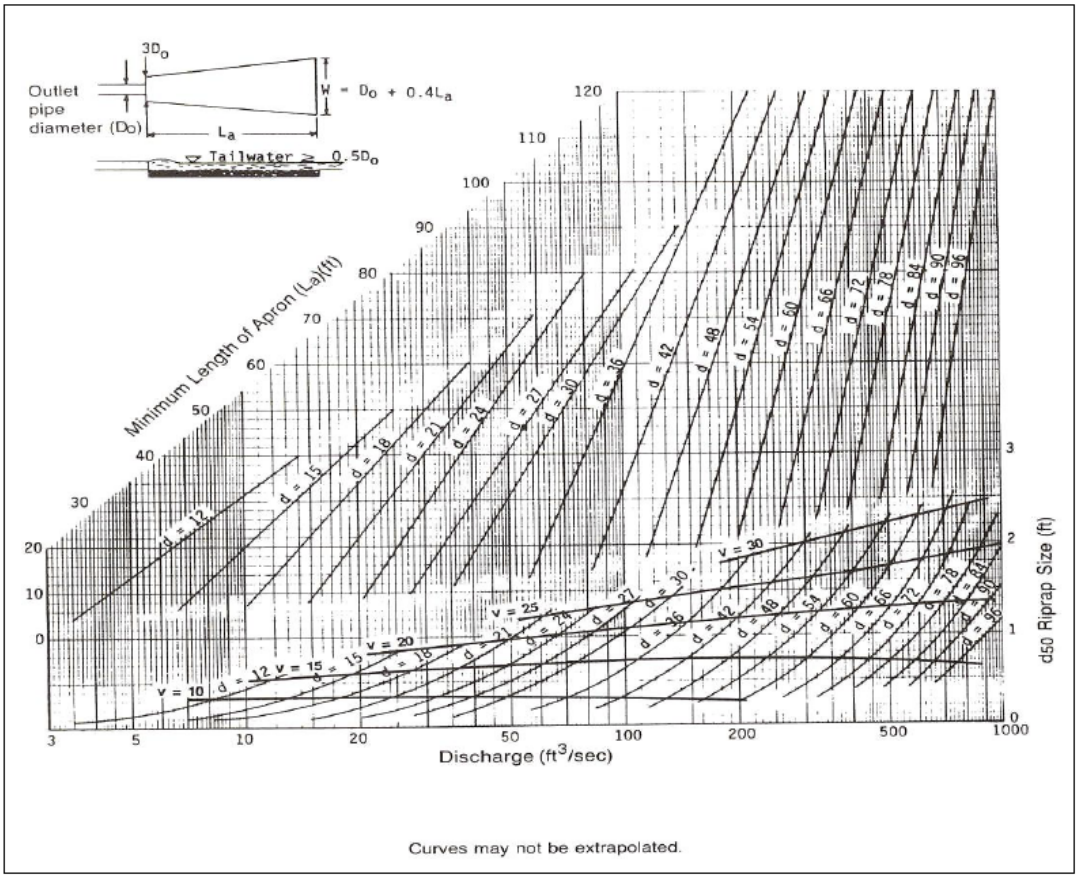

Figure 6-11. Outlet protection design for tailwater ≥ 0.5 diameter.

Bottom Grade

The apron should be constructed with no slope along its length (0.0% grade). The invert elevation of the downstream end of the apron shall be equal to the elevation of the invert of the receiving channel. There shall be no overfall at the end of the apron.

Side Slope

If the pipe discharges into a well-defined channel, the side slopes of the channel should not be steeper than 2:1 (Horizontal:Vertical).

Alignment

The apron should be located so that there are no bends in the horizontal alignment.

Geotextile

When riprap is used to line the apron, non-woven geotextile should be used as a separator between the graded stone, the soil subgrade, and the abutments. Geotextile should be placed immediately adjacent to the subgrade without any voids between the fabric and the subgrade. The geotextile will prevent the migration of soil particles from the subgrade into the graded stone. The geotextile shall be of the strength and durability required for the project to ensure the aggregate and soil base are stable. Generally, the non-woven geotextile should meet the requirements found in ASSHTO M288.

Materials
The apron may be lined with loose rock riprap, grouted riprap, or concrete. The median sized stone for riprap should be determined from the curves on Figure 6-10 and 6-11 according to the tailwater condition.

After the median stone size is determined, the gradation of rock to be used should be specified using Tables 6-7 and 6-8. Table 6-7 is used to determine the weight of the median stone size (d50). Using this median weight, a gradation can be selected from Table 6-8, which shows the commercially available riprap gradations as classified by the Alabama Department of Transportation.

Stone for riprap should consist of field stone or rough unhewn quarry stone of approximately rectangular shape. The stone should be hard and angular and of such quality that it will not disintegrate on exposure to water or weathering and it shall be suitable in all other respects for the purpose intended. The specific gravity of the individual stones should be at least 2.5.

When the apron is lined with concrete, the concrete should have a minimum compressive strength at 28 days of 3000 pounds per square inch. American Concrete Institute guidelines should be used to design concrete structures and reinforcement. As a minimum, the concrete should be reinforced with steel welded wire fabric.

Table 6-7. Size of Riprap Stones

Weight	Mean Spherical Diameter (feet)	Rectangular Shape Length	Width, Height (feet)
50	0.8	1.4	0.5
100	1.1	1.75	0.6
150	1.3	2.0	0.67
300	1.6	2.6	0.9
500	1.9	3.0	1.0
1000	2.2	3.7	1.25
1500	2.6	4.7	1.5
2000	2.75	5.4	1.8
4000	3.6	6.0	2.0
6000	4.0	6.9	2.3
8000	4.5	7.6	2.5
20000	6.1	10.0	3.3

Table 6-8. Graded Riprap

Class	Weight (lbs.)					
	d_{10}	d_{15}	d_{25}	d_{50}	d_{75}	d_{90}
1	10	-	-	50	-	100
2	10	-	-	80	-	200
3	-	25	-	200	-	500
4	-	-	50	500	1000	-
5	-	-	200	1000	-	2000

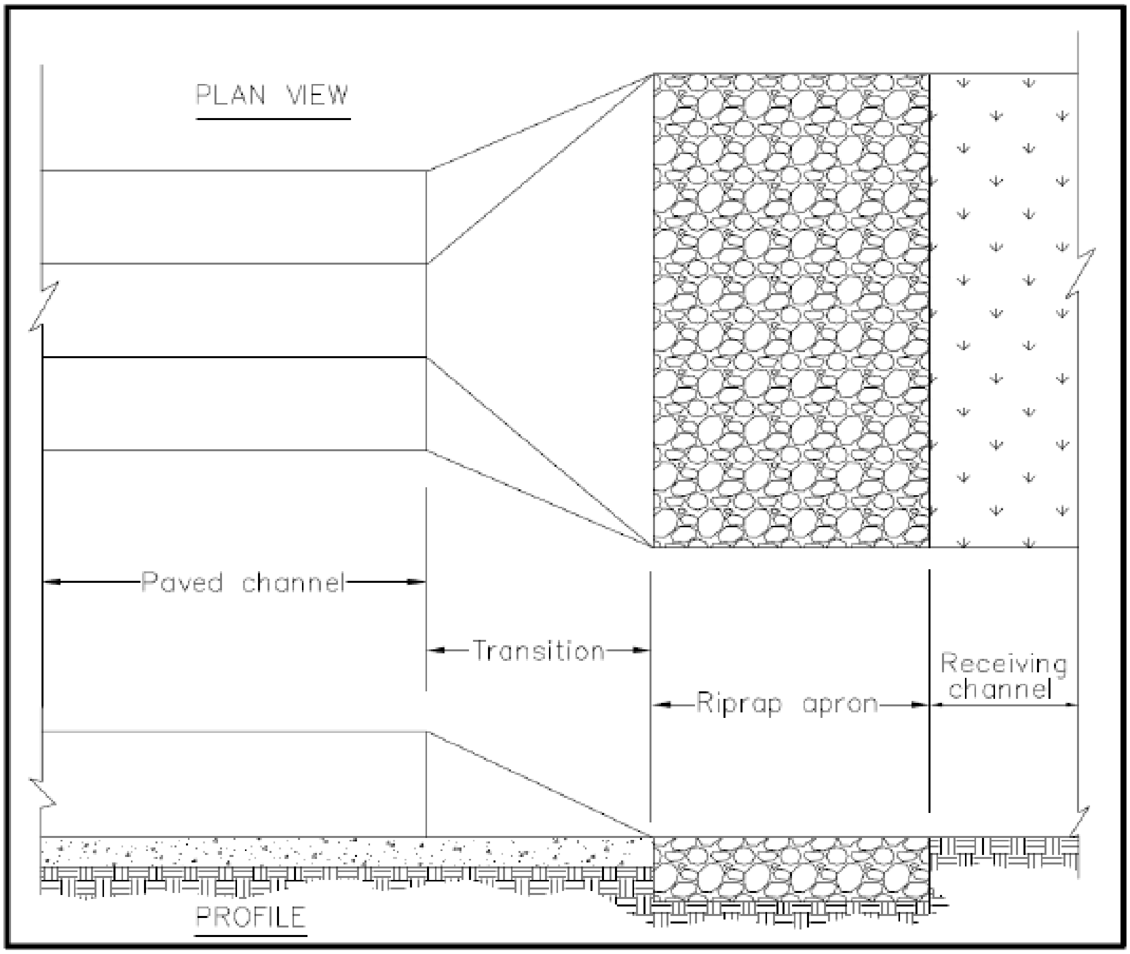

Figure 6-12. Paved Channel Outlet

1. The flow velocity at the outlet of paved channels flowing at design capacity must not exceed the permissible velocity of the receiving channel.

2. The end of the paved channel shall merge smoothly with the receiving channel section. There shall be no overfall at the end of the paved section. Where the bottom width of the paved channel is narrower than the bottom width of the receiving channel, a transition section shall be provided. The maximum side divergence of the transition shall be 1 in 3F where:

   F = v/gd, and
   F = Froude number
   V = Velocity at beginning of transition (ft/sec)
   d = depth of flow at beginning of transition (ft)
   g = 32.2 ft/sec^2

3. Bends or curves in the horizontal alignment of the transition are not allowed unless the Froude number (F) is 0.8 or less (implying supercritical flow), or the section is specifically designed for turbulent flow.

Design Problems
Example 1
Given: An 18” pipe discharges 24 cu. ft/sec at design capacity onto a grassy slope (no defined channel).

Find: The required length, width and median stone size (d50) for a ripraplined apron.

Solution
Since the pipe discharges onto a grassy slope with no defined channel, a Minimum Tailwater Condition may be assumed.

From Figure 6-10, an apron length (La) of 20 feet and a median stone size (d50) of 0.8 feet is determined.

The upstream apron width equals 3 times the pipe diameter: 3 x 1.5 feet = 4.5 feet.

The downstream apron width equals the apron length plus the pipe diameter: 20 feet + 1.5 foot = 21.5 feet.

Example 2
Given: The pipe in example No. 1 discharges into a channel with a triangular cross section, 2 feet deep and 2:1 side slopes. The channel has a 2% slope and an “n” coefficient of 0.045.

Find: The required length, width and the median stone size (d50) for a riprap lining.

Solution
Determine the tailwater depth using Manning’s Equation and the Continuity Equation.

$$Q = (1.49/n)\ R^{2/3}\ S^{1/2}\ A$$
$$24 = (1.49/n)\ [2d/4.47]^{2/3}\ (.02)^{1/2}\ (2d^2)$$

where, d = depth of tailwater
d = 1.74 feet. *

*Since d is greater than half the pipe diameter, a Maximum Tailwater Condition exists.

From Figure 6-11, a median stone size (d50) of 0.5 feet and an apron length (La) of 41 feet is determined.

The entire channel cross section should be lined, since the maximum tailwater depth is within 1 foot of the top of the channel.”
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Emergency Spillways
All detention ponds also must be equipped with emergency spillways. Mason (1982) states that the preferred location of an emergency spillway is on undisturbed ground, rather than over a prepared embankment, to reduce the erosion potential. Detention ponds treating runoff from small contributing areas can safely handle overflows as sheetflows through well-designed swales.

The NRCS guidelines for designing runoff control measures must be followed when designing emergency spillways for wet detention ponds. In addition, if the detention pond is large, specific state regulations and the Army Corps of Engineers must be followed.

Detention Pond Design Fundamentals

The basic design approaches for wet detention ponds consider the behavior of the water passing through the pond to be either plug flow or completely-mixed flow. Martin (1989) reviewed these flow regimes and conducted five tracer studies in a wet detention pond/wetland in Orlando, FL, to determine the actual flow patterns under several storm conditions. Completely-mixed flow conditions assume that the influent is completely and instantaneously mixed with the contents of the pond. The concentrations are therefore uniform throughout the pond. Under plug-flow conditions, the flow proceeds through the pond in an orderly manner, following streamlines and with equal velocity, i.e., the flow enters at a single time and travels through pond to the outlet as a batch, displacing a slug of previously-captured water. The concentrations vary in the direction of flow and are uniform in cross section. The steady-state resident times for both flow patterns are the same; the pond volume divided by the discharge rate. Historically, wet detention ponds have been designed using the plug-flow concept, probably because it had been used in conventional clarifier designs for water and wastewater treatment. In reality, detention ponds exhibit a combination flow pattern that Martin terms moderately-mixed flow. He found that the type of mixing that actually occurs is dependent on the ratio of the storm volume to the pond storage volume (the flushing ratio). If the ratio is less than one, plug flow likely predominates. If the ratio is greater than one, the flow type is not as obvious. With faster moving water in the pond, short-circuiting may reduce the available pond storage volume (and therefore the resident time), resulting in less effective treatment.


Sediment pond at landfill

<table>
<tr><td></td><td>Permanent pond acting as sediment trap during final construction</td></tr>
<tr><td>
Series of small sediment ponds at a complex construction site (Atlanta, GA)</td><td>
Temporary pond at highway construction site in area where hauling trucks are washed prior to re-entering roads (WI)</td></tr>
</table>

Figure 6-13. Example sediment ponds at construction sites.

Upflow Velocity

Linsley and Franzini (1964) stated that in order to get a fairly high percentage removal of particulates, it is necessary that a sedimentation pond be properly designed. In an ideal system, particles that do not settle below the bottom of the outlet will pass through the sedimentation pond, while particles that do settle below/before the outlet will be retained. The path of any particle is the vector sum of the water velocity (V) passing through the pond and the particle settling velocity (*v*). Therefore, if the water velocity is slow (slower than the settling rate of the particles by gravity), slowly-falling particles can be retained, assuming the residence time is sufficiently long for the particle to settle below the outlet structure's drainage point. If the water velocity is fast, then only the heaviest (fastest-falling) particles are likely to be retained. The critical ratio of water velocity to particle settling velocity must therefore be equal to the ratio of the sedimentation pond length (L) to depth to the bottom of the outlet (D):

$$\frac{V}{v} = \frac{L}{D}$$

as shown on Figure 6-14.

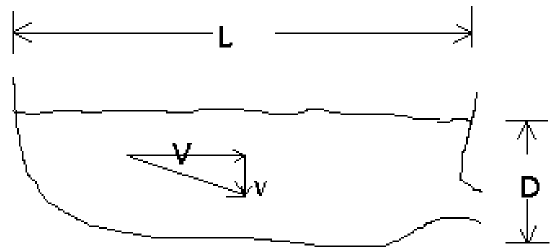


Figure 6-14. Critical Velocity and Pond Dimensions

The water velocity is equal to the water volume rate (Q, often expressed in cubic feet per second) divided by the pond cross-sectional area (A, or pond depth multiplied by pond width: DW):

$$V = \frac{Q}{A}$$

or

$$V = \frac{Q}{DW}$$

The pond outflow rate equals the pond inflow rate under steady state conditions. The time period for the steady-state condition is the time of travel from the inlet to the outlet. During rising hydrograph portions of a storm, the inflow rate (Q_{in}) will be greater than the outflow rate (Q_{out}) due to freeboard storage. Therefore, the outflow rate controls the water velocity through the pond during this condition. By substituting this definition of water velocity into the critical ratio:

$$\frac{Q_{out}}{WDv} = \frac{L}{D}$$

The water depth to the outlet bottom (D) cancels out, leaving:

$$\frac{Q_{out}}{Wv} = L$$

Or

$$\frac{Q_{out}}{v} = LW$$

However, pond length (L) multiplied by pond width (W) equals pond surface area (A). Substituting leaves:

$$\frac{Q_{out}}{v} = A$$

and the definition of upflow velocity:

$$v = \frac{Q_{out}}{A}$$

where Q_{out} = pond outflow rate (cubic feet per second),
A = pond surface area (square feet: pond length times pond width), and
v = upflow velocity, or critical particle settling velocity (feet per second).

Therefore, for an ideal sedimentation pond, particles having settling velocities less than this upflow velocity will be removed. Only increasing the surface area, or decreasing the pond outflow rate, will increase pond settling efficiency. Increasing the pond depth does lessen the possibility of bottom scour, decreases the amount of rooted aquatic plants, and decreases the chance of winter kill of fish. Deeper ponds may also be needed to provide sacrificial storage volumes for sediment between dredging operations. For construction site sediment ponds, it can be assumed that inlet zones are at the pond surface and that the outlet zones are full depth, providing a worst-case situation (as verified during field tests, such as during the Nationwide Urban Runoff Program, NURP, EPA 1983, where many ponds were monitored for several years).

For continuous flow conditions (such as for water or wastewater treatment), the following relationships can be shown:

$$t = \frac{Volume}{Flow\ rate}$$

and

$$Flow\ rate\ (Q_{out}) = \frac{Volume}{t}$$

where t = detention (residence) time. With

$$v = \frac{Q_{out}}{A}$$

and substituting:

$$v = \frac{Volume}{(t)(A)}$$

but

$$Volume = (A)(depth)$$

therefore,

$$v = \frac{(A)(depth)}{(t)(A)}$$

leaving:

$$\upsilon = \frac{depth}{t}$$

Therefore, the surface overflow rate (Q/A) is equivalent to the ratio of pond depth to detention time, and it is not possible to predict pond performance by only specifying detention time. If the pond depth was also specified (or kept within a typical and narrow range), then the detention time could be used as a performance indicator for a continuous or plug flow condition. However, it is not possible to hold all of the water in a detention pond for the specified detention period. Outlet devices typically release water at a high rate of flow when the pond stage is elevated (resulting in minimal detention times during peak flow conditions) and lower flow rates at lower stages, after most of the detained water has already been released. The average detention time is therefore difficult to determine and is likely very short for most of the water entering the pond during moderate-to-large storms (high flushing ratios). For variable-flow stormwater conditions, it is much easier to design and predict pond performance using the surface overflow rate relationships that rely on short-term outflow rate and pond area values.

The surface overflow rate (the ratio of outflow rate to pond surface area) can be kept less than a critical value for all pond stages. This results in a more direct method of designing or evaluating pond performance. Pond performance curves therefore can be easily prepared, where surface overflow rate (and therefore critical particle control) are related for all stages at a pond site, as the pond surface area and outflow rate are both directly related to the pond stage.

Under ideal settling, as described above, the upflow velocity can be considered the critical settling rate for the smallest particle in the pond; any particle that has a settling rate larger than the upflow velocity is assumed to be trapped in the pond (scour prevention is also a consideration, especially for shallow water depths and for dry ponds). Short-circuiting, described next, effectively reduces the area of the pond, allowing some larger particles to be discharged.

Effects of Short-Circuiting on Particulate Removals in Wet Detention Ponds

Under dynamic conditions, particle trapping can be predicted using the basic Hazen theory presented by Fair and Geyer (1954) that considers short-circuiting effects:

$$\frac{y}{y_0} = 1 - \left[1 + \frac{v_o}{n(Q/A)}\right]^{-n}$$

where y_o = initial quantity of solids having settling velocity of v_o
y = quantity of these particles removed
y/y_o = proportion of particles removed having settling velocity of v_o
Q = wet pond discharge
A = wet pond surface area
n = short-circuiting factor (number of hypothetical basins in series)

This equation is closely related to the basic upflow velocity equation (or surface overflow rate) shown previously. The short-circuiting factor n is typically given a value of 1 for very poor conditions, 3 for good conditions, and 8 for very good conditions. Short-circuiting allows some large particles to be discharged that theoretically would be completely trapped in the pond. However, field monitoring of particle size distributions of detention pond effluent shows that this has a very small detrimental effect on the suspended solids (and pollutant) removal rate of a pond. Figure 6-15 shows the effects of different n values on the removal of particles having different settling rates (v) compared to the critical settling rate (Q/A). For a particle having a settling rate equal to the critical values (v = Q/A), the ideal settling indicates 100% removal, while for "best performance" ($n = \infty$), the actual removal would be only about 65%. If the pond had an n of 1 (very poor performance), the removal of this critical particle would be only 50%.

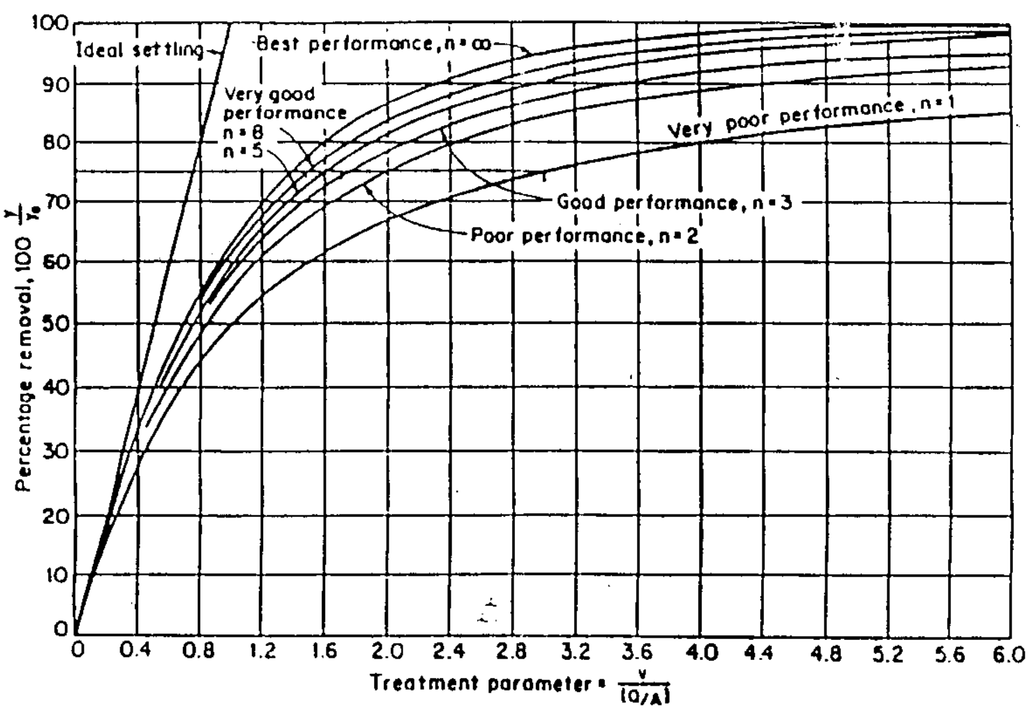


Figure 6-15. Performance curves for settling basins of varying effectiveness (AWWA 1971).

The sediment basin performance is worse for particles having settling rates larger than the critical rate due to short-circuiting. However, most wet detention ponds are greatly over-sized according to their ability to remove large particles, so this degraded performance for large particles has minimal effects on the overall suspended solids removal. The suggested detention pond design presented in this chapter only operates at the "design" stage (where the critical particle size is being removed) a few times a year. At all other times, the smallest particles being removed in the ponds are much smaller than the critical size used in the pond design. Almost all larger particles are effectively trapped because they are much larger than the design particle size (the pond is over-sized for these large particles), even if they are not being removed at their highest possible rate. In most cases, a few relatively large particles (much larger than the critical design particle size) will be observed in the pond effluent, but they have little effect on the overall SS removal.

Figure 6-16 shows example particle settling distributions for a pond, comparing effluent conditions using the short-circuiting effects of Hazen's theory. The most common particle size (the mode of the distribution) changes very little for the different effluent conditions. However, there are some larger-sized particles present in the effluent using Hazen's theory compared to the ideal theory, and the median size obviously increases as the value for n decreases.

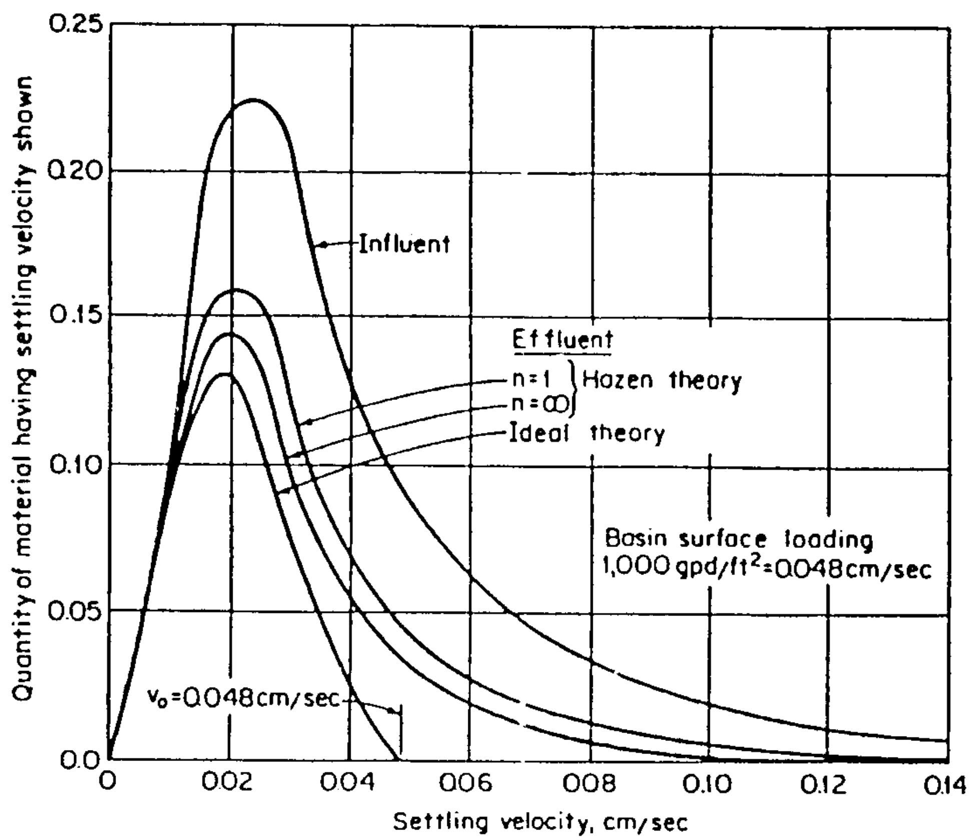


Figure 6-16. Influent and effluent particle settling rate distributions for settling basins of varying effectiveness (AWWA 1971).

Very little degraded performance was observed at a pond monitored during NURP (EPA 1983) located in Lansing, MI, that was expected to have significant short-circuiting. A golf course pond located across the street from a commercial strip was converted into a stormwater pond, but the inlets and outlets were adjacent to each other to reduce construction costs associated with longer pipe lengths. It was assumed that severe short-circuiting would occur because of the close proximity of the inlet and outlet locations. However, the pond produced suspended-solids removals close to what was theoretically predicted, and similar to other ponds having similar pond-area-to-watershed-area ratios. Actually, the close inlet and outlet locations may have resulted in less short-circuiting because the momentum of the inflowing waters likely forced the water to travel in a general circular pattern around the pond, instead of directly flowing across the pond (and "missing" some edge area) as would be expected if the outlet was located at the opposite end of the pond.

Seven events were studied at the Madison, WI, Monroe St, wet detention pond to find the short-circuiting "n" factors using observed and predicted particle size distributions in effluent water. Particle size distributions were measured using the Sedigraph method at the USGS Denver laboratory. This technique measures settling rates of different-size suspended-solid particulates down to 2 μm. The value of n is calculated using the concentrations of large particles that are found in the effluent. In ideal settling, no particles greater than the theoretical critical size (about 5 μm for the Monroe St. pond) should appear in the effluent. However, there are always a small number of these larger particles in the effluent. Generally, it is assumed that short-circuiting is responsible for these large particles in the effluent, but they could also be caused by scour of large particles from the sediment near the pond effluent location. Ignoring scour, the measured values for n were one, or less, indicating a high degree of short-circuiting in the pond. However, these observations were possibly affected by scour of bottom deposits near the subsurface effluent pipes. The maximum effect of short-circuiting on pond performance is shown on Table 6-9, which shows the average reduction in suspended solids removals for different n values compared to the best performance (n value equal to 8):

Table 6-9. Short-circuiting Effects on Sedimentation

n value	% SS removal (average)	Reduction in % SS removal compared to n=8
8	85	
3	84	1
1	80.7	4.3
0.5	78.5	6.5
0.2	59	26

The calculated values of n (based on matching measured effluent particle size distributions with distributions calculated using different values of n) ranged from about 0.2 to 1 at the Monroe St pond, indicating "very poor performance", or worse. The median value of n observed was about 0.35, indicating degradation in the annual average suspended-solids capture efficiency of about 10 percent. The effects of this short-circuiting, even with the extremely-low values of n for the Monroe St. pond, only has a minimal effect on the suspended-solids percentage removals. The long-term monitoring of the Monroe St. pond over more than five years provided an average suspended solids reduction of 87%, compared to the design goal of 90%. These values are quite close and short-circuiting was found to have a negligible effect on actual performance, as the pond surface is relatively large (0.6% of the drainage area) and the outlets were efficiently modified during retrofitting.

Therefore, while care should be taken in locating and shaping ponds to minimize potential short-circuiting problems, it should not be at the expense of other more important factors (especially size or even constructing the pond at all). Poor pond shapes probably cause greater problems by producing stagnant areas where degraded aesthetic and nuisance problems originate.

Residence Time and Extended Detention Ponds

As noted above, residence time is defined as the ratio of volume to average flow rate (volume divided by volume per time). It can be assumed to be the average length of time any parcel of water remains in the pond. As in any pond performance measure or design criteria, residence time values are very dependent on good pond configurations. Harrington (1986) stresses the need to subtract pond "dead zones" from pond volume when calculating residence times. Dead zones (and associated short-circuiting) can significantly reduce pond effectiveness.

Designing a wet pond for the treatment of runoff based on residence time alone is usually not recommended. Barfield (1986) states that residence (detention) time is not a good criteria for pond performance, but the ratio of peak discharge rate to pond surface area (the peak upflow velocity) is a good criteria of performance. The state of Maryland uses a residence time standard as part of their design criteria for "extended detention" ponds. These ponds are normally dry between events, or have a small and shallow wet pond area near the outlet, and greatly extend in surface area during storms. For these types of ponds, Harrington (1986) found, through computer modeling studies, that a residence time of about nine days is needed to achieve a 70 percent reduction of particulate residue. These types of ponds therefore are not expected to be very useful for locations where the interevent periods of rains is short, or the drain-down time of the pond is rapid.

Unfortunately, dry ponds usually do not allow permanent retention of the settled particles. Subsequent storms usually scour the fine particles previously settled to the pond bottom. Dry detention ponds have not been shown to be as consistently effective in water quality control as wet ponds. The use of a small permanently-wet detention pond or wetland at the downstream end of a dry detention pond could help recapture some of these scoured particles. A wet detention pond located immediately upstream of a dry pond is usually a much better solution, as the wet pond would act as a pre-treatment pond, keeping particles and debris out of the dry pond which should be designed for peak flow rate reductions, as long as the bottom of the dry pond is protected from scour.

The previous discussion on upflow velocity as a design criterion illustrated the relationship between particle settling rates and upflow velocity, while this discussion showed the relationship between particle settling rates and residence times. A relationship therefore exists between residence time and upflow velocity. Residence time is dependent on pond volume and outlet rate, while upflow velocity is dependent on pond surface area and outflow rate. The relationship between residence time and upflow velocity therefore is equal to the relationship between pond volume and pond surface area, or the pond depth. When a pond depth of five feet is used, the residence times of ponds designed using the upflow velocity method are generally the same residence times needed for similar control levels using the residence time criteria. Even though the two procedures result in the same basic design, it is still recommended that the upflow procedure be used for wet detention ponds during storm events. The depth and configuration design criteria are very critical for the other pond uses (aquatic life, aesthetics, and safety, besides scour prevention) and they should not be varied as part of the major design elements.

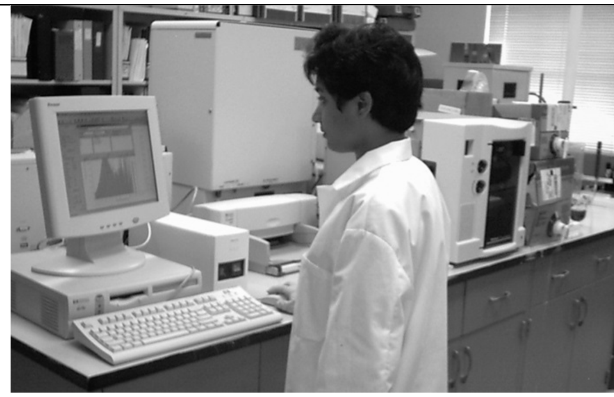
Runoff Particle Size Distributions

It is important to note that particle size distributions in the runoff are not usually related to the soil particle size distribution. As discussed in Chapter 4, rain energy preferentially erodes and transports fine particles, so the runoff particle size distribution is more a function of rain energy and transport energy. Most soils are not source limited for fine material, with the rare exception of a homogeneous sandy area having no fines. Measurements of particle size distributions of both influent and effluent water should be conducted when monitoring the performance of ponds (and most other construction site erosion controls).

Knowing the settling velocity characteristics associated with stormwater particulates is necessary when designing wet detention ponds. Particle size is directly related to settling velocity (using Stokes law, for example, and using appropriate shape factors, specific gravity and viscosity values), and settling velocity usually is used in the design of detention facilities. Particle size also can be more easily and rapidly measured in the laboratory than settling velocities. Settling tests for stormwater particulates need to be conducted for about three days in order to quantify the smallest particles that are of interest in the design of wet detention ponds. Probably the earliest description of conventional particle settling tests for stormwater samples was made by Whipple and Hunter (1981).

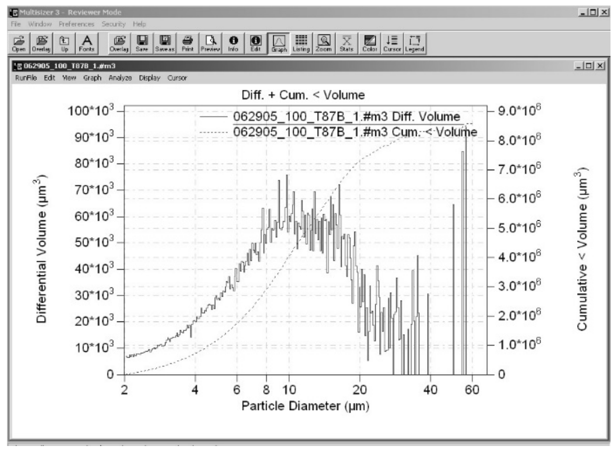
 Cascading sieves (with total solids analyses after each sieve)	 Andreseen pipette (miniature settling column)

Coulter Counter Multi-Sizer IIe

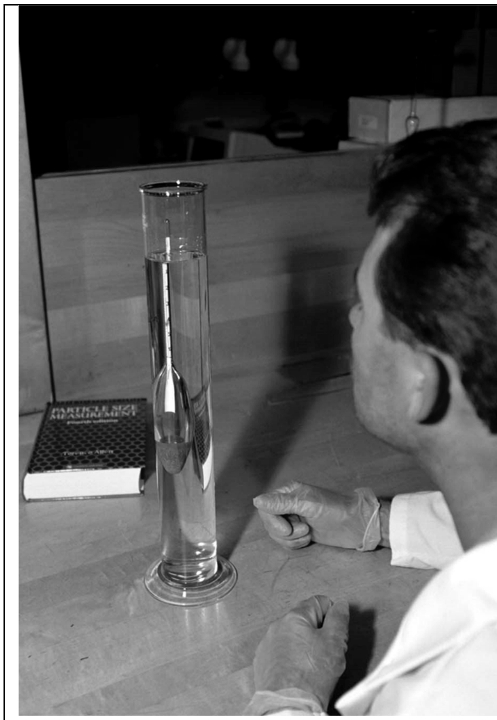


Coulter Counter Multi-Sizer 3

Multi-Sizer 3 aperture tube and stirrer

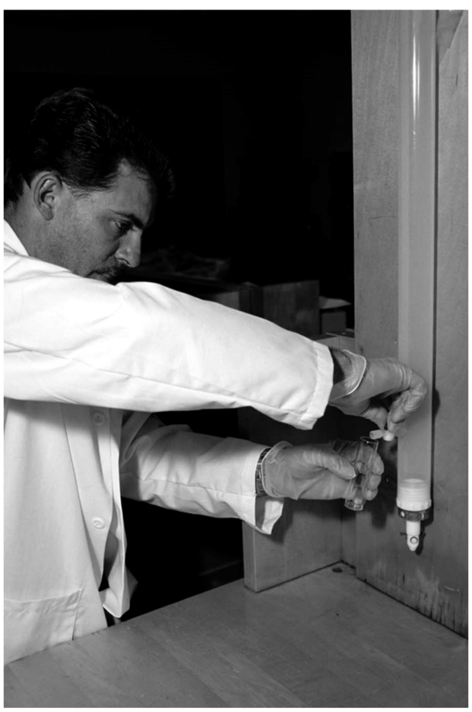


Multi-Sizer 3 computer display of particle size distribution



Pipette for high solids loadings

Field turbidimeter



Teflon™ settling column

Research light microscope with automatic video analyses of particles

Figure 6-17. Different methods to characterize particle sizes and settling rates.

Whipple and Hunter (1981) contradict the assumption sometimes used in modeling detention pond performance that pollutants generally settle out in proportion to their concentrations (first-order rate equations). However, Grizzard and Randall (1986) have shown a relationship between particulate concentrations and particle size distributions. High particulate concentrations were found to be associated with particle-size distributions that had relatively high quantities of larger particulates, in contrast to waters having low particulate concentrations. The high-particulate-concentration water therefore would have increased particulate removals in detention ponds. This relationship is expected to be applicable for pollutants found mostly in particulate forms (such as suspended solids and most heavy metals), but the relationship between concentration and settling would be much poorer for pollutants that are mostly in "soluble" forms (such as filterable residue, chlorides and some nutrients and metals). Therefore, the partitioning of specific pollutants between the "particulate" and "dissolved" forms, and eventually for different particulate size fractions, is needed.

Smith (1982) also states that settleability characteristics of the pollutants, especially their particle size distribution, are needed before detention pond analyses can be made. Kamedulski and McCuen (1979) report that as the fraction of larger particles increase, the fraction of the pollutant load that settles also increases. Randall, *et al.* (1982), during settleability tests of urban runoff, found that non-filterable residue (suspended solids) behaves like a mixture of discrete and flocculant particles. The discrete particles settled out rapidly, while the flocculant particles were very slow to settle out. Therefore, simple particle size information may not be sufficient when flocculant particles are also present. Particle size analyses could be supplemented with microscopic examinations to examine the extent of potential flocculation. Flocs can be readily distinguished from discrete particles due their nebulous characteristic in contrast to discrete grains.

Approximate stormwater particle size distributions derived from several upper Midwest and Ontario analyses, using all of the NURP data (Driscoll 1986), and for several eastern US sites that reflect various suspended solids (residue) concentrations, are shown in Figure 6-18 (Grizzard and Randall 1986). Pitt and McLean (1986) microscopically measured the particles in selected stormwater samples collected during the Humber River Pilot Watershed Study in Toronto. The upper Midwest data sources were from two NURP projects: Terstriep, *et al*. (1982), in Champaign/Urbana Ill. and Akeley (1980) in Washtenaw County, Michigan.

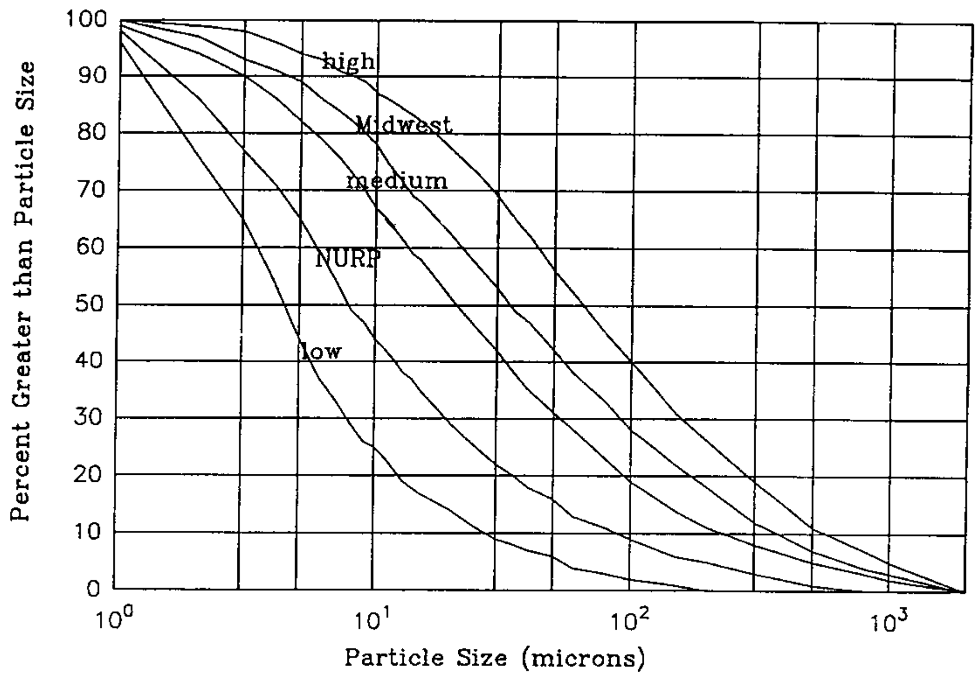


Figure 6-18. Particle size distributions for various stormwater sample groups.

Tests have also been conducted to examine the routing of particles through the Monroe St. detention pond in Madison, Wisconsin (Roger Bannerman, Wisconsin Department of Natural Resources, personal communication). This detention pond serves an area that is mostly comprised of medium-density residential land uses, with some strip commercial areas. This joint project of the Wisconsin Department of Natural Resources and the U.S. Geological Survey has obtained a number of inlet and outlet particle-size distributions for a wide variety of storms, including inlet bedload contributions. The observed median particle sizes for the inlet samples ranged from about 2 to 26 μm, with an average of 9 μm. These distributions included bedload material that was also sampled and analyzed during these tests. Figure 6-19 shows the particle size distribution for the inflow events, including bedload, for a series of about 50 runoff events at the Monroe St. detention pond in Madison, WI. The median size is about 8 μm, but it ranges from about 2 to 30 μm. About 10% of the particles may be larger than 400 μm. The largest particle size observed was larger than 2 mm. The bedload material added about 10% of the mass of these particulates and was associated with the largest particle sizes. The settling velocities of discrete particles can be predicted using Stokes and Newton's settling equations. Typically, more than 90% of all stormwater particulates (by volume and mass) are in the 1 to 100 μm range, corresponding to low Reynolds's numbers and laminar flow conditions, as required for Stokes law settling rate calculations. In most cases, stormwater particulates have specific gravities in the range of 1.5 to 2.5 (determined by conducting settling column, sieving, and microscopic evaluations of the samples, in addition to the particle counting), corresponding to a relatively narrow range of settling rates for a specific particle size.

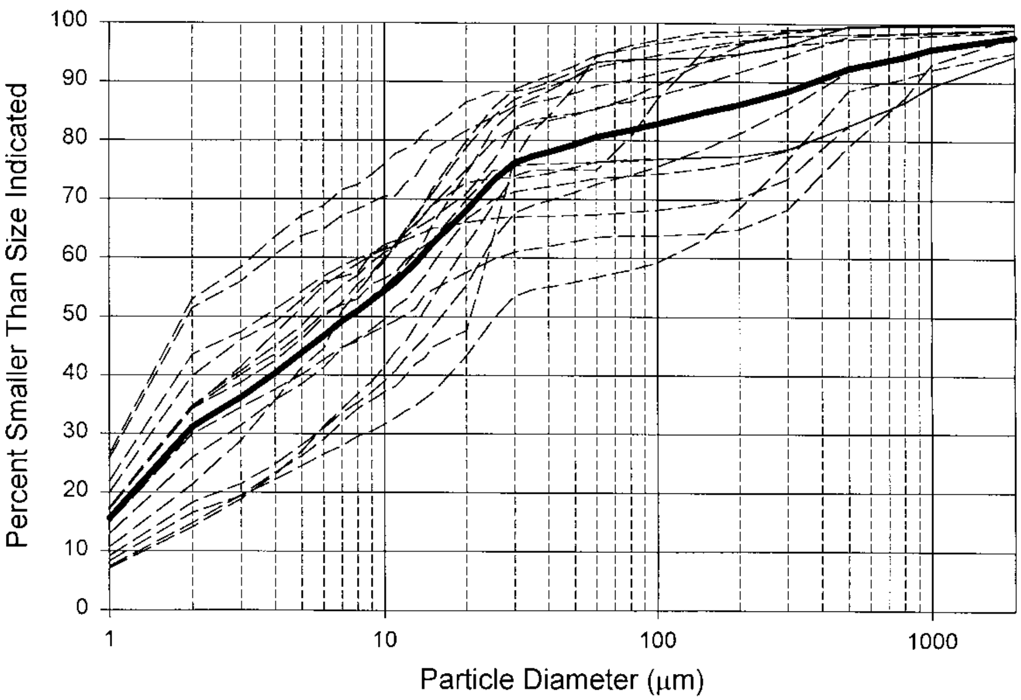


Figure 6-19. Inlet particle size distributions observed at the Monroe St. wet detention pond.

Limited data are also available concerning the particle-size distribution of erosion runoff from construction sites. Hittman (1976) reported erosion runoff having about 70 percent of the particles (by weight) in the clay fraction (less than 4 μm), while the exposed soil that is being eroded only had about 15 to 25 percent of the particles (by weight) in the clay fraction, indicating preferential erosion of the smallest particles, as expected. When the available data are examined, it is apparent that many factors affect construction-site erosion runoff particle sizes. Rain characteristics, soil type, and on-site erosion controls can all be important.

As discussed in previous chapters, many Alabama and southeastern US areas experience severe erosion problems. For example, in addition to high rain energy, many Alabama soils also are highly erosive (large k values) and result in construction site runoff that is very difficult to control. Based on about 70 construction site erosion samples collected in the Birmingham area (Nelson 1996; Pitt 1998), the characteristics of this runoff include the following:

- Measured suspended solids concentrations ranged from 100 to more than 25,000 mg/L (overall median about 4,000 mg/L).
- Turbidity ranged from about 300 to >50,000 NTU, with an average of about 4,000 NTU
- Particle sizes: 90% were smaller than about 20 μm (0.02 mm) in diameter and median size was about 5 μm (0.005 mm).
- Measured Birmingham untreated construction site erosion discharges range from about 100 to 300 tons/acre/year

There were obvious relationships between rain conditions and the observed runoff quality during these local Birmingham studies, as shown on Table 6-10.

Table 6-10. Rain Conditions and Runoff Characteristics

Measured conditions:	**Low intensity rains (<0.25 in/hr)**	**Moderate intensity rains (about 0.25 in/hr)**	**High intensity rains (>1 in/hr)**
Suspended solids, mg/L	400	2,000	25,000
Particle size (median), μm	3.5	5	8.5

Nelson 1996 and Pitt 1998

These construction site data would therefore correspond to the "low," or "all NURP" particle size distributions. The particle size distribution of material leaving construction sites is therefore quite small and hard to control. Exceptions are associated with gross soil loss associated with unstable slopes where landslides bring large amounts of the soil down the hill and off the property. Small particle sizes are much more difficult to remove by most erosion control strategies, which usually employ sedimentation (sediment ponds and silt fences) without chemical addition. Particle sizes or associated settling velocities are used with the desired outflow rate to determine the required surface area for a sediment pond.

These data show that construction site runoff can have smaller particle-size distributions than most stormwater; the local Birmingham construction-site runoff has median sizes generally in the range of 3 to 8 μm, while local stormwater from many land uses contain larger particles, with median sizes from about 8 to 65 μm.

Particle Settling Velocities

The settling velocities of discrete particles are shown in Figure 6-20, based on Stokes and Newton's settling relationships. Generally, more than 90% of all runoff particulates are in the 1 to 100 μm range, corresponding to particles that will settle with low Reynolds's numbers, and hence laminar flow conditions. The settling rates can therefore be calculated using Stokes law. This figure also illustrates the effects of different specific gravities on the settling rates. In most cases, stormwater particulates have specific gravities in the range of 1.5 to 2.5, while construction site runoff particles (low organic content subsurface soils after topsoil removal) are likely closer to 2.5. This corresponds to a relatively narrow range of settling rates for a specific particle size. Particle size is much easier to measure than settling rates. We generally recommend measuring particle sizes using automated particle sizing equipment (such as a Coulter Counter Multi-Sizer) and to conduct periodic settling column tests to determine the corresponding settling rates. If particle counting equipment is not available, then small-scale settling column tests (using 50 cm diameter Teflon™ columns about 0.7 m long) can be used. Sieve measurements, another method for creating particle size distributions, are limited to sizes greater than about 20 µm, although precision Teflon membrane filters can be used for much smaller sizes. Our labs routinely use 10, 5, 3, 1, and 0.45 µm membrane filters during characterization studies.

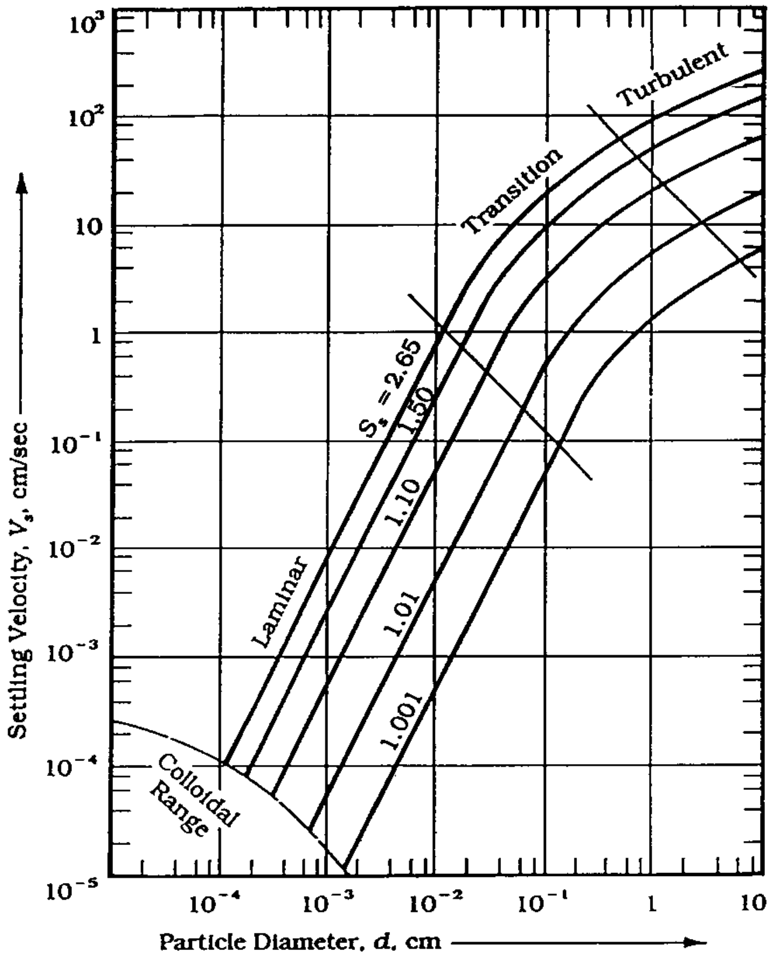


Figure 6-20. Type 1 (discrete) settling of spheres in water at 10° C (Reynolds 1982).

Particle settling observations in actual detention ponds have generally confirmed the ability of well-designed and well-operated detention ponds to capture the "design" particles. Gietz (1983) found that particles smaller than 20 μm predominated (comprised between 50 to 70 percent of the sediment) at the outlet end of an elongated pond, while they only made up about ten to 15 percent of the sediment at the inlet end. Particles between 20 and 40 μm were generally uniformly distributed throughout the pond length, and particles greater than 40 μm were only found in the inlet areas of the pond. Smaller particles also were resuspended during certain events, degrading pond performance.

Design Based on NURP Detention Pond Monitoring Results

The EPA (1983) determined that long-term detention pond performance could be estimated based on geographical location and the ratio of the pond surface area to contributing source area. Driscoll (1989; and EPA 1986) presented a basic methodology for the design and analysis of wet detention ponds. A pond operates under dynamic conditions when the storage of the pond is increasing with runoff entering the pond and with the stage rising, and when the storage is decreasing when the pond stage is lowering. Quiescent settling occurs during the dry period between storms when storage is relatively constant and when the previous flows are trapped in the pond, before being partially or completely displaced by the next storm. The relative importance of the two settling periods depends on the size of the pond, the volume of each runoff event, and the inter-event time between the rains.

Driscoll (1989) produced a summary curve (Figure 6-21) that relates wet-pond performance to the ratio of the pond surface area to the drainage area, based on the numerous NURP wet detention pond observations. The NURP ponds were in predominately residential areas that had conventional curb and gutters. This figure indicates that wet ponds from about 0.3 to 0.8 percent of the drainage area should provide about 90% reductions in suspended solids discharges. Southeastern ponds need to be larger than ponds in the Rocky Mountain region because of the substantially large amounts of rain and the increased size of the individual events and rain intensities in the southeast. Wet ponds designed to remove 90% of the suspended solids need to be about twice as large as ponds with only a 75% suspended solids removal objective.

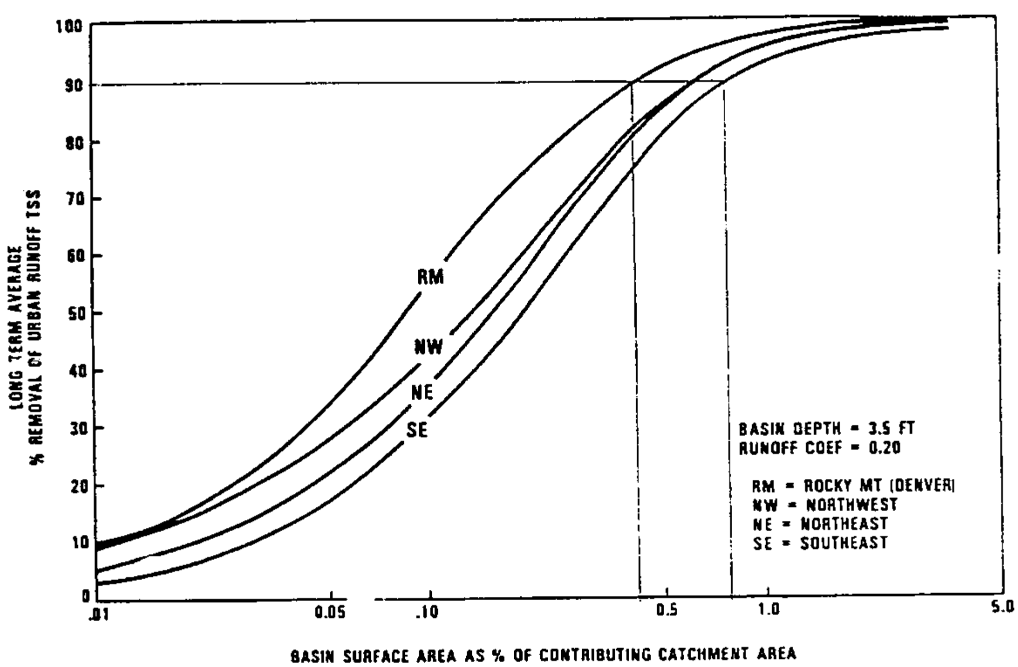


Figure 6-21. Regional differences in detention pond performance (EPA 1983).

Introduction to the Storage-Indication Method

The discharged water from a detention pond is simply displaced pond water. For relatively small storms (in relation to the pond volume), the outlet water characteristics during a specific storm are not related to the inlet water characteristics. If the storm is small, the volume of water coming into the pond can be substantially less than the resident water in the pond. In these cases, the outlet water is mostly "left-over" water from a previous event or from relatively low volume (but long duration) baseflows that had previously entered the pond since the last storm (small flushing ratio). However, if the storm is large, then the water being discharged from the pond is mostly related to the specific event (large flushing ratio). Therefore, analyses of detention pond behavior must consider the relative displacement of pond water. Long-term continuous analyses comparing many adjacent storms resulting in seasonal inlet and outlet flows of pollutants may be more appropriate than monitoring simple paired samples of inlet and effluent flows during a few random events spread over time.

The following discussion on routing includes a fairly simple procedure to examine these pond water displacement considerations and their effects on particulate trapping. The pond routing calculation procedure, the storage-indication method, presented in the remainder of this section is based on the NRCS Technical Release-20 (TR-20) procedures (SCS 1982), as presented by McCuen (1982). The reservoir routing subroutine in TR-20 (RESVOR) is based on the storage equation:

$$I - O = \frac{\Delta S}{\Delta T}$$

where I is the pond inflow and O is the pond outflow. The difference between the inflow and outflow must be equal to the change in pond storage per unit of time ($\Delta S/\Delta T$). McCuen presents a series of equations and their solutions that require the preparation of a "storage-indication" curve to produce the pond outflow hydrograph. The storage-indication curve is a plot of pond outflow (O) against the corresponding pond storage at that outflow (S) plus 1/2 of the outflow multiplied by the time increment. When the pond outflow hydrograph is developed, the upflow velocity procedure described earlier in the chapter can be used to estimate pond pollutant removal and peak flow rate reduction performance.

The relationship between the pond stage and the surface area for the pond under study is also needed in order to calculate the storage volume available for specific pond stages. Figure 6-22 is an example stage-area curve developed from topographic maps of the Monroe Street detention pond in Madison, Wisconsin. The normal pond wet surface is at 13 feet (the zero elevation is at the bottom of the pond) and the emergency spillway is located at 16 feet, for a resultant useable stage range of three feet before the emergency spillway is utilized.

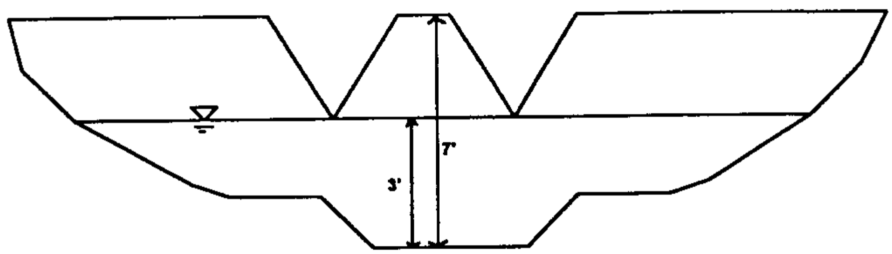


Diagram of Example Pond with Two 90 Degree V-Notch Weirs

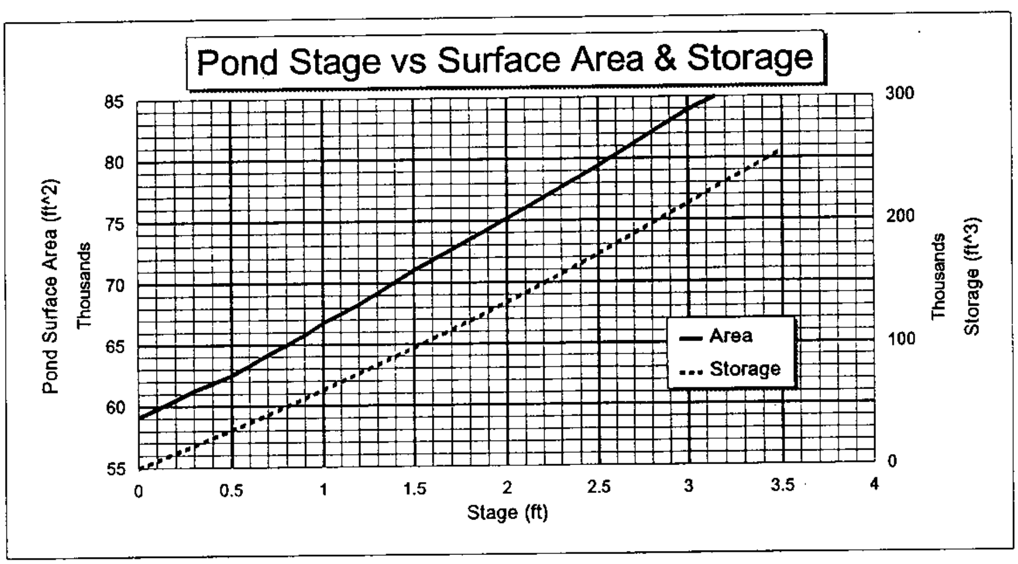


Figure 6-22. Pond-stage surface area relationship for example problem.

Table 6-11 shows the calculations used to produce the storage-indication figure (Figure 6-23) for the Monroe St. pond. This example reflects some pond modifications that were made to enhance pond performance: two 90° V-notch weirs, which increased the maximum stage range to 3.5 feet available before the emergency spillway is activated. The storage calculations assume an initial storage value of zero at the bottom of the V-notch weirs (13.0 feet). The time increment used in these calculations is ten minutes, or 600 seconds. The storage-indication curve shown as Figure 6-23 is therefore a plot of pond outflow (cfs) versus pond storage plus 300 (1/2 of 600 seconds) times the outflow rate at a given stage level. The storage-indication figure must also include stage versus outflow and storage versus outflow curves (also from Table 6-11).

Table 6-11. Calculation of Storage-Indication Relationships for Example Pond and 1.5-Inch, 3-Hour Rain.

Datum Stage (H) (ft)	Discharge Rate[1] (O) (ft^3/sec)	Surface Area (ft^2)	Storage (S) (ft^2)	S + ½ OΔt (see footnote 2)
0	0	59,100	0	0
0.1	0.016	59,800	5,980	5,985
0.2	0.09	60,500	12,100	12,130
0.3	0.25	61,250	18,375	18,450
0.4	0.51	61,850	24,740	24,890
0.5	0.88	62,520	31,260	31,520
0.6	1.4	63,300	37,980	38,400
0.7	2.1	64,200	44,940	45,570
0.8	2.9	65,000	52,000	52,870
0.9	3.8	65,800	59,200	60,340
1.0	5.0	66,767	66,770	68,270
1.2	7.9	68,300	82,000	84,370
1.5	14	71,000	107,000	111,200
1.8	22	73,500	130,000	136,600
2.0	28	75,148	150,300	158,700
2.5	49	79,400	200,000	214,700
3.0	78	83,928	251,800	275,200
3.5	115	87,500	306,300	340,800

[1] Using two 90° V-notch weirs:
$Q = 2(2.5H^{2.5})$

[2] $S + ½ O \Delta t = S + O (½ \Delta t) = S + 300 (O)$
$\Delta t = 600$ seconds

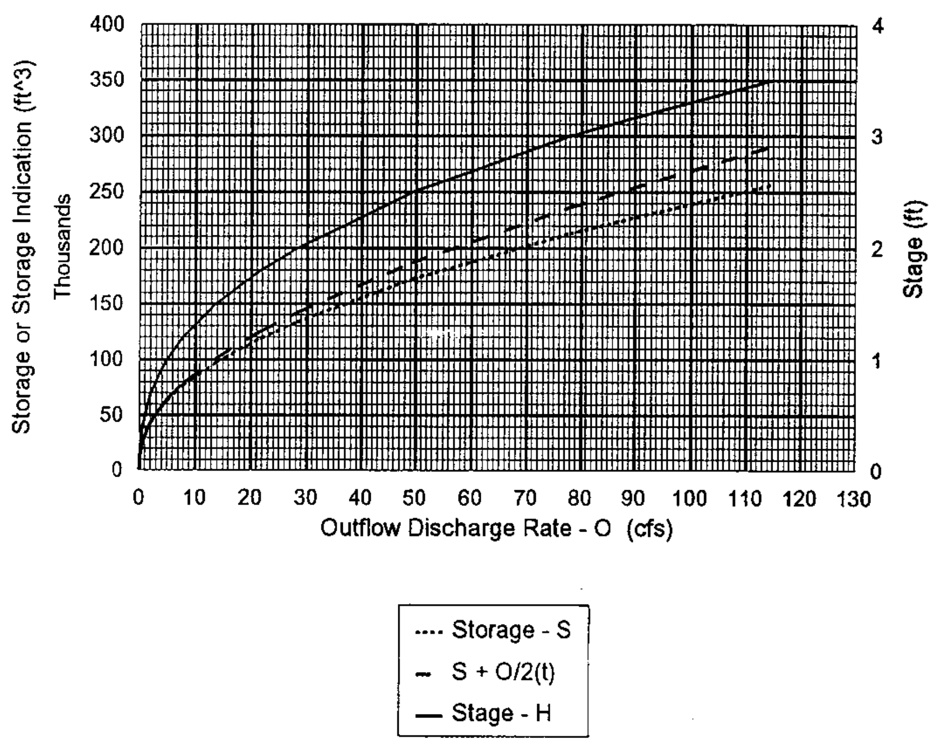


Figure 6-23. Pond-stage/storage indication curve for example problem.

Design of Wet Detention Ponds for the Control of Construction Site Sediment

A wet detention pond performance specification for water quality control has two objectives: (1) to result in a consistent level of protection for a variety of conditions, and (2) to allow a site engineer a range of options to best fit the needs of the site. The pond design also must be easily evaluated by the reviewing agency and be capable of being integrated into the complete stormwater management program for the watershed. It should have minimal effects on the hydraulic routing of stormwater flows, unless a watershed-wide hydraulic analysis is available that specifies the specific hydraulic effects needed at the specific location. WinTR-55 or HydroCaD are both excellent tools to conduct this watershed-wide hydraulic analysis to investigate the effects of the proposed pond (or series of ponds) on watershed discharge flows at critical locations for critical storms, although these are both single-event programs.

The following suggested specifications should meet these objectives under most conditions. However, the specific pond sizes should be confirmed through continuous long-term simulations using many years of actual rainfall records for the area of interest (such modeling is possible by using WinSLAMM [available at www.WinSLAMM.com]). These guidelines therefore should be considered as a starting point and modified for specific local conditions. As an example, it may be desirable to provide less treatment than suggested by the following guidelines (Vignoles and Herremans 1996). The following guidelines were developed by Pitt (1993a and 1993b), based on literature information, personal experience, and extensive modeling analyses.

1) Minimum Water Surface Area

The wet pond should have a minimum water surface area corresponding to land use and desired pollutant control. This is usually the most important aspect of the pond design that affects the pond performance. The following values were extrapolated from extensive wet detention pond monitoring, mainly from the EPA's NURP (EPA 1983) studies and other research. For construction sites, these required pond areas are 1.5% of the drainage area for approximately 90% control (expected to ideally control the 5 µm particle) and 0.5% for 65% control (ideally expected to control the 20 µm particle). If any undeveloped areas are in the pond drainage, the pond area would have to be increased in area by about 0.6% of those areas. Similarly, if any paved areas were in the drainage, the increase in pond area would need to be 3% of the paved area. Obviously, to be most efficient, any extra drainage areas should be kept to a minimum.

Table 6-12 shows how the pond area can be estimated based on drainage area characteristics.

Table 6-12. Pond Area Calculations

	Example land area	Pond size factor	Resulting pond area for example
Paved area	0.6 acres	3%	0.018 acres
Undeveloped area	3.8 acres	0.6%	0.023 acres
Construction area	27.6 acres	1.5%	0.414 acres
Total:	32.0 acres		0.455 acres (1.4% of the total area)

As will be shown in the following example, the total land area needed for the pond will be substantially larger than this value, as this area is the pond water surface area during dry weather. The pond freeboard volume (for water quality control), plus the emergency spillway area, will increase the needed area dedicated for the pond.

2) Pond Live Storage

The pond live storage (freeboard storage above the permanent pool elevation) should be equal to the runoff associated with a 1.25-inch rain over the drainage area for the land use and development type. It should be noted that this storage volume is associated with the runoff volume from a rain and not for a set runoff volume. This has the benefit of providing the same level of control (rain frequency) for all land uses. As an example, many ordinances require capture and treatment of the first 0.5 inch, or 1 inch, of runoff for an area. Unfortunately, this has the effect of providing very uneven levels of control because of different rainfall-runoff characteristics for different land uses. As an example, a residential area may require a rain of about 1.50 inches to produce 0.5 inches of runoff. However, a commercial area, such as a strip commercial development, would only require a rain of about 0.6 inches to produce 0.5 inches of runoff. The residential area is providing treatment for a much more severe rain, with a correspondingly greater level of annual control, compared to the commercial area, the opposite of what probably should occur. By requiring a set level of control associated with a rain having the same recurrence interval, a more consistent effort and benefit is obtained throughout the community. About 0.5 inches of runoff would occur at construction sites for sandy soil areas with no vegetation and about 0.6 inches of runoff for clayey soil areas with no vegetation for this 1.25-inch rain depth. Again, if other land areas are also in the drainage in addition to the construction area, the pond treatment volume would have to be increased. For any paved areas, the 1.25-inch rain would produce about 1.1 inches of runoff, and for vegetated undeveloped areas, the 1.25-inch rain would only produce about 0.1 (for sandy soils) to 0.3 (for clayey soils) inches of runoff.

Table 6-13 shows how the pond storage volume can be estimated based on drainage area characteristics (assuming clayey soil conditions):

Table 6-13. Pond Volume Calculations

	Example land area	Pond WQ volume factor[1]	Resulting pond WQ volume for example
Paved area	0.6 acres	1.1 inches	0.66 acre-inches
Undeveloped area (clayey)	3.8 acres	0.3 inches	1.14 acre-inches
Construction area (clayey)	27.6 acres	0.6 inches	16.56 acre-inches
Total:	32.0 acres		18.36 acre-inches (1.53 acre-ft)

[1] if sandy soils, the pond water quality volume factors would be:
paved areas: 1.1 inches (the same);
undeveloped areas: 0.1 inches; and
construction areas: 0.5 inches.

Figure 6-24 is a schematic showing a cross section of the pond. The area below the invert of the lowest discharge device is the dead storage and is provided to store sediment and minimize scour of the retained particulates. At least 3 ft of "dead storage" water must be in addition to the maximum stored sediment depth to minimize scour during large storm events. The water quality storage volume in the detention pond is the volume associated with the runoff associated with a 1.25 inch rain. The topmost layer in the detention pond is additional storage that is provided for drainage benefits. This storage would be provided (with the appropriate additional outlet structure) only if a basin-wide hydraulic analyses has been conducted to ensure that inappropriate interactions of the different flood hydrographs would not occur. Also, it is important to note that an emergency spillway also must be provided above the water quality storage area. Therefore, the additional storage for drainage benefits as shown in this figure would be provided to cover the range of stages of the emergency spillway.

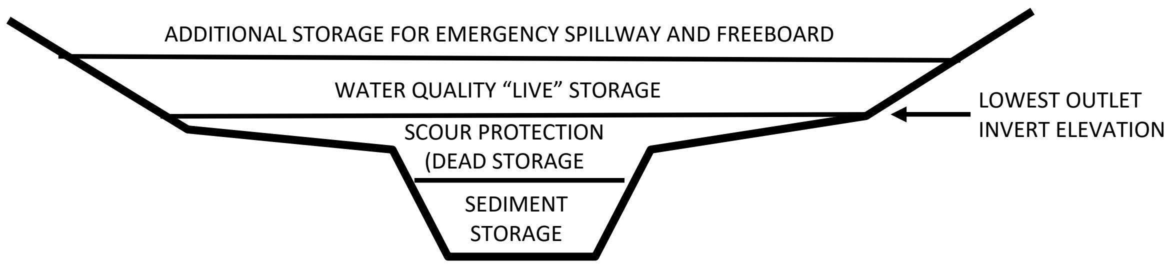


Figure 6-24. Cross-section of pond showing water quality storage portion of storage, along with other pond storage components.

3) Primary Water Quality Outlet Devices

The selection of the outlet devices for the wet detention pond (the primary water quality control device plus the emergency spillway) is the next step and is based on the surface area available at the maximum live storage stage. This outlet device must be selected based upon the desired pollutant control at every specific pond stage. This specification regulates the detention time periods and the "draining" period to produce consistent removals for all rains. The ratio of outlet flow rate to pond surface area for each stage value needs to be at the most 0.00013 ft^3 /sec/ft^2 for 5 μm (about 90% annual control) and 0.002 ft^3/sec/ft^2 for 20 μm (about 65% annual control). In practice, the desired pond-surface-area-to-stage relationship (simply the "shape" of the hole) is compared to the minimum surface areas needed at each stage for various candidate outlet structures. As an example, Table 6-14 summarizes the minimum surface areas needed for 5 μm particle control for different stage values for three different outlet structures. Also shown are the total storage values below each elevation (assuming the noted surface areas for the shallower elevations).

Table 6-14. V-notch Weir Sizes and Required Pond Areas

	45° V-notch weir		90° V-notch weir		24" pipe	
Stage (ft)	Minimum Surface Area for 5 um control (ac)	Corresponding Minimum Storage Below Stage (ac-ft)	Minimum Surface Area for 5 um control (ac)	Corresponding Minimum Storage Below Stage (ac-ft)	Minimum Surface Area for 5 um control (ac)	Corresponding Minimum Storage Below Stage (ac-ft)
0.5	0.032	<0. 01	0.08	0.02	0.28	0.07

1.0	0.18	0.05	0.44	0.15	0.98	0.39
1.5	0.5	0.22	1.2	0.56	1.8	1.1
2.0	1.0	0.60	2.5	1.5	2.4	2.1
3.0	2.8	1.6	6.8	6.2	2.4	4.5
4.0	5.8	5.9	14	17	2.4	6.9
5.0	10	14	25	36	2.4	9.3
6.0	16	27	39	67	2.4	12

Tables 6-15 through 6-18 provide a quick method of selecting appropriate outfall devices for a potential pond location. These tables indicate the minimum pond surface area needed at each stage to provide a 5-μm critical control level for a variety of conventional outfall devices. Table 6-18 presents multipliers to adjust the minimum areas for other critical particle sizes. For example, in order to improve the pond performance by selecting a 2-μm critical particle size instead of 5 μm, the pond surface area would have to be increased by about 6.7 times. If the critical particle size was increased to 10 μm, then the required pond surface would be reduced to about 27% of the pond surface area needed for 5-μm control.

Table 6-15. Surface Area Requirements for 5-μm Particle Size Control for Various V-notch Weirs.

	22.5° v-notch weir			30° v-notch weir			45° v-notch weir		
Head (ft)	Flow (cfs)	Storage (ac-ft)	Reqd. area (acres)	Flow (cfs)	Storage (ac-ft)	Reqd. area (acres)	Flow (cfs)	Storage (ac-ft)	Reqd. area (acres)
0.5	0.1	<0.01	0.01	0.1	<0.01	0.02	0.2	<0.01	0.03
1	0.5	0.03	0.1	0.7	0.05	0.1	1.0	0.05	0.2
1.5	1.4	0.1	0.2	1.9	0.2	0.3	2.9	0.2	0.5
2	2.8	0.3	0.5	3.8	0.3	0.7	5.9	0.6	1.0
3	7.8	1.2	1.4	11	1.6	1.8	16	1.6	2.8
4	16	3.3	2.8	22	4.4	3.8	33	5.9	5.8
5	28	7.2	4.9	38	9.6	6.6	58	14	10
6	44	14	7.7	60	18	10	91	27	16
	60° v-notch weir			90° v-notch weir			120° v-notch weir		
	Flow (cfs)	Storage (ac-ft)	Reqd. area (acres)	Flow (cfs)	Storage (ac-ft)	Reqd. area (acres)	Flow (cfs)	Storage (ac-ft)	Reqd. area (acres)
0.5	0.3	<0.01	0.05	0.4	0.02	0.08	0.8	0.04	0.1
1	1.4	0.07	0.3	2.5	0.2	0.4	4.4	0.3	0.8
1.5	4.0	0.3	0.7	6.9	0.6	1.2	12	1.7	2.1
2	8.2	0.8	1.4	14	1.5	2.5	25	3.3	4.4
3	28	3.5	3.9	39	6.2	6.8	69	12	12
4	46	9.5	8.1	80	17	14	140	30	25
5	81	21	14	140	36	25	250	69	43
6	130	39	22	220	67	39	390	120	68

Table 6-16. Surface Area Requirements for 5-μm Particle Size Control for Various Rectangular Weirs.

	2 ft rectangular weir			5 ft rectangular weir			10 ft rectangular weir		
Head (ft)	Flow (cfs)	Storage (ac-ft)	Reqd. area (acres)	Flow (cfs)	Storage (ac-ft)	Reqd. area (acres)	Flow (cfs)	Storage (ac-ft)	Reqd. area (acres)
0.5	2.1	0.10	0.4	5.7	0.3	1.0	12	0.5	2.0
1	6	0.5	1.1	16	1.2	2.8	33	2.4	5.7
1.5	10	1.2	1.8	29	3.2	5.0	59	6.3	10
2	15	2.3	2.6	43	6.4	7.6	90	13	16
3	24	5.7	4.2	80	17	14	160	35	29
4	32	11	5.6	110	34	20	250	71	43
5	37	17	6.5	150	47	26	340	120	59

6	39	23	6.9	190	77	33	430	190	75
	15 ft rectangular weir			20 ft rectangular weir			30 ft rectangular weir		
	Flow (cfs)	Storage (ac-ft)	Reqd. area (acres)	Flow (cfs)	Storage (ac-ft)	Reqd. area (acres)	Flow (cfs)	Storage (ac-ft)	Reqd. area (acres)
0.5	17	0.8	3.0	23	1.0	4.1	35	1.5	6.1
1	49	3.7	8.6	66	5.1	12	99	7.3	17
1.5	90	9.9	16	120	13	21	180	20	32
2	140	20	24	190	27	32	280	40	49
3	250	54	44	340	72	59	510	110	89
4	380	110	66	510	150	89	780	220	140
5	520	190	91	710	250	120	1100	390	190
6	680	290	120	920	390	160	1400	610	250

Table 6-17. Surface Area Requirements for 5-μm Particle Size Control for Various Drop-tube Structures.

	8" diameter drop structure			12" diameter drop structure			18" diameter drop structure		
Head (ft)	Flow (cfs)	Storage (ac-ft)	Reqd. area (acres)	Flow (cfs)	Storage (ac-ft)	Reqd. area (acres)	Flow (cfs)	Storage (ac-ft)	Reqd. area (acres)
0.5	0.5	0.02	0.09	0.9	0.04	0.2	1.6	0.07	0.3
1	0.7	0.07	0.1	2.2	0.2	0.4	4.4	0.3	0.8
1.5	0.7	0.1	0.1	2.2	0.4	0.4	6.5	0.8	1.1
2	0.7	0.2	0.1	2.2	0.6	0.4	6.5	1.4	1.1
3	0.7	0.3	0.1	2.2	0.9	0.4	6.5	2.5	1.1
4	0.7	0.4	0.1	2.2	1.3	0.4	6.5	3.6	1.1
5	0.7	0.6	0.1	2.2	1.7	0.4	6.5	4.7	1.1
6	0.7	0.7	0.1	2.2	2.1	0.4	6.5	5.8	1.1
	24" diameter drop structure			30" diameter drop structure			36" diameter drop structure		
	Flow (cfs)	Storage (ac-ft)	Reqd. area (acres)	Flow (cfs)	Storage (ac-ft)	Reqd. area (acres)	Flow (cfs)	Storage (ac-ft)	Reqd. area (acres)
0.5	1.6	0.07	0.3	1.9	0.08	0.3	2.0	0.09	0.4
1	5.6	0.4	1.0	6.3	0.4	1.1	7.2	0.5	1.3
1.5	11	1.1	1.8	13	1.3	2.3	16	1.5	2.8
2	14	2.1	2.4	21	2.8	3.7	27	3.4	4.7
3	14	4.5	2.4	25	6.9	4.4	42	9.4	7.3
4	14	6.9	2.4	25	11	4.4	42	17	7.3
5	14	9.3	2.4	25	16	4.4	42	24	7.3
6	14	12	2.4	25	20	4.4	42	31	7.3

Table 6-18. Corrections for Needed Surface Areas for Particle Size Controls other than 5 μm.

Particle size for control (μm)	Typical percentage of particles larger than indicated size	Particle settling rate (cm/sec)	Required area multiplier, compared to 5 μm
1	100	1.5×10^{-4}	27
2	94	6×10^{-4}	6.7
5	88	4×10^{-3}	1.0
10	78	1.5×10^{-2}	0.27
20	62	6×10^{-2}	0.067
40	47	2×10^{-1}	0.02
100	28	8×10^{-1}	0.005

As an example, if a pond required a surface area of 3 acres at two feet above the lowest invert level, several outlet device options could be used to provide at least 5-μm critical particle size control:

All V-notch weirs from 22.5^{o} through 90^{o} (but not 120^{o})

Only a 2-foot-long rectangular weir
All drop tubes from 8” to 24”

Obviously, all stage levels have to be examined. The device selected must provide the desired level of control at the most critical stage (usually at the deepest depth). In most cases, the outlet device that has the largest capacity that meets the discharge requirements should be used. Under-sized discharge devices would likely cause increased flows and more frequent discharges through the emergency spillway, possibly causing a decrease in sediment trapping performance.

These procedures will treat, to the specified critical particle size, the largest storms that do not enter the emergency spillway to be treated to at least equal to the critical particle size specified. As an example, the above calculations focus on the 5 μm particle, at least, being controlled at the highest stage of the primary outfall structures in order to provide an approximate worst-case 5 μm control (90% annual control of suspended solids). The outfall device is selected to provide an outfall rate no greater than a critical value, which when divided by the pond surface area at that stage, will be no larger than the settling rate of the critical particle size. In almost all cases, the critical stage will be at the top of the primary outfall device, and all stages below that will more than meet the critical objective and will therefore be controlling particles much smaller than the critical size specified in the objective. It may seem that the pond is therefore over-designed and that the pond is larger than needed. However, the 5 μm critical particle size is typically substantially larger than the 90^{th} percentile particle size, and the added control provided at the lower stages in the pond is generally needed to provide this level of control on an annual basis. As indicated previously, the 90^{th} percentile particle size is typically only 3 μm, or smaller.

4) Emergency Spillway

An emergency spillway is always needed, even for temporary detention ponds at construction sites. Most local regulatory agencies will require an emergency spillway that is capable of discharging a specific design storm, typically in the range of 25 to 100-yr events, depending on the size of the pond and the extent of possible damage associated with failure. The typical procedure is to use HydroCAD or WinTR-55 to calculate the peak discharge for the large event. The graphical peak discharge method in TR-55 is commonly used to estimate the peak flow associated with the design storm, and the TR-55 “structure” methods are then used to estimate the emergency spillway design. WinTR-55 or HydroCAD can be used to check the size of the emergency spillway sized using the TR-55 procedures. This spillway design should consider the flows through the outlet device selected for water quality benefits also.

Vertical riser with inlet grate (MD photo) (normally the culvert discharge for the riser would be closer to the pond bottom to facilitate de-watering)

Temporary outlet made from timber placed at correct elevation and covered with plastic trap to protect spillway (Auckland Regional Council)

Vertical riser having multiple outlets and wrapped with geotextile fabric

Figure 6-25. Different sediment pond outlet structures.

Figure 6-26 shows that for Type II and III rains, the storage volume would have to be about 55% (0.55) of the runoff volume, if the peak runoff rate is to be reduced to 10% of its influent peak flow rate.

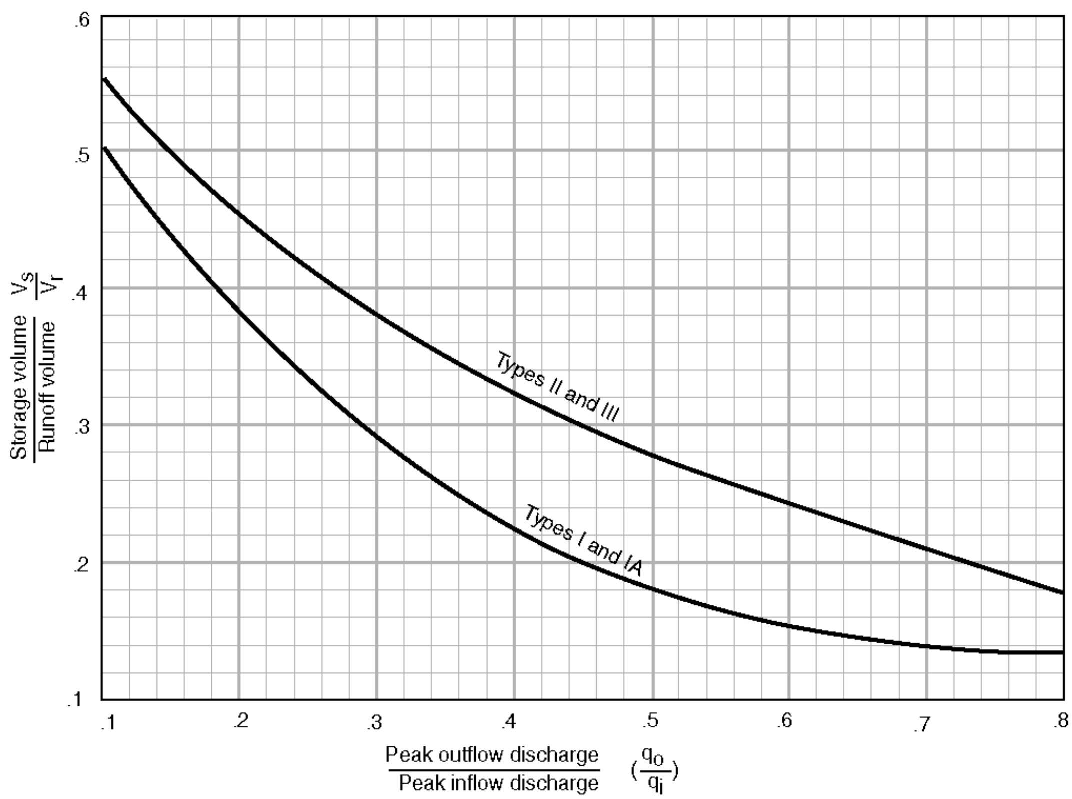


Figure 6-26. SCS TR-55 plot used to size additional freeboard needed for emergency spillway.

The SCS (now NRCS) methods can be used to size an emergency spillway. The pond is sized to provide the water quality benefits, and additional storage associated with the emergency spillway stage is V_S, read from Figure 6-26. The design storm volume that must safely be accommodated by the emergency spillway is taken as V_r. The ratio of these values can be used with this figure to estimate the peak flow attenuation that the pond will provide. The peak inflow discharge rate, q_i, can be estimated using the SCS graphical peak discharge method (or the tabular hydrograph method, WinTR-55, or HydroCAD). The peak outfall discharge, q_o, is then calculated based on the measured attenuation factor.

Example: Sizing an emergency spillway

Given: V_S = 1.53 acre-ft
V_r = 7.5 acre-ft
and V_S/V_r = 0.20

Find the necessary size for the emergency spillway.

For type II or III rain categories:

$q_o/q_i = 0.72$

If the calculated peak discharge rate entering the pond (q_i) = 8.7 cfs, the resulting peak discharge rate leaving the pond, q_o, (through the water quality primary outlet plus the emergency spillway) is therefore: 0.72 (8.7) = 6.3 cfs. TR-55 shows how to calculate the needed emergency spillway for a specific discharge goal, considering multiple outlet structures. This peak discharge rate is needed to size the emergency spillway, plus the additional freeboard that must be added to the pond design to accommodate the emergency spillway and desired outlet flow rate.

Example: Sizing a Compound Weir Structure

The following example illustrates a compound weir structure, having a drop tube for water quality control, plus a rectangular weir for the emergency spillway. In this example, $q_o = WQ_{out}$ + emergency $spillway_{out}$

Rain depth for the emergency spillway design (P) = 8 inches
CN = 86 (therefore, Ia = 0.0366)
Using the figure relating P and Q through the curve number (Chapter 3), the direct runoff (Q) = 6.2 inches, and Ia/P = 0.041
Area (A_m) = 0.021 mi^2 (13.2 acres)
T_c = 20 min (0.3 hr)

The peak unit discharge rate from the tabular hydrograph method is 498 csm/in

The peak discharge is therefore: (498 csm/in)(0.021 mi^2)(6.2 in) = 63.7 ft^3/sec

Also, the volume of runoff for this event is: V_R = [(6.2 in)(13.2 ac)]/12 in/ft = 6.82 ac-ft

As shown above, the pond surface area was determined to be about 0.4 acres at the permanent pool depth (the elevation for the water quality outlet invert). Table 6-17 confirms that a 12-inch drop tube structure would work for this pond over a wide range of stage conditions, while providing a desired worst case 5-µm particle control. The outlet flow rate for this drop tube is almost constant for heads of 1 to 6 ft (2.2 ft^3/sec). The required maximum discharge rate for this pond (for both the water quality outlet plus the emergency spillway) is 46.5 ft^3/sec. The ratio of the outlet to the inlet flow rate is therefore:

$q_o/q_i = 46.5/63.7 = 0.73$

The ratio of the storage volume (V_S) to the runoff volume (V_R), for Type II rains (from Figure 6-26) is 0.2, for this ratio of outlet to inlet peak flow rates. Using the rectangular weir discharge equation, the length (L_W in feet) of a rectangular weir, for a given stage (H_W in feet) and desired outflow rate (q_o in ft^3/sec) can be expressed as:

$$L_w = \frac{q_o}{3.2 H_w^{1.5}}$$

The desired q_o for the rectangular weir is 46.5 – 2.2 = 44.3 ft^3/sec. If the maximum stage for the emergency spillway is 1 ft, then length for the emergency spillway is:

$$L_w = \frac{q_o}{3.2 H_w^{1.5}} = \frac{44 ft^3/\sec}{3.2(1 ft)^{1.5}} = 13.8 ft$$

If the water quality outlet had varying discharge rates for different stages (as is common), then the stage for that outlet must also be known so the actual discharge rate contribution from that outlet to the total discharge rate objective can be used in the calculation. As an example, a 45° V-notch weir would be a suitable outlet for water quality control for this pond. This weir, for a 0.4-acre pond, would provide 5-µm control up to about 1.4 feet of head, for a 0.4-acre pond (assuming the associated storage volume is adequate). At this stage, the discharge rate from the 45° V-notch weir is about 2.5 ft^3/sec. With another foot of storage (as stage) for the maximum elevation of the emergency spillway (2.4 ft above the invert of the V-notch), the V-notch weir discharge rate would increase to about 10 ft^3/sec. The remaining discharge required to be handled by the emergency rectangular weir would therefore now be: 46.5 – 11 = 35.5 ft^3/sec, and the length for the emergency spillway would be:

$$L_w = \frac{q_o}{3.2 H_w^{1.5}} = \frac{35.5 ft^3/\sec}{3.2(1 ft)^{1.5}} = 11.1 ft$$

This method is known to be conservative with resulting over-sized emergency spillway storage values. A computer model (such as WinTR-55 or HydroCAD) should therefore be used to verify the performance of the desired pond configuration for a variety of storm conditions.

5) Other Pond Features

The ponds must also be constructed according to specific design guidelines to insure the expected performance and adequate safety, such as those provided by the US Bureau of Reclamation (1987). The guidelines need to specify such items as pond depth, side slopes, and shape.

Example Pond Design for Construction Site Sediment Control and Comparison with Modeling Results

Table 6-19 shows the conditions for an area on a construction site that requires a sediment pond. The drainage area, 53 acres, is mostly an active construction site, but some undeveloped land and paved areas also drain to the pond location. The pond therefore needs to be enlarged to accommodate the additional runoff from these areas. The table shows the drainage-area percentage needed for the pond, along with the pond volume to obtain approximately 90% suspended solids reductions.

Figure 6-27. Temporary construction site pond filled with sediment

Table 6-19. Size of Pond for Construction Area

	Area (acres)	% of area needed for pond surface	Pond surface area (acres)	Water quality volume (inches of runoff)	Pond volume (acre-inches)
Construction area	37	1.5%	0.56	0.6	22.2
Undeveloped area	14	0.5	0.07	0.3	4.2
Paved area	2	3.0	0.06	1.1	2.2
Total:	53		0.69		28.6

The total water quality volume ("live storage") of the pond is 28.6 acre-inches, or 2.38 acre-ft. The surface of the pond between events (during dry weather) is 0.69 acres, or about 1.3% of this drainage area. The top area of the pond during filling and drawdown, and associated side slopes, are calculated based on various assumed pond depths, as shown in a later example.

In this example, the pond depth is 3 ft, the side slopes are 12% and the top area is 0.9 acres. An additional 1 ft of storage to accommodate an emergency spillway is also provided, for a maximum top area needed of about 1 acre. The selection of the main discharge device is based on the water surface at the top of this water quality volume. From Table 6-15, a 12-inch vertical drop tube riser pipe, having its opening at the normal pond water surface level, would to be a good choice.

Three feet of standing water is needed above the maximum sediment depth in order to minimize scour. In addition, sacrificial sediment storage must also be provided in the pond. Using RUSLE, estimate the total construction period sediment load to the pond. Assume that the construction period is a half year, and that the following conditions apply:

R = 350
LS = 4.95 (based on typical slope lengths of 600 ft at 10% slope)
k = 0.28
C = 0.25 (assuming that ¼ of the construction site area is being actively being worked (probably about double too large for a 37-acre construction site considering some areas limit the active construction area to 5 acres at one time), and the rest of the area is effectively protected)

The calculated unit area erosion loss for this construction period is therefore about 243 tons per acre per year. Since the construction period is one-half year and the area is 37 acres, the total sediment loss is estimated to be about 4,490 tons. For a loam soil, this sediment volume is about 4,600 yd^3, assuming the conventional conversion factor of tons x 1.02 = yd^3 for a loam soil. The pond area at the bottom of the 3 ft of standing water is ½ acre, requiring about 2 ft of sediment storage. Table 6-20 lists the pond areas for each depth increment.

Table 6-20. Example Pond Profile

Pond depth (ft)	Pond area (acres)
0	0
1	0.35
2	0.50
3	0.57
4	0.63
5	0.70
6	0.77
7	0.73
8	0.90
9	0.97

This design was entered into WinDETPOND, a continuous water and sediment routing model for ponds (www.WinSLAMM.com) and evaluated for water quality benefits. Table 6-21 shows the program results for this pond. A series of rains ranging from 0.01 to 4.0 inches was used in the evaluation. The maximum pond stage is estimated to be about 7.4 ft for the 4-inch rain, more than a half foot below the broad-crested weir emergency spillway. The peak reduction factor (the reduction of the influent peak flow rate at the outfall) is very large for the small events, as expected, and still remains about 0.5 for the largest event. Ratios in this range will help reduce erosive flows to the receiving waters. The "event flushing ratio" indicates the volume of runoff entering the pond during each rain, compared to the water volume storage in the pond at the beginning of the rain (assuming the pond receded to its dry weather elevation). This pond flushing value is very small for the small events and increases to greater than 1 for rains larger than about 3 inches. The last two columns indicate sedimentation performance of the pond. The flow-weighted particle size in the effluent is greater than 4 μm after 3 inches of rain. However, the expected percentage suspended solids control (assuming the "low" particle size distribution – a very demanding particle size distribution that usually results in low removal estimates) remains greater than 80% for all rains less than about 2 inches. The worst case shown, for the 4-inch rain, drops down to less than 40% control.

Table 6-21. Summarized Results from WinDETPOND to Evaluate Detention Pond at Construction Site

```
DETPOND for Windows Version 8.4.1
(c) Copyright Robert Pitt and John Voorhees 1996
All Rights Reserved

Pond file name:  C:\PROGRAM FILES\WINDETPOND\EROSION CONTROL POND EXAMPLE.PND
Pond file description:  This is an example of an erosion control pond
Rain file name:  C:\Program Files\WinDetpond\BHAMSRCE.RAN
Date of run:  07-18-2002    Time of run:  22:59:47

Detention Pond Water Quality Performance Summary, by Event
```

Rain Number	Rain Depth (in)	Rain Duration (hrs)	Rain Intensity (in/hr)	Maximum Pond Stage (ft)	Event Inflow Volume (ac-ft)	Peak Reduction Factor (%)	Event Flushing Ratio	Flow-weighted Particle Size(Ideal)	% Part Solids Removed (Ideal)
1	0.01	3.00	0.00	5.00	0.000	1.00	0.000	0.0	100.0
2	0.05	7.00	0.01	5.00	0.002	0.99	0.001	0.0	100.0
3	0.10	8.00	0.01	5.01	0.007	0.99	0.003	0.1	99.8
4	0.25	10.00	0.02	5.07	0.052	0.99	0.022	0.1	99.5
5	0.50	12.00	0.04	5.19	0.137	0.97	0.059	0.3	98.9
6	0.75	14.00	0.05	5.30	0.230	0.94	0.099	0.5	98.2
7	1.00	14.00	0.07	5.42	0.342	0.90	0.147	0.7	96.7
8	1.50	14.00	0.11	5.64	0.610	0.85	0.262	1.2	88.5
9	2.00	14.00	0.14	5.87	0.939	0.78	0.403	1.8	80.2
10	2.50	14.00	0.18	6.26	1.528	0.67	0.656	2.9	68.1
11	3.00	14.00	0.21	6.64	2.266	0.57	0.973	4.0	57.2
12	4.00	14.00	0.29	7.37	4.014	0.50	1.724	6.5	39.1

As noted earlier in Chapters 3 and 4, most of the erosion potential is associated with the numerous moderate rains (greater than 1 inch) and the few large rains (up to 4 inches). This pond will likely provide 65 to 95+% control for the moderate rains but will drop off significantly for the largest rains. It is possible to improve the performance of the pond by changing the outlet weir to a smaller-capacity outlet, which would provide additional retention for the larger events. Table 6-22 illustrates how this temporary pond would affect the annual particulate solids losses from this construction site. The overall pond performance is expected to be about 75% effective, much less than the initial goal of 90% control. The performance of this pond could be improved if the design was better optimized for the larger, more erosive events. This could be done by choosing a more restrictive outlet device at higher pond stages and also by providing more storage (larger surface area and storage volume), for example.

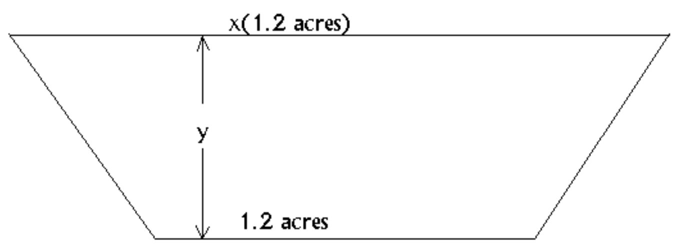
Table 6-22. Performance of Temporary Sediment Pond at Construction Site (Birmingham rains)

Rain range (inches)	Mid Point Rain (inches)	% of annual R in category	% particulate solids removed for pond	Weighted total annual particulate solids removal (%)
0.01 to 0.05	0.03	0.0	100	0
0.06 to 0.10	0.08	0.1	100	0.1
0.11 to 0.25	0.18	0.7	99.8	0.7
0.26 to 0.50	0.38	3.5	99.5	3.5
0.51 to 0.75	0.63	4.8	98.9	4.7
0.76 to 1.00	0.88	8.2	98.2	8.1
1.01 to 1.50	1.26	16.1	96.7	15.6
1.51 to 2.00	1.76	15.4	88.5	13.6
2.01 to 2.50	2.26	10.9	80.2	8.7
2.51 to 3.00	2.76	7.5	68.1	5.1
3.01 to 4.00	3.5	16.3	57.2	9.3
over 4.01	5.67	16.5	39.1	6.5
4583 events	41.5 years	100.0		75.9 % annual particulate solids removal

Example Detention Pond Shape Calculations

The following discussion presents a calculation example for determining pond depth and side slopes, assuming that the wet pond surface is 1.2 acres and the runoff volume for treatment is 6.3 acre-feet

The depth associated with the wet storage volume can be estimated assuming a prismatic cross-section (simplified, compared to a conical section):



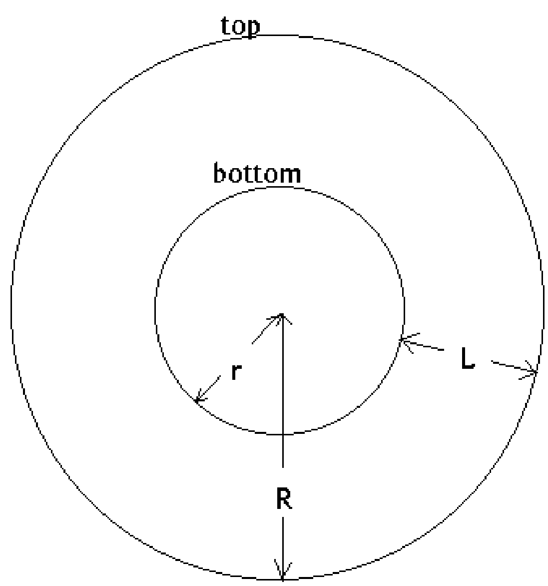
Approximately: [1.2 + x(1.2)]y/2 = 6.3 acre-ft.

Re-arranging gives: x = [(10.5)/y] - 1

The following table can be used to determine the top-area multiplier, x, for various depths of the “live storage” area of the pond (the section affected by the primary water quality outlet device and located on top of the permanent pool depth, and below the invert of the emergency spillway. This includes any additional storage needed for flood control), Once x is known, the top area is simply the bottom area multiplied by x.

y (depth, ft)	x (multiplier)	top area
2	4.3	4.3 (1.2 acres) = 5.2 acres
3	2.5	3.0 acres
4	1.6	1.9 acres
5	1.1	1.3 acres

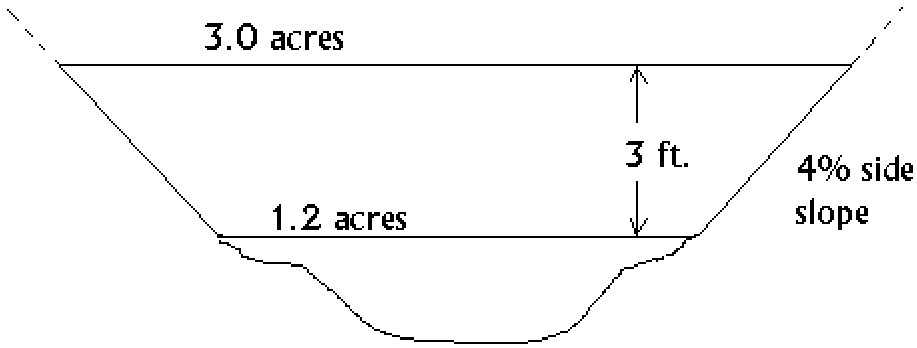
For this example, depths less than 2 feet are too shallow and would require much larger pond top surface areas. "Live depths" greater than 5 feet may be too deep for most locations and result in very steep side slopes for this example. If an approximate circular pond is assumed, the following table summarizes the calculations for the side slopes of the pond for different alternative depths.



$r = (A/\pi)^{1/2} = [1.2\text{acres}(43{,}560\ \text{ft}^2\ \text{per acre})/\pi)]^{1/2} = 130\ \text{ft}$

Depth (ft)	Top Area (acres)	Top Radius (ft)	Slope Length (ft)	Side Slope
2	5.2	270	270 - 130 = 140	2/140 = 1.4%
3	3.0	200	200 - 130 = 70	3/70 = 4.3%
4	1.9	160	160 - 130 = 30	4/30 = 13%
5	1.3	135	135 - 130 = 5	5/5 = 100%

Generally, the pond side slopes should be in the range of about 10 to 25% (steep enough to provide good drainage, but not so steep to cause potential safety problems). This example uses 3 ft depth with a corresponding side slope of about 4%, perhaps a bit shallow but deemed sufficient for this purpose and to better fit the site characteristics. The preliminary pond cross-section is



The outfall device is selected by comparing the maximum allowable discharge rate for the surface area of the pond (surface overflow rate) at several pond depth increments. These maximum allowable discharges are compared with weir ratings (as tabulated previously, for example) to select the permissible weirs that can be used:

$Q_{out} = vA$
$v = 1.3 \times 10^{-4}$ ft/sec for 5 μm particle

Stage (above normal water surface, ft)	Pond Area (acres)	Maximum Allowable Discharge (cfs)
0	1.2	6.8
0.5	1.5	8.5
1	1.8	10
1.5	2.1	12
2	2.4	14
3	3.0	17 (usually most critical)

Hence, a single 45° V-notch weir, or two 22-1/2° V-notch weirs, from Table 6-15, are suitable outlet choices.

The emergency spillway (mandatory) and additional flood control storage volume (if necessary) would be selected using NRCS TR-55 (SCS 1986) procedures.

Example Sizing of Sediment Pond at Construction Site

This example problem considers the sizing of all the main components of a sediment pond at a construction site:

- the basic pond area,
- the "live" storage volume,
- the pond side slopes, top surface area, and "dead storage" volume,
- the selection of the primary discharge device,
- the additional storage volume needed for the emergency spillway,
- the sizing of the emergency spillway, and
- the sacrificial storage volume for sediment accumulation.

Consider the following site information:
The pond performance goal is 90% suspended-solids removal. The pond needs to safely pass the flows from the 25-yr storm. The area is characterized by clayey soils. The following are the areas associated with each land use in the drainage area:

- paved areas: 0.2 acres
- undeveloped areas: 1.2 acres
- construction area: 32 acres
- total site area: 33.4 acres

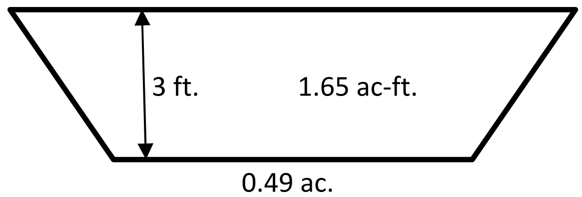
Table 6-23. Basic pond area and "live" storage volume calculations

Site Subarea	Pond Surface Area (acres)	Pond "Live" Volume, runoff from 1.25 inches of rain fall (acre- inches of runoff)
paved area (0.2 acres)	3% of 0.2 acres = 0.006 acres	1.1 inches x 0.2 acres = 0.22 ac-in
undeveloped area (1.2 acres)	0.6% of 1.2 acres = 0.007 acres	0.3 inches x 1.2 acres = 0.36 ac-in
construction area (32 acres)	1.5% of 32 acres = 0.48 acres	0.6 inches x 32 acres = 19.2 ac-in
Total:	0.49 acres	19.8 ac-in = 1.65 ac-ft

<u>Pond side slopes and top surface area:</u>

1) If 3 ft deep:

Top area:



$$\frac{(0.49\,acres + X)3\,ft}{2} = 1.65\,ac - ft$$

$X = 0.61 acres$

at 0.61 acres:

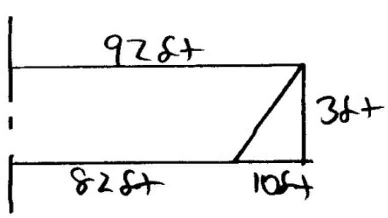
$\pi r^2 = 26{,}570\ ft^2$

r = 92 ft

at 0.49 acres:

$\pi r^2 = 21{,}340 ft^2$

r = 82 ft



side slope = 3 ft/(92-82 ft) = 3 ft/10 ft = 0.3 = 30%   too steep

2) If 1 ft deep:

Top area:

$$\frac{(0.49\,acres + X)1\,ft}{2} = 1.65\,ac - ft$$

$$X = 2.81\,acres$$

at 2.81 acres:

$$\pi r^2 = 122{,}400\,ft^2$$

r = 197 ft

at 0.49 acres, r = 82 ft

side slope = 1 ft/(197-82 ft) = 1 ft/115 ft = 0.012 = 1.2% too shallow

3) If 2 ft deep:

Top area:

$$\frac{(0.49\,acres + X)2\,ft}{2} = 1.65\,ac - ft$$

$$X = 1.16\,acres$$

at 1.16 acres:

$$\pi r^2 = 50{,}530\,ft^2$$

r = 126 ft

at 0.49 acres, r = 82 ft

side slope = 2 ft/(126-82 ft) = 2 ft/44 ft = 0.045 = 4.5% suitable, but on the low side

Selection of primary outlet device:
At the top of the live storage volume, this pond will have provided 2 ft of stage and 1.16 acres of maximum pond surface area.

According to the weir discharge table (Table 6-15), a 45° V-notch weir requires at least 1.0 acre of pond surface at 2 feet of stage in order to provide about 90% control of sediment. A 30° V-notch weir would require only 0.7 acres, while a 60° V-notch weir would require at least 1.4 acres. None of the rectangular weirs would be suitable, as the smallest 2 ft weir requires at least 2.6 acres at 2 feet of stage. The 45°

weir is closest to the area available and is therefore selected for this pond. Another suitable outlet structure would be an 18" drop tube structure which requires at least 1.1 acres.

<u>Sacrificial storage volume:</u>
Calculate the sediment loss for the complete construction period for the site area draining to the pond. Chapter 4 describes how to calculate the sediment loss for different phases of the construction period and for different areas of the site. For a simple analysis, assume the following typical site conditions:

R = 350
LS = 1.28 (based on typical slope lengths of 300 ft at 5% slope)
k = 0.28
C = 0.24 (assuming that 5 of the 32 acres of the construction area is being actively worked with a C=1, and the other 27 acres of the construction area is effectively protected with a C=0.1)

The calculated unit area erosion loss for this construction period is therefore:

(350)(1.28)(0.28)(0.24) = 30 tons per acre per year.

Since the construction period is for one year and the active construction area is 32 acres, the total sediment loss is estimated to be about 960 tons. For a loam soil, the sediment volume is about 980 yd^3, or 0.8 acre-ft, assuming the conventional conversion factor of tons x 1.02 = yd^3 for a loam soil.

The pond water surface is approximately 0.5 acres. With a three-foot-deep dead storage depth to minimize scour, the surface area at the bottom of this 3 ft scour protection zone (and the top of the sediment storage zone), can be about 0.35 acres (about 25% underwater slope).

The sacrificial storage zone can be about 3 ft deep also, resulting in a bottom pond area of about 0.18 acre, as shown in the following calculations:

Top of sacrificial storage area is 0.35 acres, and at 0.35 acres:

$$\pi r^2 = 15{,}250 ft^2$$

r = 70 ft

Therefore, the area of the bottom of the sacrificial storage area needed to provide 0.8 acre-ft of storage, if 3 feet deep can be approximated by:

$$\frac{(0.35 acres + X)3 ft}{2} = 0.8 ac - ft$$

$$X = 0.18 acres$$

at 0.18 acres, r = 50 ft

side slope = 3 ft/(70-50 ft) = 3 ft/20 ft = 0.15 = 15%

These sediment storage volumes assume average conditions and provide no factor of safety. If an unusually severe rainy period occurs, it may be necessary to dredge the pond and provide other major maintenance before the end of the construction period.

<u>Selection of emergency spillway:</u>
TR-55 can be used to estimate the peak flood flow rate that the emergency spillway must accommodate. Since these ponds are generally temporary, the design storm is usually smaller than for permanent stormwater ponds (which are commonly designed as control up to the 100-year event). Also, temporary ponds usually do not include an attenuated flow rate goal, like permanent ponds. These flow rate goals for permanent ponds need to be based on comprehensive basin-wide hydraulic analyses to be effective. Therefore, this example will only consider the capacity of the emergency spillway to meet the design storm flow rate. The design storm for this pond will be the 25-year event (one that has a 4% probability of occurring in any one year). The time of concentration of this small watershed was previously calculated to be 12minutes. The watershed characteristics affecting the peak flow rate are therefore:

- Watershed area: construction area (32 acres), paved area (0.2 acres), and undeveloped area (1.2 acres) = 33.4 acres = 0.052 mi^2
- Clayey (hydrologic soil group D) soils
- Time of concentration (Tc): 12 minutes (0.2 hours). Since the pond is at the bottom of this watershed, there is no “travel time” through down-gradient subwatershed areas.
- Rain intensity for a “25-year” rain for the Birmingham, AL, area, with a 12-minute time of concentration (from the local IDF curve, Figure 6-28): 6.6 inches/hour (Type III rain)

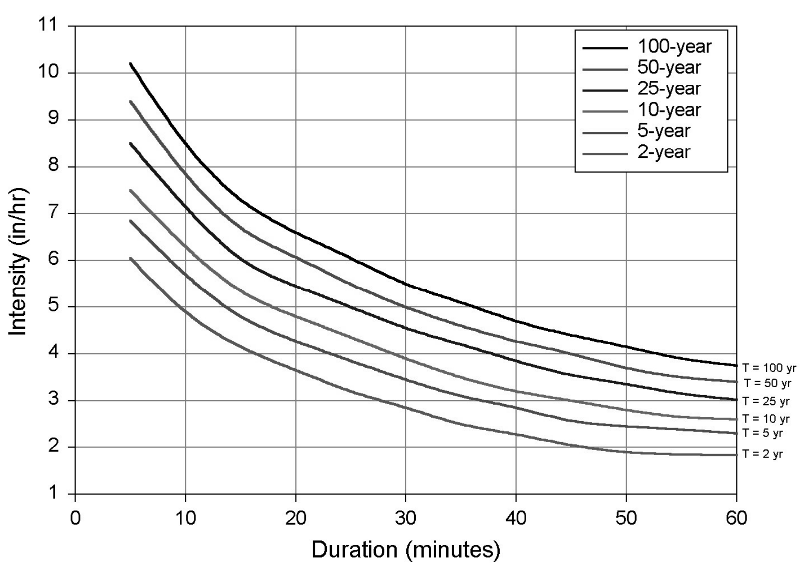


Figure 6-28. Historical intensity, duration, and frequency (IDF) curve for Birmingham, AL (from National Weather Service, Hydro-35)

Since the undeveloped area has such a comparatively low CN and it is a very small fraction of the site, it will be ignored for these example calculations. The flows from the undeveloped area will be very low and will enter the pond after the flows from the other areas. If the undeveloped area was a significant fraction of the watershed area, it should be examined as a separate subwatershed and the resulting hydrographs combined. Ignoring the undeveloped area, the weighted curve number is therefore estimated to be:

$$CN_W = \left(\frac{32}{32.2}\right)(94) + \left(\frac{0.2}{32.2}\right)(98) = 94$$

The initial abstraction (Ia) for this curve number (from Table 6-24) is 0.128 inches. The 24-hour, 25-year rain has a total rain depth (P) of 6.9 inches. The Ia/P ratio is therefore: 0.128/6.9 = 0.019, which is much less than 0.1. Therefore, the tabular hydrograph table to be used would be Exhibit III, corresponding to a Tc of 0.2 hour. The top segment of "csm/in" (cubic feet per second per square mile of watershed per inch of direct runoff) values are therefore used, corresponding to Ia/P values of 0.1, or less. The top row is also selected as there is no travel time through downstream subwatersheds. Examining this row, the largest value is 565 csm/in, occurring at 12.3 hours. The amount of direct runoff for a site having a CN of 94 and a 24-hr rain depth of 6.9 inches is 6.2 inches (from Figure 6-29). The A_mQ value (area in square miles times the direct runoff in inches) for this site is: (0.052 mi^2)(6.2 inches) = 0.32 mi^2-in. This value is multiplied by the csm value to obtain the peak runoff rate for this design storm: (0.32 mi^2-in)(565 csm/in) = 182 ft^3/sec.

Table 6-24. I_a Values for Runoff Curve Numbers (SCS 1986)

Curve Number	I_a (inch)	Curve Number	I_a (inch)	Curve Number	I_a (inch)
40	3.000	60	1.333	80	0.500
41	2.878	61	1.279	81	0.469
42	2.762	62	1.226	82	0.439
43	2.651	63	1.175	83	0.410
44	2.545	64	1.125	84	0.381
45	2.444	65	1.077	85	0.353
46	2.348	66	1.030	86	0.326
47	2.255	67	0.985	87	0.299
48	2.167	68	0.941	88	0.273
49	2.082	69	0.899	89	0.247
50	2.000	70	0.857	90	0.222
51	1.922	71	0.817	91	0.198
52	1.846	72	0.778	92	0.174
53	1.774	73	0.740	93	0.151
54	1.704	74	0.703	94	0.128
55	1.636	75	0.667	95	0.105
56	1.571	76	0.632	96	0.083
57	1.509	77	0.597	97	0.062
58	1.448	78	0.564	98	0.041
59	1.390	79	0.532		

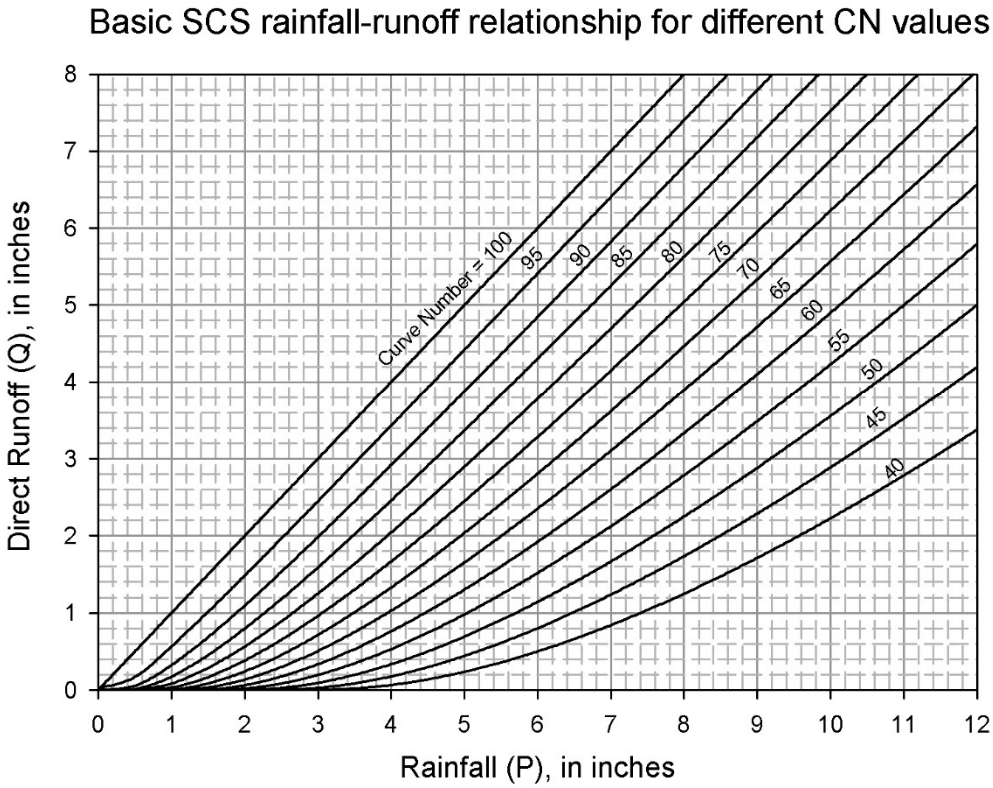


Figure 6-29. Basic SCS rainfall-runoff relationship for different CN values (SCS 1986).

The first trial for an emergency spillway will be a rectangular weir, with one foot of maximum stage. At the one foot of stage for this weir plus the spillway, the 45° V-notch weir will have a total of 3 feet of stage. The V-notch weir will discharge 16 ft^3/sec at this stage. Therefore, the rectangular weir will need to handle: 182 – 16 ft^3/sec = 166 ft^3/sec. The rectangular weir can be sized from the rectangular weir equation presented earlier:

$$L_w = \frac{q_o}{(3.2)(H_w)^{1.5}} = \frac{166\, ft^3/\sec}{(3.2)(1)^{1.5}} = 52\, ft$$

This may be large for this pond because it may not be practical to protect the discharge embankment from erosion nor easy to collect and route the flow from such a wide weir, so another alternative is to try for a rectangular weir having 2 ft of maximum stage. At this elevation (4 ft total), the 45° V-notch weir will discharge 33 ft^3/sec. Therefore, the rectangular weir will need to handle: 182 – 33 ft^3/sec = 149 ft^3/sec. The rectangular weir can be sized from the rectangular weir equation presented earlier:

$$L_w = \frac{q_o}{(3.2)(H_w)^{1.5}} = \frac{149\, ft^3/\sec}{(3.2)(2)^{1.5}} = 16\, ft$$

This is a suitable length but does result in an additional foot of pond depth. For this example, the 52-foot-long weir is selected.

<u>Final pond profile and expected performance:</u>
This pond therefore has the shape, and outlet structures shown of Table 6-25.

Table 6-25. Final Pond Profile

Pond Depth (ft from bottom of pond, the datum)	Surface Area at Depth (acres)	Pond Storage below Elevation (calculated by Detpond) (acre-ft)	Pond slope between this elevation and next highest noted elevation	notes
0	0	0	-	the pond bottom (datum) must be 0 acres for the routing calculations
0.1	0.18	-	15%	the area close to the bottom can be the calculated/desired pond bottom area. This is the bottom of the sacrificial storage area for the sediment
3	0.35	0.8	25%	this is the top of the sacrificial storage area for the sediment
6	0.49	2.0	4.5%	this is the bottom of the “dead” storage area, at least 3 feet above the pond bottom (this is 6 feet above the absolute bottom, but is 3 feet above the top of the maximum sediment accumulation depth)
8	1.16	3.7	4.5%	this is the bottom (invert) of the water quality outlet structure (and live storage volume), a 45° V-notch weir
9	1.5	5.0	4.5%	this is the top of live storage volume, and the bottom of the emergency spillway, a 52 ft long rectangular weir
10	1.8	6.7	-	1 foot of freeboard above maximum expected water depth, the top of the pond

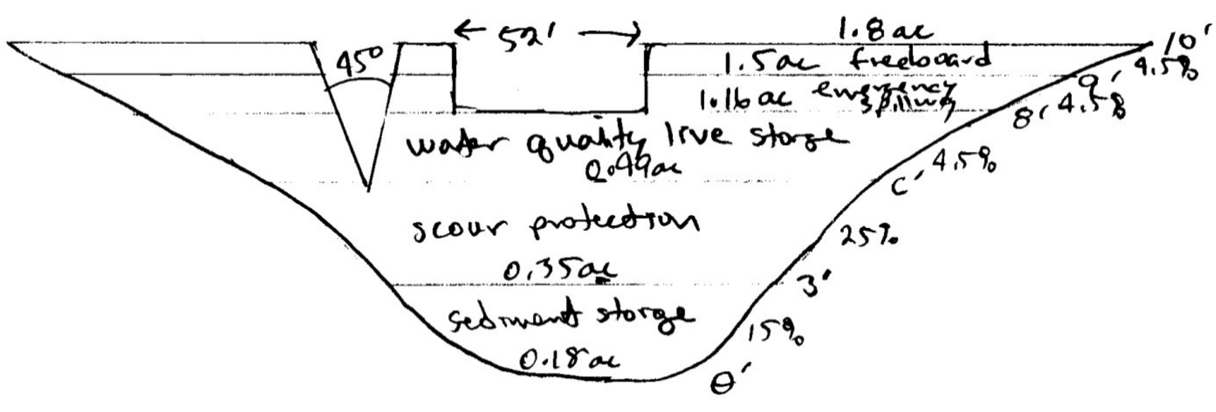


Figure 6-30. Pond profile.

In summary, this pond has a total of 3 acre-ft of live storage, plus the needed 0.8 acre-ft for sediment storage. Table 6-26 summarizes the results of modeling the pond using WinDETPOND (www.WinSLAMM.com). This example shows the expected pond performance for a variety of rain depths, ranging from very small rains to larger events. The maximum pond stages reflect the maximum depth of water in the pond during these events (out of the total 10 feet available). The pond has very high levels of control (using the “medium” particle size distribution) for most events.

Table 6-26. Pond Performance by Rain Depth

Rain Depth (in)	Maximum Pond Stage (ft)	Event Inflow Volume (ac-ft)	Peak Reduction Factor (Fraction)	Event Flushing Ratio	Flow-weighted Particle Size (µm)	Particulate Solids Removed (%)
0.01	6	0	0.98	0	0	100
0.05	6	0	0.97	0	0	100
0.1	6	0.001	0.96	0	0.1	99.9
0.25	6.02	0.014	0.96	0.007	0.2	99.8
0.5	6.07	0.043	0.95	0.02	0.3	99.7
0.75	6.14	0.085	0.95	0.041	0.4	99.6
1	6.21	0.134	0.93	0.064	0.5	99.5
1.5	6.36	0.263	0.88	0.126	0.8	98.9
2	6.51	0.435	0.83	0.209	1.2	97.3
2.5	6.78	0.785	0.74	0.377	1.9	94.4
3	7.05	1.236	0.65	0.593	2.7	91.4
4	7.52	2.325	0.53	1.115	4.4	84.8

The continuous simulation feature of WinDETPOND allows the user to predict the overall pond performance based on actual rain records. Table 6-27 summarizes the pond performance for a 30-year period of rain (3,346 events, ranging from 0.01 to 13.6 inches). During these 30 years, the expected maximum pond stage was slightly more than 8 ft. The emergency spillway was used a total of four times in this period (generally, expected flows through an emergency spillway of about twice a year is reasonable for such small structures). The flow-weighted particulate solids removal rate was approximately 92%. Therefore, this pond is likely over-designed for these conditions and could be somewhat reduced in area and depth.

Table 6-27. Pond Performance Summary

	Maximum Pond Stage (ft)	Event Inflow Volume (ac-ft)	Peak Reduction Factor (Fraction)	Event Flushing Ratio	Flow-weighted Particle Size (µm)	Particulate Solids Removed (%)
Maximum	8.1	23	0.99	11	6.8	100
Average	6.2	0.10	0.64	0.05	n/a	n/a
Flow-weighted Average	n/a	n/a	0.62	1.4	2.6	92
Median	6.1	0.012	0.87	0.0057	0.39	99.6
Standard Deviation	0.22	0.54	0.40	0.26	0.57	1.9
COV	0.035	5.1	0.63	5.1	1.1	0.019

Sediment ponds are commonly used at construction sites, and most guidance manuals have included information on their construction and use. The following sidebar is an excerpt from the *Alabama Handbook* (ASWCC 2018) as an example of typical guidance in current guidance manuals, especially incorporating some new features for enhanced performance:

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Sidebar: "Practice Description

An earthen embankment suitably located to capture runoff, with an emergency spillway lined to prevent spillway erosion, interior porous baffles to reduce turbulence and evenly distribute flows, and equipped with a floating skimmer or other approved surface dewatering device that removes water from the top of the basin. Flocculants are commonly used with a sediment basin to increase sediment capture.

Planning Considerations

Sediment basins are needed where drainage areas are too large for other sediment control practices.

Select locations for basins during initial site evaluation. Locate basin so that sudden failure should not cause loss of life or serious property damage. Install sediment basins before any site grading takes place within the drainage area.

Select sediment basin sites to capture sediment from all areas that are not treated adequately by other sediment control measures. Always consider access for cleanout and disposal of the trapped sediment. Locations where a pond can be formed by constructing a low dam across a natural swale are generally preferred to sites that require excavation. Where practical, divert sediment-free runoff away from the basin.

Because the emergency spillway is actually used relatively frequently, it is generally stabilized using geotextile and riprap that can withstand the expected flows without erosive velocities. The spillway should be placed as far from the inlet of the basin as possible to maximize sedimentation before discharge. The spillway should be located in natural ground (not over the embankment) to the greatest extent possible.

The use of approved flocculants properly introduced into the turbid runoff water at the inlet of the basin and/or at the first baffle should be considered to help polish the discharge from the basin for meeting turbidity requirements. A fore bay or sump area prior to the basin should be considered for capture of heavier particles.

Baffles

Porous baffles effectively spread the flow across the entire width of a sediment basin or trap and cause increased deposition within the basin. Water flows through the baffle material, but is slowed sufficiently to back up the flow, causing it to spread across the entire width of the baffle (Figure 6-31). Spreading the flow in this manner utilizes the full cross section of the basin and reduces turbulence which shortens the time required for sediment to be deposited.

The installation should be similar to a sediment barrier (silt fence) (Figure 6-32) utilizing posts and wire backing. The most proven material for a baffle is 700 – 900 g/m2 coir erosion blanket (See following picture). Other materials proven by research to be equivalent in this application may be used. A support wire or rope across the top will help prevent excessive sagging if the material is attached to it with appropriate ties. Another option is to use a sawhorse type of support with the legs stabilized with rebar inserted into the basin floor. These structures work well and can be prefabricated off site and quickly installed.

Baffles need to be installed correctly in order to fully provide their benefits. Refer to Figure 6-32 and the following key points:

- The baffle material needs to be secured at the bottom and sides by using staples or stakes, trenching, or securing horizontally to the bottom. Flow should not be allowed under the baffle.

- Most of the sediment will accumulate in the first bay, so this should be readily accessible for maintenance.

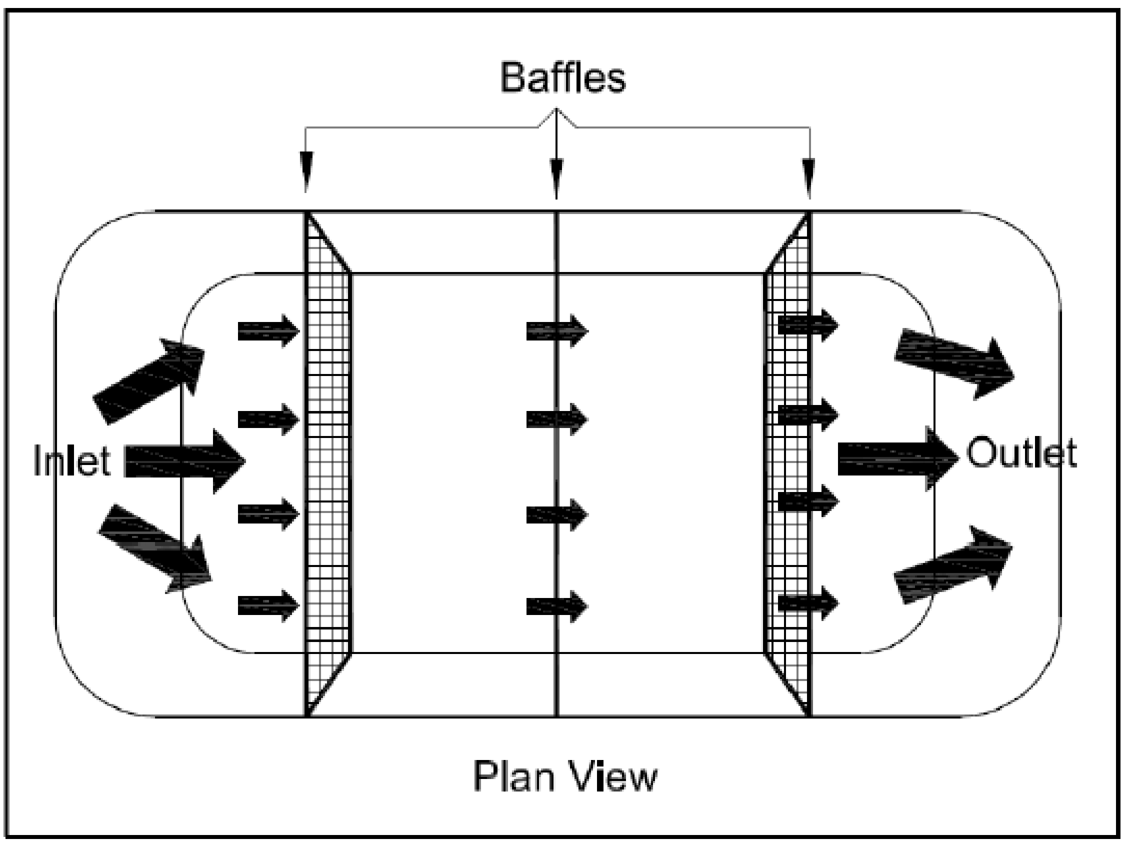


Figure 6-31. Porous baffle in a sediment basin
(from North Carolina Erosion and Sediment Control Planning and Design Manual.)

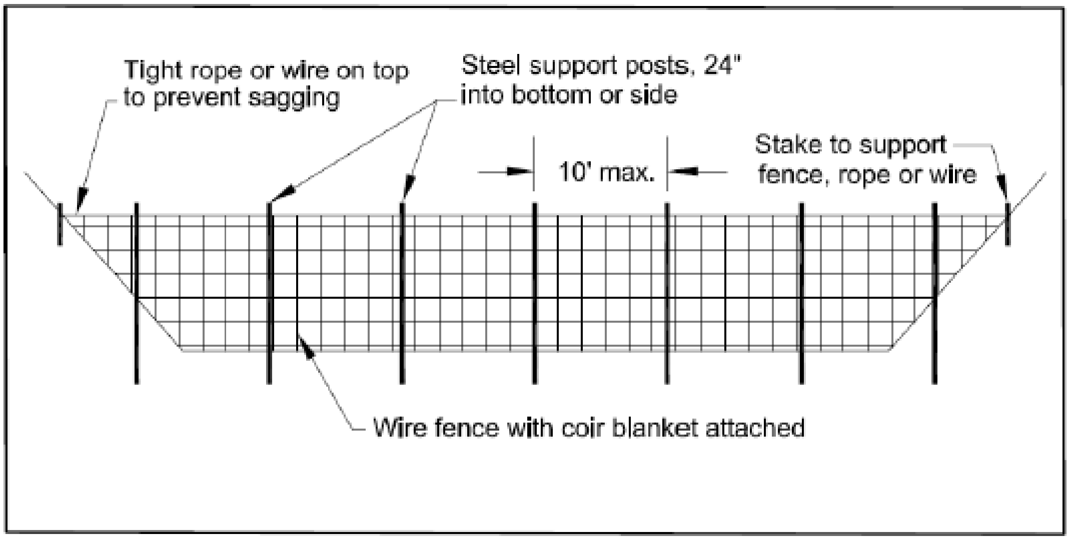


Figure 6-32. Cross-section of a porous baffle in a sediment basin. Note there is no weir because the water flow through the baffle material.
(from North Carolina Erosion and Sediment Control Planning and Design Manual.)

Figure 6-33. Example of porous baffle made of 700 g/m^2 coir erosion blanket as viewed from the inlet

Basin Dewatering

Sediment basins should be dewatered from the surface. A device often used for this is a skimmer that withdraws water from the basin's water surface, thus removing the highest quality water for delivery to the uncontrolled environment. One type of skimmer is shown in Figure 6-34. By properly sizing the skimmer's control orifice, the skimmer can be made to dewater a design hydrologic event in a prescribed period.

An advantage of the skimmer is that it can be reused on future projects. Skimmers are generally maintenance free, but may require occasional maintenance to remove debris from the orifice.

All basin dewatering devices must dewater the basin from the top of the water surface. The rate of dewatering must be controlled. A dewatering time of 48 to 120 hours (2 to 5 days) is required for the basin to function properly.

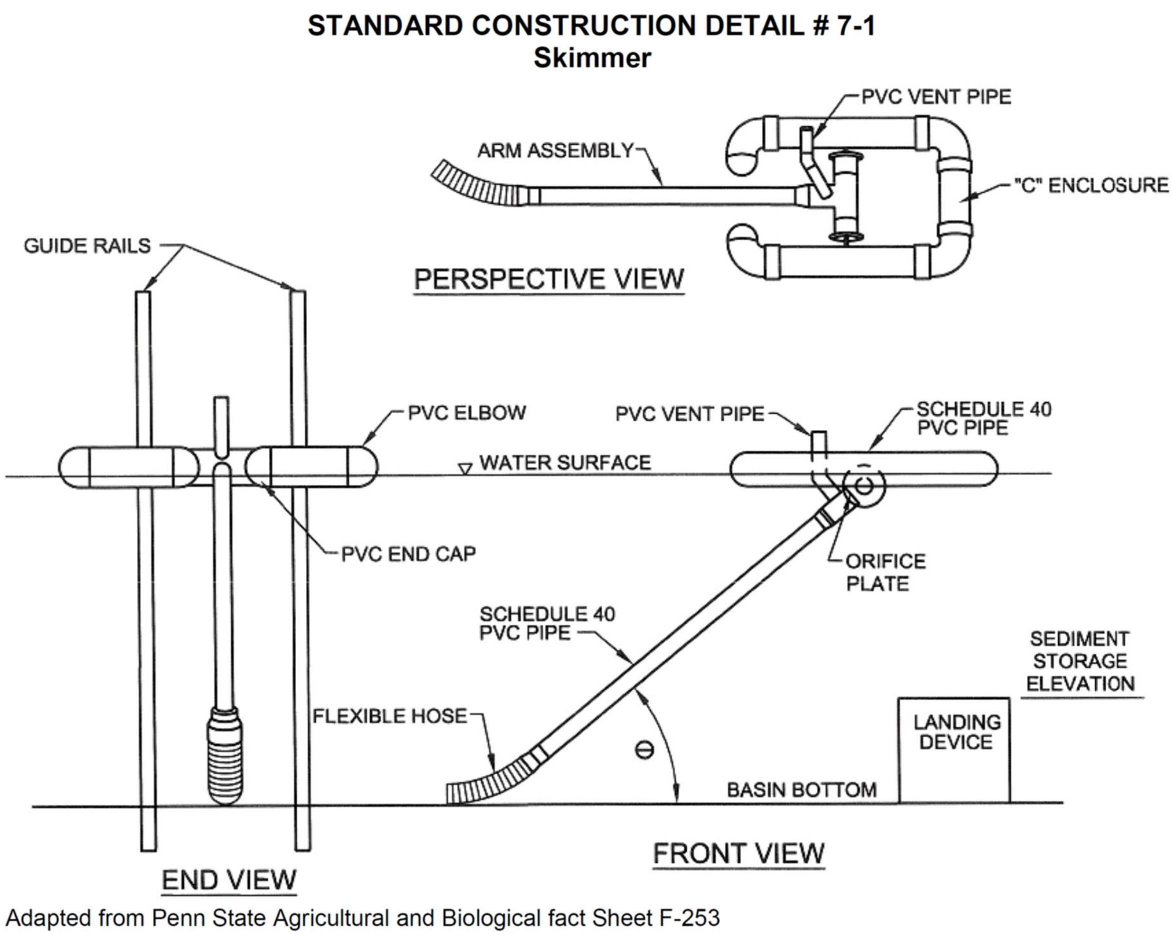


Figure 6-34. Schematic of a skimmer
(from Pennsylvania Erosion and Sediment Control Manual, 2012)

Design Criteria

Summary:	Temporary Sediment Trap
Emergency Spillway:	Trapezoidal spillway with non-erosive lining. 10 – year, 24 – hour rainfall event
Recommended Maximum Drainage Area:	10 acres
Minimum Volume:	3,600 cubic feet per acre of drainage area
Minimum L/W Ratio:	2:1
Minimum Depth:	2 feet
Dewatering Mechanism:	Skimmer(s) or other approved basin dewatering device.
Dewatering Time:	2 – 5 days
Baffles Required:	3

Compliance with Laws and Regulations
Design and construction should comply with state and local laws, ordinances, rules and regulations.

Design Basin Life
Structures intended for more than 3 years of use should be designed as permanent structures. Procedures outlined in this section do not apply to permanent structures.

Dam Height
In order to ensure public safety, the maximum dam height should be 10 feet, measured from the designed (settled) top elevation of the dam to the lowest point at the downstream toe.

Drainage Area
In order to minimize risk to the public and environment, the maximum drainage area for each sediment basin should be minimized. The recommended maximum drainage area is 10 acres. The absolute maximum drainage area should be 100 acres.

Basin Locations
Select areas that:

- Are not intermittent or perennial streams
- Allow a maximum amount of construction runoff to be brought into the structure
- Provide capacity for storage of sediment from as much of the planned disturbed area as practical
- Exclude runoff from undisturbed areas where practical
- Provide access for sediment removal throughout the life of the project
- Interfere minimally with construction activities

Basin Shape
Ensure that the flow length to basin width ratio is 2:1 or larger to improve trapping efficiency. Length is measured at the elevation associated with the minimum storage volume. Generally, the bottom of the basin should be level to ensure the baffles function properly. The area between the inlet and first baffle can be designed with reverse grade to improve the trapping efficiency.

Research has shown that the surface area of the basin should be maximized to improve trapping efficiency. Results of tests show that a surface area of 435 sq. ft. per CFS (peak discharge for the 10-year, 24-hour event), is needed for effective trapping efficiency.

Storage Volume
Ensure that the sediment storage volume of the basin is at least 3,600 cubic feet per acre for the area draining into the basin. Volume is measured below the emergency spillway crest. Remove sediment from the basin when approximately one-half of the storage volume has been filled.

Baffles
Space the baffles to create equal zones of volume within the basin.

The top of the baffle should be the same elevation as the maximum water depth flowing through the emergency spillway. Baffles are most effective at a height of 3 feet; however, site conditions may warrant taller baffles.

Baffles should be designed to go up the sides of the basin banks so water does not flow around the baffles. Most of the sediment will be captured in the inlet zone. Smaller particle size sediments are captured in the latter cells.

The design life of the fabric can be up to 3 years, but may need to be replaced more often if damaged or clogged.

Spillway Capacity
The emergency spillway system must carry the peak runoff from the 10-year 24- hour storm with a minimum 1 foot of freeboard (distance between the surface of the water with the spillway flowing full and the top of the embankment). Base runoff computations on the most severe soil cover conditions expected in the drainage area during the effective life of the structure.

Sediment Cleanout Elevation
Determine the elevation at which the invert of the basin would be half-full. This elevation should also be marked in the field with a permanent stake set at this ground elevation (not the top of the stake).

Basin Dewatering
The basin should be provided with a surface outlet. A floating skimmer should be attached to a Schedule 40 PVC barrel pipe of the same diameter as the skimmer arm. The skimmer apparatus will control the rate of dewatering. The skimmer should be sized to dewater the basin in 48-120 hours (2-5 days). The barrel pipe should be located under the embankment with at least one anti-seep collar at the center of the embankment projecting a minimum of 1.5 ft in all directions from the pipe. A drainage diaphragm can be used in lieu of an anti-seep collar. The barrel pipe outlet must be stable and not cause erosion.

Skimmer Orifice Diameter
<u>Skimmer Selection Procedure</u>

The manufacturer's skimmer performance charts are recommended for use in selecting skimmers for use in dewatering sediment control basins. Always verify performance with the manufacturer's information.

Required input data:

Basin volume = ________ ft3

Desired dewatering time = ________ days

Procedure:

1. First use the basin volume (ft3) and the desired dewatering time (days) and determine the required skimmer outflow rate in cubic feet per day (ft3/d) from the following equation

2. Scan the manufacturer's skimmer performance charts and select the (a) skimmer size and (b) the skimmer orifice diameter (in inches) if desired.

Example: Select a skimmer that will dewater a 20,000 ft^3 sediment basin in 3 days.

Solution: First compute the required outflow rate as

$$Q = \frac{V}{t_d} = \frac{20000 ft^3}{3\ days} = 6670\ ft^3/day$$

Now go to the manufacturer's selection charts and select an appropriate skimmer. For example, a 2-inch skimmer with no orifice could have an outflow rate of 5,429 ft^3/d, which will require about 3.5 days to dewater the basin. A 4-inch skimmer with a 2.5 inch diameter orifice could have an outflow rate of 8,181 ft^3/d and dewater the basin in about 2.5 days.

Example: A More Precise Alternative: Most skimmers come with a plastic plug that can be drilled forming a hole that will limit the skimmer's outflow to any desired rate. Thus, for a specific skimmer the orifice that will dewater a basin in a more precisely chosen time can be determined. The flow through an orifice can be computed as

$$Q = CA\sqrt{2gH}$$

where C is the orifice coefficient (usually taken to be 0.6), A is the orifice crosssectional area in ft^2, g is the acceleration of gravity (32.2 ft/sec^2), and H is the driving head on the orifice center in feet. The orifice equation can be simplified to yield the orifice flow in gpm using the diameter D (in inches) and the head in feet as

$$Q = 12D^2\sqrt{H}$$

Or the orifice flow in ft^3/d using the diameter D (in inches) and the head in feet as

$$Q = 2310D^2\sqrt{H}$$

If we solve the orifice equation for the orifice diameter using the desired outflow rate (6670 ft^3/d) and the head driving water through the skimmer (0.333 ft for a 4- inch skimmer) as

$$D = \sqrt{\frac{Q}{2310\sqrt{H}}} = \sqrt{\frac{6670}{2310\sqrt{0.333}}} = 2.24\ inches$$

We see that if the plastic plug were drilled to a diameter of 2.24 inches and placed in a 4-inch skimmer, the dewater rate would be 6,670 ft3/d and the 20,000 ft3 basin would dewater in 3 days.

Outlet Protection
Provide outlet protection to ensure erosion does not occur at the pipe outlet.

Basin Emergency Spillway
The emergency spillway should carry the peak runoff from a 10-year storm. The spillway should have a minimum 10 foot bottom width, 0.5 foot flow depth, and 1 foot freeboard above the design water surface.

Construct the entire flow area of the spillway in undisturbed soil to the greatest extent possible. Cross section should be trapezoidal, with side slopes 3:1 or flatter for grass spillways (Figure 6-35) and 2:1 for riprap. Select vegetated lining to meet flow requirements and site conditions.

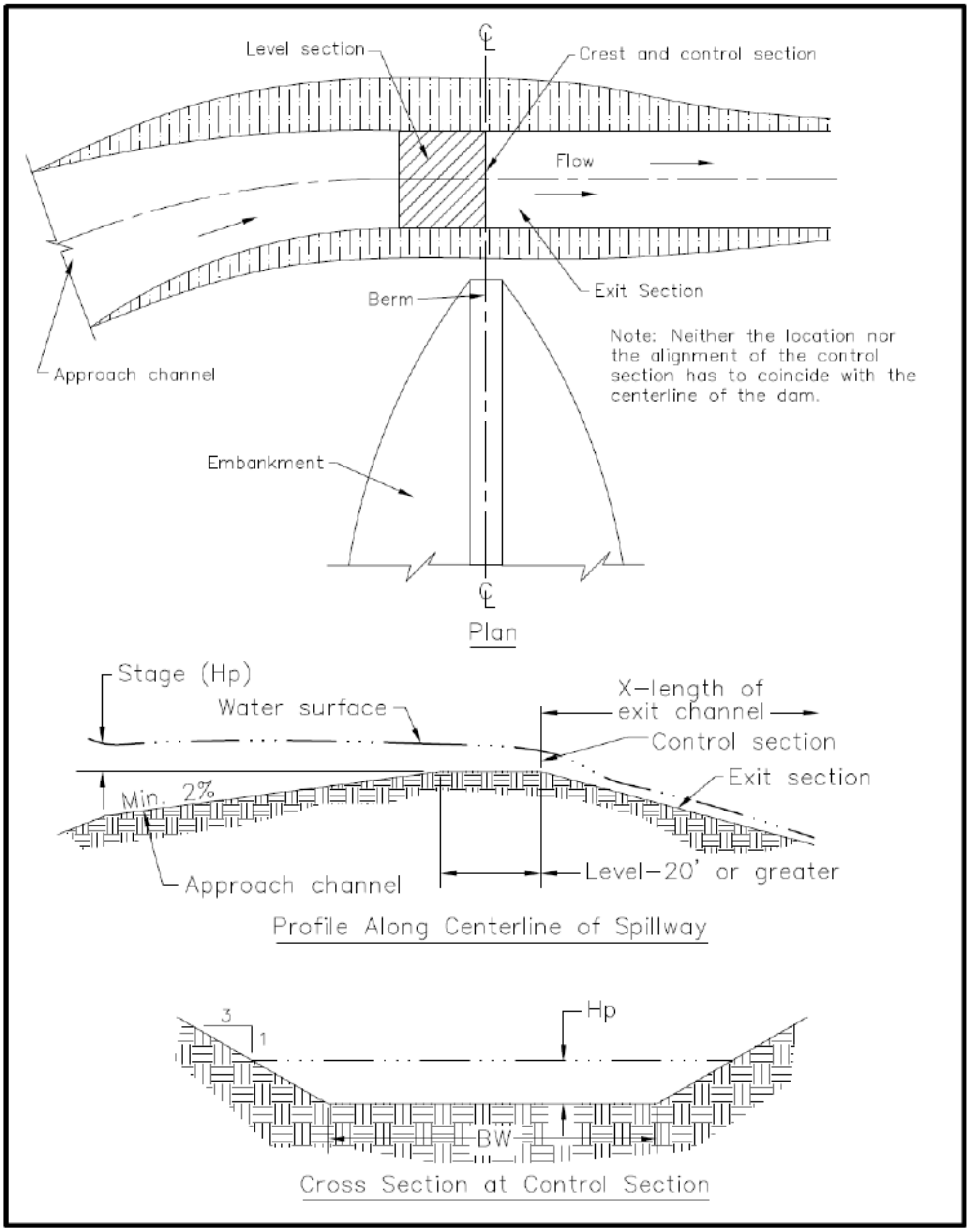


Figure 6-35. Excavated grass spillway views

Inlet Section

Ensure that the approach section has a slope toward the impoundment area of not less than 2% and is flared at its entrance, gradually reducing to the design width of the control section. The inlet portion of the spillway may be curved to improve alignment.

The Control Section

The control section of the spillway should be level and straight and at least 20 ft long for grass spillways and 10 feet for riprap. Determine the width and depth for the required capacity and site conditions. Wide, shallow spillways are preferred because they reduce outlet velocities.

The Outlet Section
The outlet section of the spillway should be straight, aligned and sloped to assure supercritical flow with exit velocities not exceeding values acceptable for site conditions.

Outlet Velocity
Ensure that the velocity of flow from the basin is nonerosive for existing site conditions. It may be necessary to stabilize the downstream areas or the receiving channels.

Embankment
Embankments should not exceed 10 feet in height, measured at the center line from the original ground surface to the designed (settled) top elevation of the embankment. Keep a minimum of 1 foot between the designed (settled) top of the dam and the design water level in the emergency spillway. Additional freeboard may be added to the embankment height which allows flow through a designated bypass location. Construct embankments with a minimum top width of 8 feet and side slopes of 2.5:1 or flatter.

There should be a cutoff trench in stable soil material under the dam at the centerline. The trench should be at least 2 feet deep with 1.5:1 side slopes, and sufficiently wide (at least 8 ft.) to allow compaction by machine.

Embankment material should be a stable mineral soil, free of roots, woody vegetation, rocks or other objectionable materials, with adequate moisture for compaction. Place fill in 9-inch layers through the length of dam and compact by routing construction hauling equipment over it. Maintain moisture and compaction requirements according to the plans and specifications. Hauling or compaction equipment must traverse each layer so that the entire surface has been compacted by at least one pass of the equipment wheels or tracks.

Excavation
Where sediment pools are formed or enlarged by excavation, keep side slopes at 2:1 or flatter for safety.

Erosion Protection
Minimize the area disturbed during construction. Divert surface water from disturbed areas. When possible, delay clearing the sediment impoundment area until the dam is in place. Keep the remaining temporary pool area undisturbed. Stabilize the spillway, embankment, and all disturbed areas with permanent vegetation. The basin bottom should also be established to a vegetative cover as this promotes sediment deposition.

Trap Efficiency
Improve sediment basin trapping efficiency by employing the following considerations in the basin design:

- Surface area—In the design of the settling pond, allow the largest surface area possible. The shallower the pool, the better.

- Length—Maximize the length-to-width ratio of the basin to provide the longest flow path possible.

- Baffles—Provide a minimum of three porous baffles to evenly distribute flow across the basin and reduce turbulence.

- Inlets—Area between the sediment inlets and the basin bottom should be stabilized by geotextile material, riprap with geotextile, a pipe drop, or other similar methods (Figure 6-36 shows the area with rocks). Inlets to basin should be located the greatest distance possible from the spillway.

- Dewatering—Allow the maximum reasonable detention period before the basin is completely dewatered (at least 48 hours).

- Inflow rate—Reduce the inflow velocity to nonerosive rates and divert all sediment-free runoff

- Establish permanent vegetation in the bottom and side slopes of the basin.

- Introduce the appropriate PAM material either at the turbulent entrance of the runoff water into the basin and/or apply to the first baffle. Apply the PAM according to manufacturer's recommendations.

Safety

Avoid steep side slopes. Fence basins properly and mark them with warning signs if trespassing is likely. Follow all State and local safety requirements.

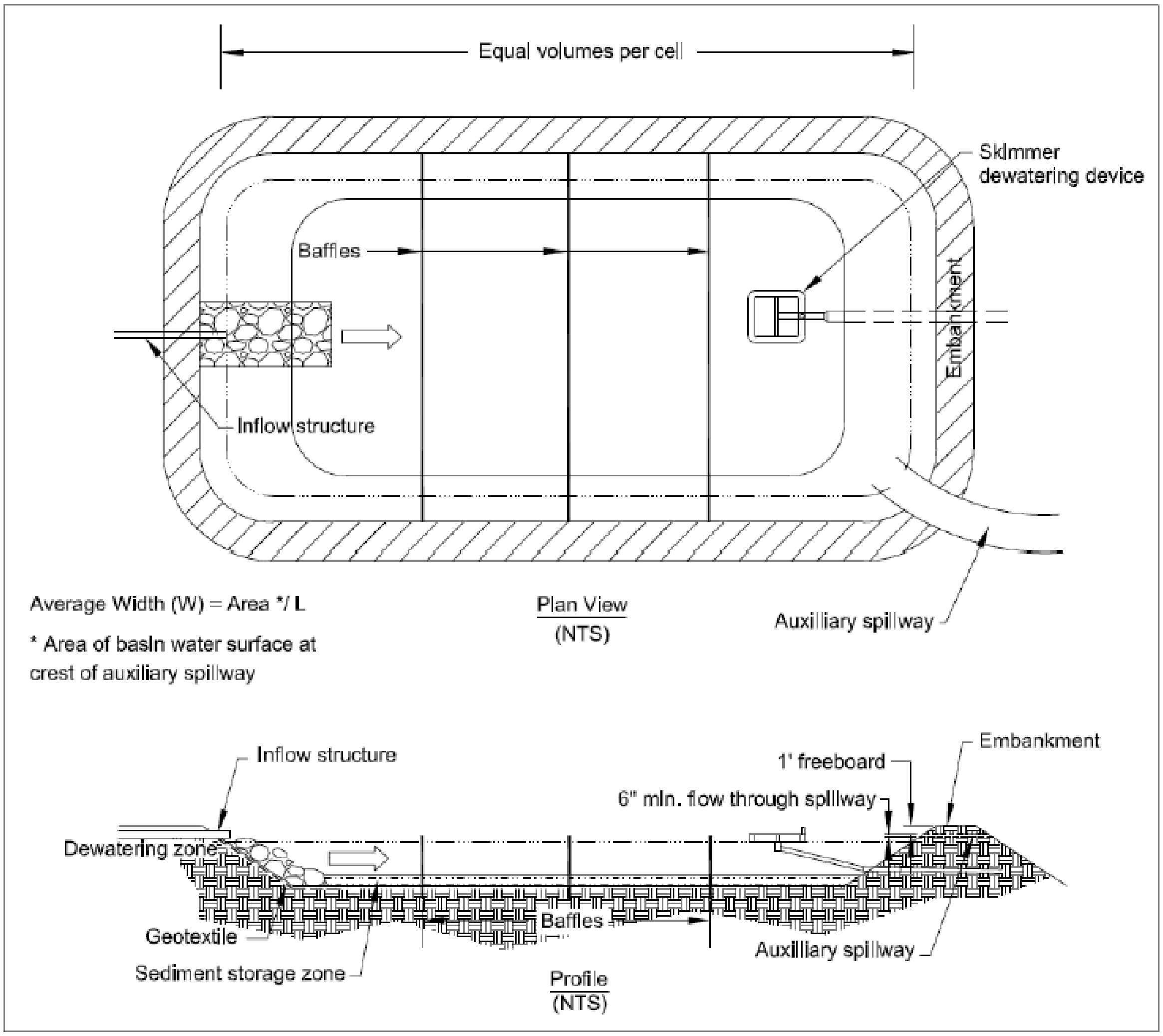


Figure 6-36. Example of a sediment basin with a skimmer outlet and emergency spillway (modified from Pennsylvania Erosion and Sediment Control Manual, March 2000)

Design Procedure

Step 1. Determine peak flow, Q10, for the basin drainage area utilizing the NRCS runoff curve number method.

Step 2. Determine any site limitations for the sediment pool elevation, emergency spillway or top of the dam.

Step 3. Determine basin volumes:

- Compute minimum volume required (3,600 ft^3/acre of drainage area).
- Specify sediment cleanout level to be clearly marked (one-half the design volume). Specify that the basin area is to be cleared after the dam is built.

Step 4. Determine area of basin, shape of basin, and baffles:

- Check length/width ratio (should be 2:1 or larger) and the surface area (435 sq.ft./Qp10).
- Ensure the bottom of the basin is level.
- Design and locate a minimum of 3 coir baffles. The baffle spacing should produce equal volumes of storage within the basin when the basin if full. The top elevation of the baffles will be set in Step 7.

Step 5. Size the skimmer, skimmer orifice, and barrel pipe.
Use Table 6-28 or the precise alternative design to size the orifice. Generally, a Schedule 40 PVC barrel pipe the same size as the skimmer arm is used under the embankment.

Step 6. Design the anti-seep collar.
Ensure that antiseep collar is no closer than 2 ft from a pipe joint and as close to the center of the embankment as possible. Collar must project at least 1.5 ft from the pipe and be watertight.

Step 7. Determine the emergency spillway dimensions.
Size the spillway bottom width and flow depth to handle the Q10 peak flow. Tables 6-28 and 6-29 can be used for the design process for grassed emergency spillways. Use appropriate design procedures for spillways with other surfaces. Set top of baffles at the elevation of the designed maximum flow depth of the emergency spillway.

Step 8. Spillway approach section.
Adjust the spillway alignment so that the control section and outlet section are straight. The entrance width should be 1.5 times the width of the control section with a smooth transition to the width of the control section. Approach channel should slope toward the reservoir no less than 2%.

Step 9. Spillway control section.

- Locate the control section in natural ground to the greatest extent possible.
- Keep a level area to extend at least 20 ft (grass) or 10 ft (riprap) upstream from the outlet end of the control section to ensure a straight alignment.
- Side slopes should be 3:1 (grass) or 2:1 (riprap).

Step 10. Design spillway exit section.

- Spillway exit should align with the control section and have the same bottom width and side slopes.
- Slope should be sufficient to maintain supercritical flow, but make sure it does not create erosive velocities for site conditions. (Stay within slope ranges in appropriate design tables.)
- Extend the exit channel to a point where the water may be released without damage.

Step 11. Size the embankment.

- Set the design elevation of the top of the dam a minimum of 1 ft above the water surface for the design flow in the emergency spillway.
- Constructed height should be 10% greater than the design to allow for settlement.
- Set side slopes 2.5:1 or flatter.
- Determine depth of cutoff trench from site borings. It should extend to a stable, tight soil layer (a minimum of 2 ft deep).
- Select borrow site remembering that the spillway cut may provide a significant amount of fill.

Step 12. Erosion control

- Select surface stabilization measures to control erosion.
- Select groundcover for emergency spillway to provide protection for design flow velocity and site conditions. Riprap stone over geotextile fabric may be required in erodible soils or when the spillway is not in undisturbed soils.
- Establish all disturbed areas including the basin bottom and side slopes to vegetation.

Step 13. Safety.

- Construct a fence and install warning signs as needed.

Table 6-28. Design Table for Vegetated Spillways Excavated in Erosion Resistant Soils (side slopes 3 horizontal: 1 vertical)

Discharge Q CFS	Slope Range		Bottom Width Feet	Stage Feet
	Minimum Percent	Maximum Percent		
15	3.3	12.2	8	.83
	3.5	18.2	12	.69
20	3.1	8.9	8	.97
	3.2	13.0	12	.81
	3.3	17.3	16	.70
25	2.9	7.1	8	1.09
	3.2	9.9	12	.91
	3.3	13.2	16	.79
	3.3	17.2	20	.70
30	2.9	6.0	8	1.20
	3.0	8.2	12	1.01
	3.0	10.7	16	.88
	3.3	13.8	20	.78
35	2.8	5.1	8	1.30
	2.9	6.9	12	1.10
	3.1	9.0	16	.94
	3.1	11.3	20	.85
	3.2	14.1	24	.77
40	2.7	4.5	8	1.40
	2.9	6.0	12	1.18
	2.9	7.6	16	1.03
	3.1	9.7	20	.91
	3.1	11.9	24	.83
45	2.6	4.1	8	1.49
	2.8	5.3	12	1.25
	2.9	6.7	16	1.09
	3.0	8.4	20	.98
	3.0	10.4	24	.89
50	2.7	3.7	8	1.57
	2.8	4.7	12	1.33
	2.8	6.0	16	1.16
	2.9	7.3	20	1.03
	3.1	9.0	24	.94
60	2.6	3.1	8	1.73
	2.7	3.9	12	1.47
	2.7	4.8	16	1.28
	2.9	5.9	20	1.15
	2.9	7.3	24	1.05
	3.0	8.6	28	.97
70	2.5	2.8	8	1.88
	2.6	3.3	12	1.60
	2.6	4.1	16	1.40
	2.7	5.0	20	1.26
	2.8	6.1	24	1.15
	2.9	7.0	28	1.05
80	2.5	2.9	12	1.72
	2.6	3.6	16	1.51
	2.7	4.3	20	1.35
80	2.8	5.2	24	1.24
	2.8	5.9	28	1.14
	2.9	7.0	32	1.06
90	2.5	2.6	12	1.84
	2.5	3.1	16	1.61
	2.6	3.8	20	1.45
	2.7	4.5	24	1.32
	2.8	5.3	28	1.22
	2.8	6.1	32	1.14
100	2.5	2.8	16	1.71
	2.6	3.3	20	1.54
	2.6	4.0	24	1.41
	2.7	4.8	28	1.30
	2.7	5.3	32	1.21
	2.8	6.1	36	1.13
120	2.5	2.8	20	1.71
	2.6	3.2	24	1.56
	2.7	3.8	28	1.44
	2.7	4.2	32	1.34
	2.7	4.8	36	1.26
140	2.5	2.7	24	1.71
	2.5	3.2	28	1.58
	2.6	3.6	32	1.47
	2.6	4.0	36	1.38
	2.7	4.5	40	1.30
160	2.5	2.7	28	1.70
	2.5	3.1	32	1.58
	2.6	3.4	36	1.49
	2.6	3.8	40	1.40
	2.7	4.3	44	1.33
180	2.4	2.7	32	1.72
	2.4	3.0	36	1.60
	2.5	3.4	40	1.51
	2.6	3.7	44	1.43
200	2.5	2.7	36	1.70
	2.5	2.9	40	1.60
	2.5	3.3	44	1.52
	2.6	3.6	48	1.45
220	2.4	2.6	40	1.70
	2.5	2.9	44	1.61
	2.5	3.2	48	1.53
240	2.5	2.6	44	1.70
	2.5	2.9	48	1.62
	2.6	3.2	52	1.54
260	2.4	2.6	48	1.70
	2.5	2.9	52	1.62
280	2.4	2.6	52	1.70
300	2.5	2.6	56	1.69

Example of Table Use:

Given: Discharge, Q10 = 87 cfs, Spillway slope (exit section) = 4%.

Find: Bottom Width and Stage in Spillway.

Procedure: Using a discharge of 90 cfs, note that the spillway (exit section) slope falls within slope ranges corresponding to bottom widths of 24, 28, and 32 ft. Use bottom width of 32 ft, to minimize velocity. Stage in the spillway is 1.14 ft.

Note: Computations are based on: Roughness coefficient, n = 0.40 and a maximum velocity of 5.50 ft. per sec.

Table 6-29. Design Table for Vegetated Spillways Excavated in Very Erodible Soils (side slopes 3 horizontal: 1 vertical)

Discharge Q CFS	Slope Range		Bottom Width Feet	Stage Feet
	Minimum Percent	Maximum Percent		
10	3.5	4.7	8	.68
15	3.4	4.4	12	.69
	3.4	5.9	16	.60
20	3.3	3.3	12	.80
	3.3	4.1	16	.70
	3.5	5.3	20	.62
25	3.3	3.3	16	.79
	3.3	4.0	20	.70
	3.5	4.9	24	.64
30	3.3	3.3	20	.78
	3.3	4.0	24	.71
	3.4	4.7	28	.65
	3.4	5.5	32	.61
35	3.2	3.2	24	.77
	3.3	3.9	28	.71
	3.5	4.6	32	.66
	3.5	5.2	36	.62
40	3.3	3.3	28	.76
	3.4	3.8	32	.71
	3.4	4.4	36	.67
	3.4	5.0	40	.64
45	3.3	3.3	32	.76
	3.4	3.8	36	.71
	3.4	4.3	40	.67
	3.4	4.8	44	.64
50	3.3	3.3	36	.75
	3.3	3.8	40	.71
	3.3	4.3	44	.68
60	3.2	3.2	44	.75
	3.2	3.7	48	.72
70	3.3	3.3	52	.75
80	3.1	3.1	56	.78

Example of Table Use:

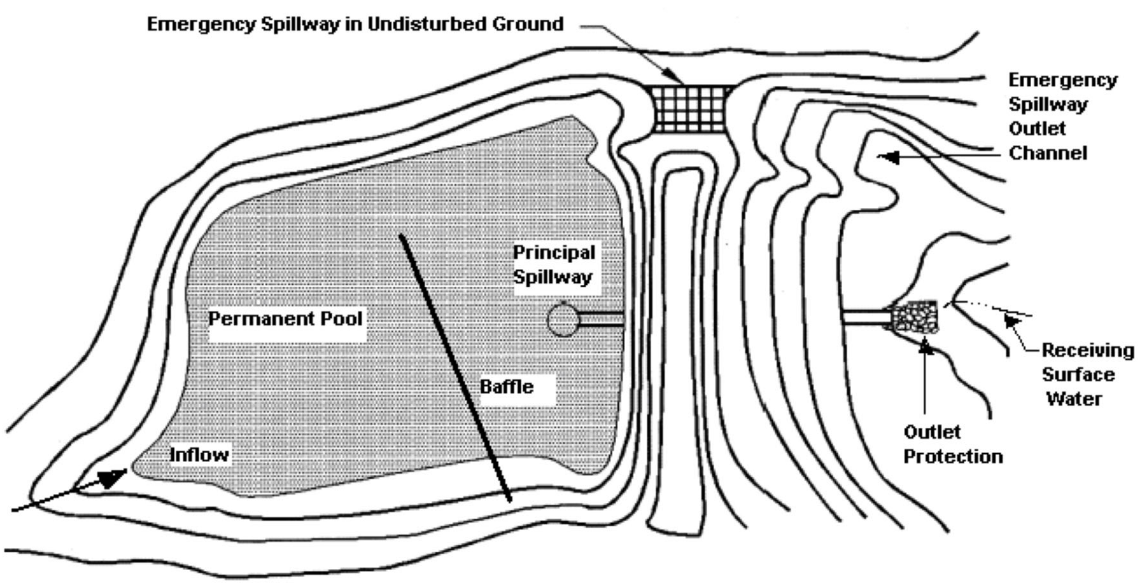
Given: Discharge, Q10 = 38 cfs, Spillway slope (exit section) = 4%.

Find: Bottom Width and Stage in Spillway.

Procedure:	Using a discharge of 40 cfs, note that the spillway (exit section) slope falls within slope ranges corresponding to bottom widths of 36 and 40 ft. Use bottom width of 40 ft, to minimize velocity. Stage in the spillway is 0.64 ft.
Note:	Computations are based on: Roughness coefficient, n = 0.40 and a maximum velocity of 3.50 ft. per sec.”

Another pond schematic is from the *Pennsylvania Erosion and Sediment Control* Manual (2012)

Example of a sediment basin with a skimmer outlet and emergency spillway:

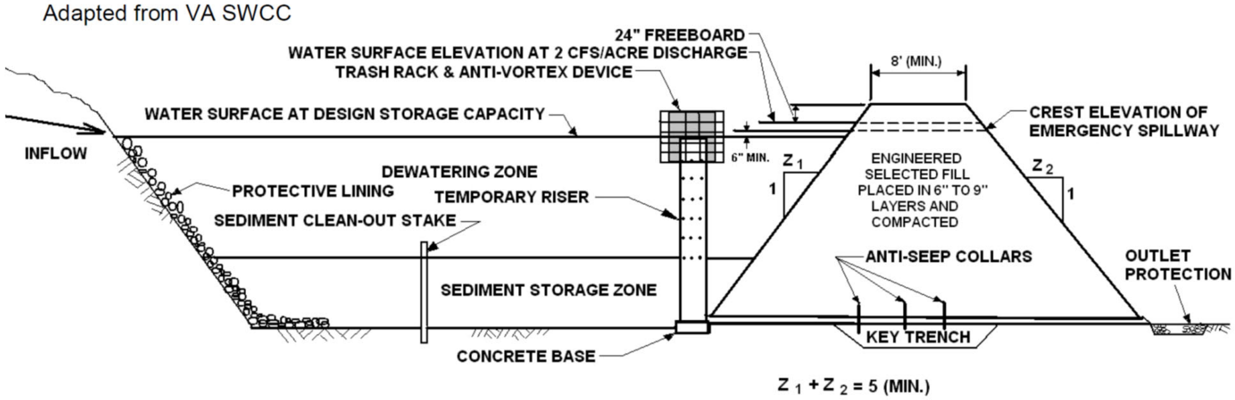


AVERAGE WIDTH (W) = $\frac{\text{AREA AT ELEVATION 3}}{\text{L}}$

WHERE: L = MAXIMUM LENGTH OF BASIN AT ELEVATION 3

PLAN VIEW

Adapted from VA SWCC



PA DEP

TYPICAL SECTION

Skimmer on a rock barrier:

Chester County Conservation District

The following example compares two methods (preset sediment and dewatering zone volume sizing criteria vs. particle control objective) to size a construction site sediment pond. The allowable effluent turbidity is, for this example, 280 NTU based on the proposed and then suspended EPA turbidity numeric effluent limit for construction sites. This example does not use a polymer to enhance settling or to prevent soils from eroding, relying on simple sedimentation processes alone.

Site information:

- 25 acres having 100 single-family residences on 1/4-acre lots
- A minimum of 10 acres under active grading at one time
- The development is in Dauphin County, PA

RUSLE is used to calculate the amount of sediment:

A = (R)(K)(LS)(C)(P)

Assumptions:

- 1 year of development, R = 125 for Dauphin County

- Duncannon silt loam soil and initial grading will remove approximately 6 inches of soil (K value from Web Soil Survey for 0 – 9 inches), K = 0.37
- Typical 2% slopes and slope lengths of 300 ft, LS = 0.43
- Bare soil, C = 1
- No agricultural practices, P = 1

A = (125)(0.37)(0.43)(1)(1) = 19.9 tons/ac(25 ac) = ~500 t

For 500 tons of sediment is generated on 25-ac site per year and assuming a silt loam soil:

$$500tons \times \frac{0.87yd^3}{ton} = 22yd^3\left(\frac{27ft^3}{yd^3}\right) = 435ft^3$$

Per Pennsylvania E&SC Manual, "A sediment storage zone of 1,000 cubic feet per disturbed acre — over the life of the project within the watershed of the basin is required. The sediment storage zone should be at least 1 foot in depth. This zone is in addition to any permanent pool requirement." Therefore, the required sediment storage zone per the statement requirements is 25,000 ft^3 or approximately 50 years of storage. This storage is sized to account for all land graded over the life of the project even if the construction is done in phases. While this scenario assumed a 1-year life from initial grading to final stabilization, construction timelines are often extended due to weather and other unforeseen circumstances. While this appears to be substantially oversized, unlike this book's design guidance which incorporates a scour protection zone, Pennsylvania does not requiring a scour protection zone above the sediment storage zone. Plus, the minimum depth for the sediment storage zone is 1 ft, which is less water than required to prevent scour of previously trapped sediment or the bottom of the sedimentation pond. This oversizing of the sediment storage zone could be designed with a 1 ft height or for improved protection, since the sediment is likely to be filling the area slowly, design this zone with a minimum depth of 3 feet in order to provide the scour protection zone. Scour protection will be provided for a time until the sediment height in the sediment storage zone is too shallow to prevent scour.

The Pennsylvania regulations do allow a discount in pond size and volume for maintaining an 18-in permanent pool above the sediment storage zone in order to prevent scour.

The Pennsylvania manual also specifies the minimum surface area (SA min) at the top of the sediment storage zone:

$$SA\ min = 1.2\left({}^{q_{out}}/_{v_s}\right)$$

Where q_{out} = basin discharge rate at top of the sediment storage zone and bottom of dewatering zone
v_s = Particle settling velocity as follows:
For sand, loamy sand, & sandy loam soils: v_s = 1.2 X 10^{-3} ft/sec
For loam, silt, & silt loam soils: v_s = 7.3 X 10^{-5} ft/sec
For clay loam, silty clay, & clay soils: v_s = 1.2 X 10^{-5} ft/sec

The Duncannon silt loam soil is assumed to have a settling velocity of 7.3 x 10^{-5} ft/sec, per the manual. Substituting:

$$SA\ min = 1.2\left({q_{out}}/{7.3x10^{-5} ft/sec} \right)$$

As reported by Nelson (1996), the particle size control needed to achieve the 280 NTU is 3 to 5 µm. The approximate settling velocity is therefore 8 x 10^{-4} cm/sec. This corresponds to a settling velocity of 2.8 x 10^{-5} ft/sec, less than the recommended settling velocity in the sediment storage zone. To be consistent with the state procedure, this example will use 7.3 x 10^{-5} ft/sec.

A dewatering zone of 5,000 cubic feet is required for each disturbed and undisturbed acre on the construction site, plus for each undisturbed tributary acre to the basin. Reductions in the dewatering zone are allowed unless the basin is in a High Quality or Exceptional Value watershed. However, the minimum required dewatering zone in non-special protection watersheds is 3,600 cubic feet per acre. The minimum depth of the dewatering zone is 3 feet.

This example assumes that the design takes credit for a permanent pool on top of the sediment storage zone, and takes credit for a length:width ratio of > 4:1, and for a dewatering time of 4 days. This results in a dewatering zone volume of 3600 cubic feet per acre. The credits in Pennsylvania are as follows:

(1) A reduction of 700 cubic feet per acre may be claimed for basins with principal spillways that dewater from the top 6 inches of the dewatering zone.
(2) A reduction of 700 cubic feet per acre for basins with permanent pools greater than or equal to 18 inches average depth. The sediment storage zone is in addition to the permanent pool.
(3) A reduction of 350 cubic feet per acre for basins with flow length to average basin width ratios of 4L:1W or greater at the top of the dewatering zone.
(4) A reduction of 350 cubic feet per acre for basins with dewatering times ranging from 4 to 7 days.

The basin dewatering zone volume is 3600 ft^3/ac multiplied by 25 ac, or 90,000 ft^3. This must drain in 4 to 7 days, for an average dewatering rate over 4 days of 0.26 ft^3/sec. This is based on using a skimmer where the driving head for flow will be relatively constant through the orifice to enter the skimmer tube. This will be q_{out}.

$$SA\ min = 1.2\left({0.26 ft^3/sec}/{7.3x10^{-5} ft/sec} \right) = 3561 ft^2 = 0.08 ac$$

This SA min value results in a 25,000 ft^3 storage zone that is 0.08 in area and approximately 7 to 8 ft deep. This depth creates a safety hazard and is therefore not recommended. A sediment storage zone of 1-ft depth results in a surface area of 0.57 ac, while a sediment storage zone of 2-ft depth results in a surface area of 0.26 ac. This is the flow rate divided by the surface area (Q/A) as specific in the surface overflow rate (SOR) method, and is the critical settling rate of the smallest particle being trapped. For the 2-ft depth scenario, this results in a surface area of 11,325 ft^2. This results in a particle settling rate of (0.26 ft^3/sec)/11,325 ft^2) = 2.29 x 10^{-5} ft/sec, which is less than the settling velocity for a 4 µm particle.

The rest of the pond can be sized, including the design of the principal and emergency spillways to transport 2 cfs/ac or, in this example, 50 cfs. As this example illustrates, these design procedures are complementary. In general, the 3,600 ft^3/ac requirement with a 4-day dewatering translates to the sedimentation of 5 to 10 µm particle sizes, close to the particle size control needed to achieve the required effluent turbidity limit of 289 NTU.

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Case Study – Interstate 86

The Federal Highway Administration is in the process of upgrading the nation's interstate system. New York's Southern Tier Expressway, also known as NYS Route 17, is one of the nation's highways undergoing re-construction in many segments to meet interstate standards. At Parkesville, New York, in Sullivan County a section of the new Interstate 86 is being constructed to bypass Parksville, eliminating many at grade crossings that currently exist along Route 17. This new construction leaves the old road just west of the village and elevates up onto the slope of steep hills just south of the Little Beaver Kill Creek and returns to the original Route 17 grade approximately 2.3 miles to the east.

The construction consists of a four-lane highway with two bridges crossing Little Beaver Kill Creek, 3 smaller spans over hillside drainage areas, and an interchange located at Parksville. The sequence of operations, based on the design, required large areas to be exposed at one time. The central project area was approximately 125 acres disturbed along a linear corridor. In addition, there was a 45-acre waste area located upslope of the project, to receive excess excavation and cleared material from the project site.

Figure 6-37. North facing fill slope just south of the Parksville project offices (D. Lake photo)

A Stormwater Pollution Prevention Plan (SWPPP) was prepared by a consulting engineering firm for the offsite operations while the NYS DOT prepared the SWPPP for the onsite construction activities. Construction began in 2009 and was well underway by the time poor weather arrived in late fall. The offsite waste area had been divided into seven cells to receive the excess excavated material. The entire waste area had been cleared in one operation and the cells were located from back to front. The back part of the waste area was higher in elevation than the front. Two sediment basins were located in the front portion of the waste area.

Figure 6-38. Excavated slopes in the project area. This material is taken to the waste area (D. Lake photo)

Figure 6-39. Haul road to the waste area from the project site (D. Lake photo)

At first, the project advanced according to plan. But as the weather closed in and construction continued, the trucks hauling the waste soil material could not travel back far enough in the waste area to reach the cell locations where they were to dump. They began dropping their loads in the front of the area filling up these forward areas.

Figure 6-40. Excess excavation deposited in a forward cell of the waste area (D. Lake photo)

Construction operations continued during this inclement weather period. During rains, highly turbid runoff from the waste area flowed down into the site area combining with additional turbid runoff and discharged into Little Beaver Kill Creek, a highly valued trout stream. These water quality violations caused the site to be shut down until the problems were corrected.

The majority of the soils on the site contained a significant percentage of fine-grained clay; some that was colloidal in character. Once in suspension, these fine materials did not readily settle out. These small particles passed directly through the sand filter systems that were initially installed to capture them. This fine material also plugged geotextile fabrics that were placed around perforated sediment basin outlet pipes. This caused runoff to overtop the west sediment in the waste area, eroding a significant portion of the dam. The east basin sustained damage to the drop inlet riser due to ice formation because it was constructed out in the pool and not in the embankment.

Figure 6-41. Waste area eastern sediment basin. The drop inlet riser in the pool area was damaged due to ice formation over the winter (D. Lake photo)

Figure 6-42. West sediment basin in the waste area with an eroded cut in the downstream face of the dam (D. Lake photo)

Figure 6-43. The western sediment basin outlet pipe. There is no reduction in turbidity due to flow through joints that have been separated by riser damage from winter ice action (D. Lake photo)

Figure 6-44. Turbid discharge leaving the construction site that originates primarily from the flow from the waste area but also with intervening site area (D. Lake photo)


Figure 6-45. Water quality violations at one location on the Little Beaver Kill Creek from the combined flows from the waste area and project site (D. Lake photo)


Figure 6-46. A sand filter constructed around a vertical dewatering riser in a sediment basin within the project site (D. Lake photo)

Figure 6-47. Turbid flow moving through the sand filter system, entering the perforated outlet pipe which discharges to a drainage swale offsite (D. Lake photo)

Figure 6-48. Steep slope at Parksville on-ramp construction covered with plastic to prevent erosion into the Little Beaver Kill (D. Lake photo)

It is important that every opportunity should be taken to minimize the exposed soil, especially during extreme construction weather periods and with high value resources adjacent to the project area. Large exposed areas should be covered with temporary mulch with areas that will stand for long periods of times seeded with a temporary seed mixture. Water management on and adjacent to the site is critical for erosion control. Steep slopes, poor soils and large exposed areas create challenges for site management. The sequence of construction and phasing plan should be adjusted to limit the risk at the site. It may even be necessary to cover very steep exposed areas with plastic or geotextile until final grading and stabilization are completed. Polymer systems should be evaluated for application particularly if the soils on the site are highly colloidal.

Good site control begins with a comprehensive evaluation of the site's character and recognizing the possible problems that could occur during construction. The SWPPP should be designed accordingly and maintained with appropriate personnel responsible for its daily implementation and inspection.

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Example Use of Chemical-Assisted Sedimentation at Construction Sites

Larcombe (1999) of the Auckland Regional Council (ARC), New Zealand, prepared a report (*Technical Publication on Chemical Removal of Sediment from Earthworks Stormwater*) describing the use of chemical-assisted sedimentation for the control of construction site sediment. They tested both solid forms of flocculants (Magnasol Floc Blocs Allied Colloids, Australia Pty Ltd., NZ agent Chemiplas NZ Limited) and liquid chemicals at several construction areas. Test sites included areas along the extension of the northern motorway (ALPURT), and at a residential subdivision development (Greenhithe). The extensive field trials using aluminum sulfate (Alum) and polyaluminum chloride (PAC) were carried out during construction of the initial stages of the northern motorway. The ARC then developed a passive dosing system for the treatment of the construction site runoff treating the flow during passage into and through the pond. This system proved highly effective under a wide range of storm conditions. The following discussion is summarized from that report.

Conditions when Chemical Treatment may be Necessary

The requirements for sediment ponds at construction sites are given in the Auckland Regional Council guidance (TP 90, *Erosion and Sediment Control*, 1999). The performance of ponds constructed according to these specifications is generally good, but a number of situations have been identified where chemical treatment can provide a marked improvement in sediment removal. Chemical treatment is important when a pond of the required size cannot be constructed. This may occur because of topographical constraints, difficult soil conditions, or the presence of natural habitat of high value. In some situations, the design of the pond cannot be optimized in terms of shape, depth, location of inlet and outlet, or energy attenuation of the inflow. Some soil types produce solids in the runoff that have very poor settling characteristics in a normal sediment pond. There is also a higher risk of increased erosion and sediment losses during rainstorms in areas having highly erodible soils or having very steep or long slope lengths. Some common uses of construction sites, such as repeated machinery movement on haul roads, can result in high sediment loadings in stormwater. Finally, chemical treatment provides a means of reducing the sediment discharge to highly sensitive receiving environments.

Initial Tests
Two types of chemicals were considered for the initial bench testing and field trials, polyelectrolyte flocculants (polymer or polyacrylamide (PAM)) and aluminum coagulants (aluminum sulfate (alum) and polyaluminum chloride, (PAC)).

Polyelectrolyte Flocculants
According to the ARC (Beca Carter Hollings & Ferner Ltd, undated), "anionic polyacrylamide is a negatively charged flocculant commonly used for industrial applications including raw potable water clarification, and for clarification, thickening and dewatering of wastewater and sludge. Because these polymers have a high affinity for solids, the remaining concentration in treated waters is very low in all but serious overdose situations. On the other hand, cationic polyacrylamides are positively charged and are commonly used in a number of municipal wastewater treatment plants to improve solids removal during pre-settlement. They are recognized as flocculants with greater toxicity implications for fish and other aquatic organisms than anionic or non-ionic polyelectrolytes. This is because the gills of fish are negatively charged, and the cationic polymer binds to them resulting in mechanical suffocation."

Bench testing showed that a number of polyacrylamides resulted in good removal of suspended solids from the construction site runoff water. However, they identified several difficulties hindering the use of liquid polyacrylamides at construction sites. The most serious difficulty is that liquid polyacrylamide concentrates are highly viscous and would require onsite predilution with water to achieve a suitable consistency for dosing and mixing with construction site runoff. This would require mixing equipment and storage tanks, along with electric power. In addition, the diluted polyacrylamide has a limited storage life. High viscosity and the need for pre-dilution were not problems for the aluminum coagulants.

Three solid polyacrylamide products (Floc Bloc), marketed by Allied Colloids, were evaluated in bench-scale tests. The products were: Percol AN1 and AN2 (both anionic polyacrylamide blends) and Percol CN1 (a cationic polyacrylamide blend). The floc blocs were 300 x 100 x 85 mm and weighed 3 kg. AN2 performed best when using runoff from sites having either clay or limestone soils. AN2, being an anionic polyacrylamides, also had a lower toxicity. Effective dose rates were between 1 and 4 mg/L of dry AN2. Higher concentrations led to reductions in flocculation and suspended sediment removal. AN2, even at excessive dosages of about 8 mg/L, did not affect pH.

Aluminum Coagulants
A major issue with aluminum coagulants is they contain large amounts of ionic aluminum, the toxic form of aluminum. Generally, dissolved aluminum at concentrations as high as 0.050 or 0.100 mg/L and at pH between 6.5 and 8.0 present little threat of toxicity. At lower pH, the toxicity increases due to possible mucus formations on the gills of fish. The toxic aluminum associated with the coagulant dose is very rapidly reduced by the precipitation and coagulation reactions. The insoluble precipitates (incorporating metals, nutrients, and solids) that form after aluminum coagulants are added to water are stable and denser than water. The alum floc that is formed is not toxic to benthic organisms. Most pollutants are tightly bound to the aluminum matrix with little likelihood of release from either dried or wet sludges within normal pH and redox ranges.

During the initial tests at the ALPURT site, the ARC (Beca Carter Hollings & Ferner Ltd, undated) determined that there was a need for chemical treatment of runoff from catchments having clay soils that naturally produced more acidic runoff. They decided to compare PAC with alum as a coagulant, as PAC is less acidic. Table 6-30 shows the treatment data using representative runoff samples from clay soil catchments. Samples were taken after 1 hour of settling. Longer settling times would have resulted in further reductions in suspended solids, but these tests were to compare the alkalinity and pH effects of these two alternative coagulants. These tests show that PAC has a consistently lower detrimental effect on pH reduction, and it results in higher effluent alkalinity.

Table 6-30. pH Data for Alum and PAC Treated Stormwater Samples

Source	Coagulant	Al conc. (mg/L)	pH	Alkalinity (mg/L as $CaCO_3$)	SS (mg/)L
Oteha Valley Rd SE Pond	initial test water	-	5.64	1	1504
	Alum	8	4.42	<1	71
	Alum	12	4.34	<1	71
	PAC	8	4.64	<1	107
	PAC	12	4.63	<1	85
Lonely Track Rd Gully1	initial test water	-	6.68	16	680
	Alum	8	4.64	<1	117
	Alum	12	4.54	<1	113
	PAC	8	6.03	7	81
	PAC	12	5.54	3	112
Awanohi Rd Adj. Okura Rd	initial test water	-	7.15	60	1130
	Alum	8	5.88	13	84
	Alum	12	4.85	<1	84
	PAC	8	6.71	43	229
	PAC	12	6.45	35	78

Source: Beca Carter Hollings & Ferner Ltd, undated

Solid Floc Blocks

The initial tests indicated advantages to the use of the solid floc blocks, particularly on sites with difficult access; sites with only small construction areas, or sites where there was a need for short-term treatment only. They therefore followed up their initial tests with detailed field assessments to determine the best methods for using the blocs to obtain the most effective suspended solids removal under highly-variable flow conditions.

Field trials using solid floc blocs:

Preliminary field trials used an AN2 floc bloc to treat sediment-laden runoff from a construction site having limestone soils. The first trials placed the floc blocs in plastic mesh bags in plywood flumes through which the runoff from the site was directed. Those trials encountered problems with the high bedload of solids in the runoff flow that accumulated against and partially buried the floc bloc, inhibiting the dissolution of the chemical. The trial was then moved to a channel between a forebay and the settlement pond (for pre-treatment of the water to remove the large materials), and demonstrated that new floc blocs achieved good treatment for low flows (about 2 L/s) and when the suspended solids was between 10,000 to 20,000 mg/L. However, the high influent solids in the runoff continued to be a problem, and following an intense rainfall event, both the forebay and floc bloc channel were filled with sediment. As the construction site area was gradually stabilized, the quality of runoff improved. Additional tests in a new flume showed that effective treatment was achieved for new floc blocs at flows of about 2 L/s with suspended solids concentrations up to 5,000 mg/L.

Figure 6-49. Floc blocks and flume detail, initial installation (Source: Beca Carter Hollings & Ferner Ltd, undated)

Figure 6-50. Floc blocks within channel between forebay and pond (Source: Beca Carter Hollings & Ferner Ltd, undated)

Figure 6-51. Pond inlet channel full of sediment and buried floc blocks (Source: Beca Carter Hollings & Ferner Ltd, undated)

Table 6-31 data was typical for the floc block experiments. These samples were obtained near the end of the storm event on May 12, 2000.

Table 6-31. Floc Block Performance

Time	Sample Type	Flow (L/s)	pH	SS (mg/L)
0840	Inflow to flume	5	6.04	1,150
0850	Pond Discharge	20	6.61	1,870
0900	Inflow via culvert	10	6.97	1,980
0935	Pond discharge	10	6.07	1,810
1035	Pond discharge	6	6.78	1,720

Source: Beca Carter Hollings & Ferner Ltd, undated

These data show that high concentrations of suspended solids were present in the pond discharge before and after the storm. The floc blocks did not appear to have had any significant treatment effect during the period of peak runoff flow.

The Auckland Regional Council concluded that a constant stormwater flow through a floc bloc treatment flume is best in terms of providing the optimum chemical dose for suspended solids removal. It was difficult to set up an array of floc blocs that provided optimal dosing for highly variable flows. They conclude that for any floc bloc system, it was desirable to restrict the maximum flow to about *2*0 L/s. The treatment capacity of the tested floc bloc (AN2) at a limestone-soil site was about 2 L/s per bloc at 10,000 mg/L suspended solids, and about 1 L/s per bloc at 20,000 mg/L suspended solids. They concluded that floc bloc treatment has a potential for removal of suspended solids, particularly for small catchments, when flow balancing can be achieved prior to treatment, and the stormwater is of consistent quality. However, there were only moderate observed decreases in suspended solids concentrations during the floc block tests (about 50 to 75%) and resulting in still very-high effluent concentrations. These limited removals were possibly due to problems associated with highly varying flows, degradation of the floc blocks, and burial of the floc blocks in sediment.

Serious cracking of the floc blocs was noted during an initial dry period of several weeks in the summer. Large pieces fell from the blocs, eventually forming a sticky mass that blocked the bottom of the bloc cages and interfered with the flow paths during subsequent periods of runoff. An intense rain (about 30 mm of rain during 40 minutes) caused extensive site erosion and the very high sediment loads filled the forebay and treatment flume, in addition to the 60 m^3 of sediment trapped in the pond. Although the floc bloc treatment system was overwhelmed by bedload during this event, the treated pond had lower suspended solids concentrations in the discharge than the other two ponds (2,400 mg/L vs. 7,300 mg/L). During other, more-moderate events, treated pond effluent concentrations were about 500 mg/L, compared to typical effluent concentrations of about 1,000 to 2,000 mg/L from untreated ponds.

The researchers found that a construction site having saturated soils can produce runoff flows of more than 60 L/s per hectare under the intense rainfall conditions that may occur in the Auckland Region. Also, the runoff rates from construction sites can be extremely variable, making it difficult to provide an appropriate array of floc blocs that will provide optimal dosing for such variable flows. Also, with large numbers of blocs in a single channel system, there could be some potential for overdosing in low-flow conditions.

Liquid Coagulants

Initially, the installation of a runoff-proportional dosing system was designed, which required a flow measurement weir or flume, an ultrasonic sensor and signal generating unit, and a dosing pump. Together with the cost of site preparation, chemical storage tanks and secure shelter, the cost per treatment system was estimated to be about $NZ12,000 (about $US9,000). Although the use of a pressure transducer for flow measurement would have reduced the cost to about $NZ9,000 (about $US7,000), it would have been difficult to maintain the flow measurement weir because of the large amount of eroded sediment from the construction site. An alternative system that passively provided a chemical dose proportional to rainfall intensity was developed. The rainfall-driven system had the major advantage that it did not require either a runoff flow measurement system or a dosing pump (nor electricity). This system had a total cost of approximately $NZ2,400 (about $US1,800) per installation. The following photos show an example of this system at a New Zealand construction site, including the main internal components. It should be noted that these costs are now outdated, but do reflect the relative costs of the alternatives.

Figure 6-52. Auckland Regional Council rainfall-driven chemical dosing system.

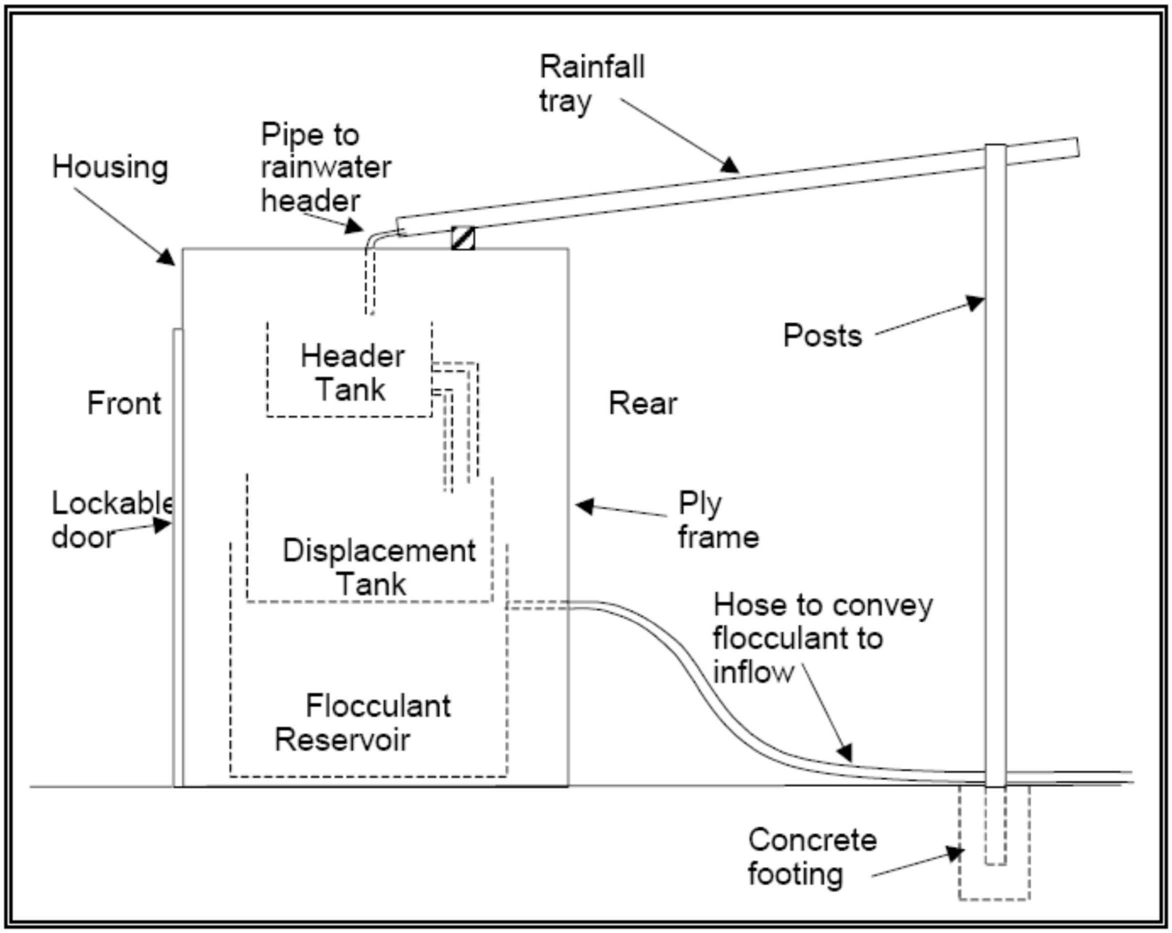

Figure 6-53. Auckland Regional Council rainfall-driven chemical dosing system, side view (Beca Carter Hollings & Ferner Ltd, undated).

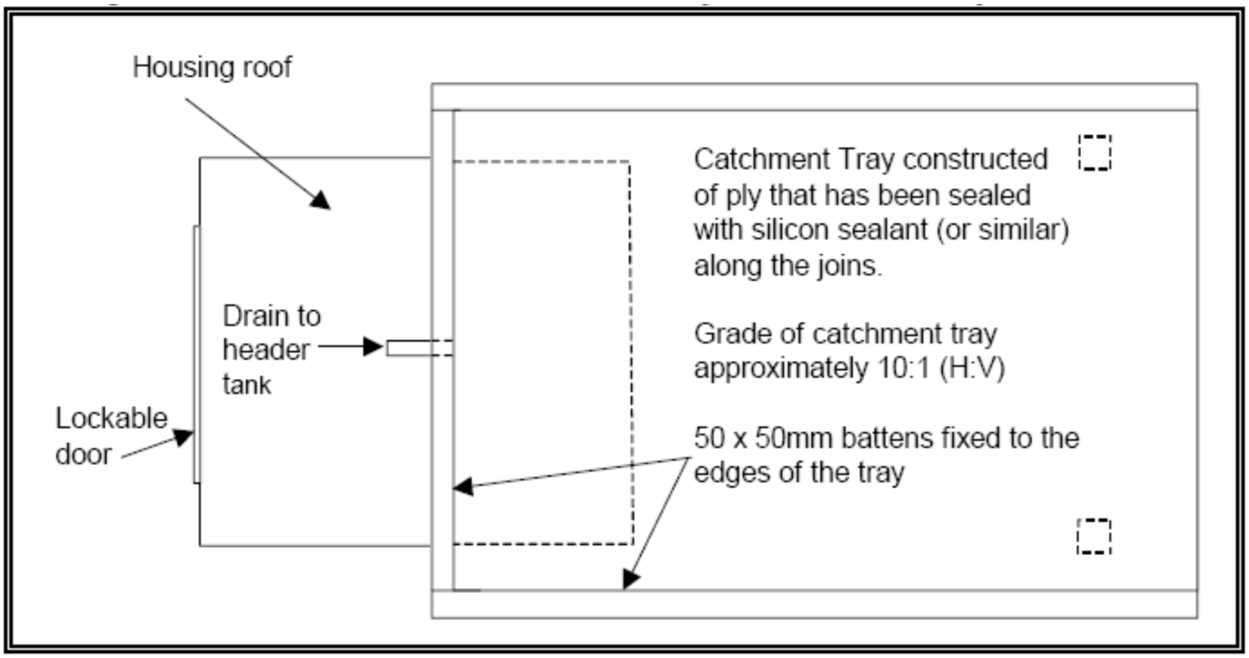

Figure 6-54. Auckland Regional Council rainfall-driven chemical dosing system, top view (Beca Carter Hollings & Ferner Ltd, undated).

Figure 6-55. Auckland Regional Council rainfall-driven chemical dosing system, top plywood catchment tray (Beca Carter Hollings & Ferner Ltd, undated).

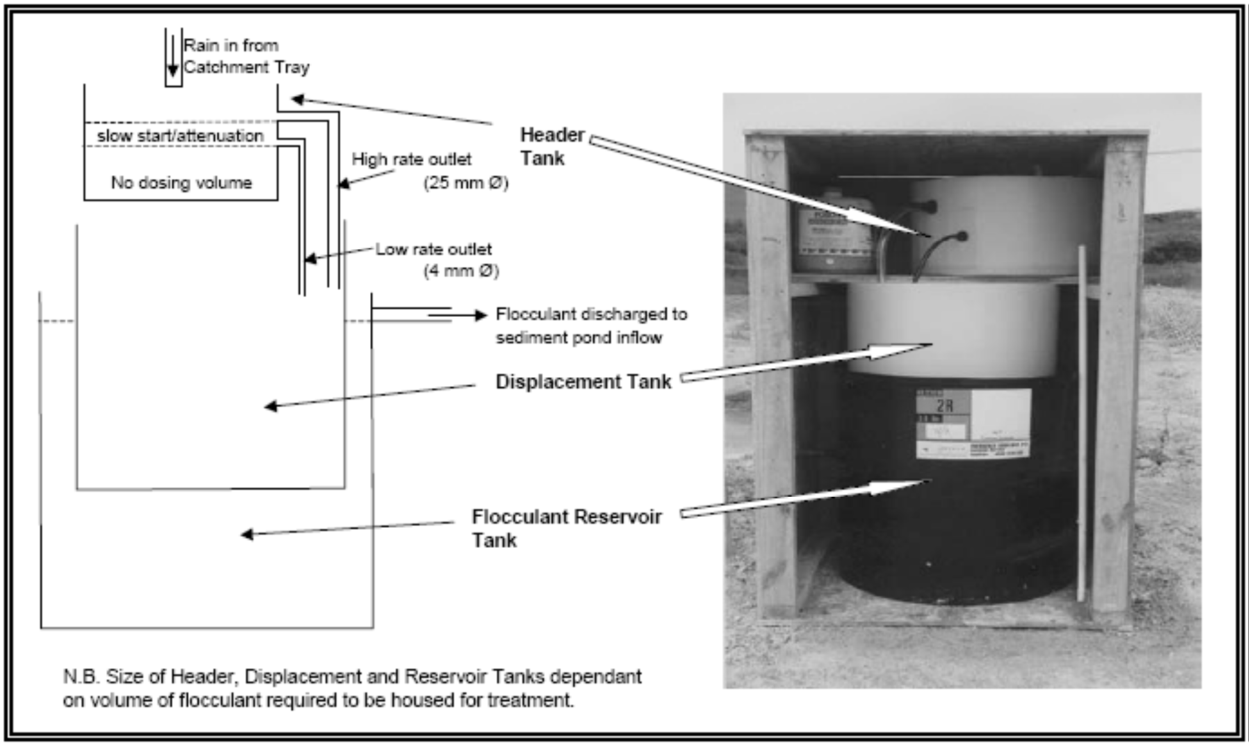

Figure 6-66. Auckland Regional Council rainfall-driven chemical dosing system showing schematic components with field installation (Beca Carter Hollings & Ferner Ltd, undated).

Figure 6-67. Earl Shaver, then of the Auckland Regional Council, showing the main components of the rainfall-driven chemical dosing system.

The rainfall volume collected from a small roof (area proportionate to the construction site drainage area and chemical dosage desired) is used to displace the liquid chemical from a storage tank into the runoff channel before a sediment pond. This design (based on the field trails) assumes that 100% of the rainfall falling onto saturated disturbed areas and 60% of the rainfall falling onto stabilized areas, needs to be treated.

The roof runoff is drained by gravity into an elevated header tank that has a volume below an overflow equal to the detention storage of the site. The above photo shows the second overflow tube above the main overflow tube; this will cause an increased dosage rate for very high rain intensities. The overflow tubes from this elevated header tank are directed into a displacement tank that is floating in the main chemical tank. As the water flows into this floating displacement tank from the elevated header tank, the chemical is pushed out the reservoir tank and through the dosage line to the dosing location in the flow path.

Example: Volumetric Design

The following example is from the Auckland Regional Council report (Larcombe 1999), assuming a 1 ha (2.5 acre) site and using PAC. The target dosage is 8 mg/L (the actual dosage needs to be determined from bench-scale tests using actual site runoff, or runoff from a similar site). Liquid PAC obtained from Fernz Chemicals contains 10.1% Al_2O_3 by weight, equivalent to 53,500 mg/kg aluminum or 64,200 mg/L aluminum, as the density of PAC is 1.20. Therefore, 1L of PAC would treat 8,020 L of construction site runoff at a dose rate of 8 mg aluminum per liter.

• Roof runoff area calculation:

Each hectare of catchment area would generate about 500 m^3 of runoff per 50 mm of rainfall, assuming the soil was saturated. The volume of PAC required to treat 500 m^3 of runoff is 62.3 L at 8 mg/L. The density of PAC is 1.2. Therefore, 74.8 L of rainwater is needed to displace 62.3 L of PAC. This would require an area of 1.5 square meters for a 50 mm rain. Table 6-32 presents the rainfall catchment area required for different PAC dose rates (at 10.1% Al_2O_3 by weight).

Table 6-32. Rainfall Catchment Area Required for Different PAC Derived Aluminum Dose Rates

Aluminum dose required (mg/L)	Roof catchment area per hectare of saturated disturbed ground (m^2)	Roof catchment area per hectare of stabilized catchment (m^2)
2	0.375	0.225
4	0.75	0.45
6	1.125	0.675
8	1.5	0.90
10	1.875	1.125
12	2.25	1.35

• Header tank size calculation:

The header tank allows initial abstraction losses on the site to be considered (provides a delayed dosage at the beginning of the rain) and continued dosing after the rain ends, but as the runoff continues. For the Auckland test sites, the header tank allows 15 mm of rainfall before dosing commences. This would require a header tank volume below the lowest overflow of 15 L per m^2 of roof rainfall catchment area. The lowest overflow consists of a 4mm internal diameter tube, while the high rate outlet has sufficient capacity to carry the maximum predicted flow from the roof catchment during short term rainfalls of about 40mm/hour.

• Displacement tank and chemical reservoir tank size calculation:

The displacement tank should fit neatly inside the reservoir tank when floating on the liquid chemical. A larger displacement tank and reservoir tank system will reduce the required frequency of servicing. Auckland Regional Council recommends that the minimum displacement tank capacity should be the 24-hour rainfall for a 2-year return period. In their field studies, this was about 86 mm of rain. With a 1.5 m^2 roof catchment area, this would result in a volume of 129 L. Their standard design used a 400 L displacement tank inside a 550 L reservoir tank, providing dosing of up to 320 L of PAC. Their standard design called for the outlet tubing to be placed at the 400 L chemical level in the reservoir tank so it could hold the contents of two standard 200 L drums of PAC. The outlet tubing level is determined with the floating displacement tank in place to account for the slight displacement associated with the weight of the empty displacement tank.

Setup and Servicing of the Rainfall Driven Dosing System

• Header tank setup and maintenance:

The level of the low-capacity overflow from the header tank (the vertical position of the tubing exiting the tank) is set to allow for initial abstractions before chemical dosing starts. In the summer, after a week or more without rain, this was found to be about 15mm in the Auckland test areas. However, when a very intense rain of about 15 mm in 15 minutes fell on dry ground, substantial runoff occurred, and the delay in the start of dosing resulted in insufficient dosing. In wet weather, the header tank was set with no delay in dosing. During long dry periods, the header tank volume below the low capacity outlet is adjusted to provide for no dosing during the first part of the next rainfall. This is to prevent overdosing of the sediment pond which may cause reduced pH levels and associated increased free aluminum concentrations, plus it also conserves PAC. After each event, the water is removed from the header tank using a siphon. It also would be possible to install a drain valve in the bottom of the header tank for easier emptying.

• Displacement and chemical reservoir tank maintenance:

The chemical level in the reservoir tank and the water level in the displacement tank also need to be periodically checked. If the water level is too high, or the chemical level too low, then maintenance is needed. The displacement tank may be either emptied using a siphon, or bailed out by hand. The chemical reservoir can be filled using a hand operated drum pump to refill the reservoir from the 200 L delivery drum.

• Monitoring and adjustment for changing site conditions:

The passive chemical dosing treatment system needs to be carefully monitored during the first few runoff events to check that the system is effective, and to ensure that overdosing is not occurring. If overdosing is suspected (because the pond dead storage water is exceptionally clear), samples should be analyzed for pH and dissolved aluminum. If overdosing is occurring, reducing the size of the rainfall catchment tray can reduce the chemical dose. This can be done by placing a diagonal batten across the tray and directing some of the runoff through a waste hole.

Field Trials of Chemical-Assisted Sedimentation

Alum additions:

Initial tests indicated that alum additions (at 5.5 mg aluminum/L) worked well under a wide range of rain conditions at a site having limestone soils, including during one event having 25 mm of rain in 25 minutes. During this intense rain, the alum-treated pond had a 92% reduction in suspended solids, compared to only 10% in the same pond for a similar heavy rain during a period of no alum addition. The pH was reduced by about 0.5 pH units and the discharged dissolved aluminum concentration was about 0.1 mg/L during these tests. The pH did not undergo major reductions during bench-scale tests, even when the dosage approached 12.6 mg/L.

Polyaluminum Chloride (PAC) additions:

The runoff from test sites having clay soils had more acidic runoff than the sites that had limestone soils. At the clay sites, alum-treated runoff (after the pond) had pH values that ranged from 4.3 to 5.9, while runoff treated with PAC had pH values ranging from 5.5 to 6.7. They therefore decided that PAC was a more suitable choice, especially for clayey soil conditions. Overall, the Auckland Regional Council has data from 21 different sediment ponds that used passive PAC additions, with drainage areas ranging from 0.5 to 15 ha (1.3 to 38 acres). The overall suspended solids treatment efficiency of PAC-treated ponds has been between 90 – 99 % for ponds having good physical designs. Lower treatment efficiencies have occurred where there have been problems with decants not operating properly, or physical problems such as multiple inflow points, high inflow energy, and poor separation of inlets and outlets. The following photo shows the typical multiple decant risers used at Auckland Regional Council sediment pond sites to allow more efficient settling of the floc by varying the flow rate as the stage changes. The lower flow rates associated with low stages allowed increased treatment rates.

Figure 6-68. Multi-level, perforated, floating discharges (decants) to better retain floc.

PAC was tested for ALPURT project during the 1998/99 summer, and during the winter of 1999. A total of 21 systems were used, with contributing catchments ranging between 0.5 and 15 hectares. Table 6-33 presents representative data for PAC-dosed stormwater from sites having clay soils. The data shows that a high degree of suspended-solids reduction was achieved in the PAC dosed ponds. The influent concentrations of suspended solids for the PAC-treated ponds ranged from 750 to 26,300 mg/L (median of about 16,000 mg/), while the treated effluent ranged from 3 to 966 mg/L (median of approximately

50 to 100 mg/L). The percentage suspended solids reductions ranged from 92 to >99%, with a median of about 99%. The untreated pond had much poorer levels of treatment (about 10%).

Table 6-33. Suspended Solids Removal from PAC Treated Stormwater

Pond	Date	Inflow Flow (L/sec)	Inflow SS (mg/L)	Outflow Flow (L/sec)	Outflow SS (mg/L)	SS Reduction (%)
Mason's Rd	28.11.1998	3	26,300	3	144	99.4
Mason's Rd	04.12.1998	2	5,100	2	40	99.2
OVR E	13.06.1999	15	1,639	8	51	96
OVR E	04.07.1999	2	749	2	56	92
23800E	28.11.1998	8	14,800	6	966	93
23800E	22.01.1999	1	18,700	2	67	99
B1 Gully	08.04.1999	0.3	4,300	0.4	3	99.9
B1 Gully	01.05.1999	0.5	16,900	3.0	59	99.6

Source: Beca Carter Hollings & Ferner Ltd, undated

There was considerable variation of inflow suspended solids concentrations between the different ponds sampled (Table 6-34). These large variations reflected the characteristics and condition of the construction sites. All of the treated ponds achieved good suspended solids reductions (77 – 98%) compared to that of untreated ponds (4 – 12%). The PAC dosing caused an obvious reduction in pH in all ponds, except at Lonely Culvert. It is interesting to note that the dissolved aluminum concentrations in the outflow from the untreated pond were much higher (0.29 – 0.31 mg/L) than in the outflows from the treated ponds (0.010 – 0.084 mg/L). The dissolved aluminum concentration is related to the characteristics of the suspended solids, with high concentrations of dissolved aluminum occurring in samples that also had high concentrations of very fine suspended solids. Therefore, the effluent from the untreated ponds, having high concentrations of fine sediment, also had high concentrations of dissolved aluminum. When the PAC was added at too high a concentration, the pH levels dropped to as low as 4.7, although the effluent dissolved aluminum was still low and the suspended solids concentrations were very low (as low as 10 mg/L). Typical effluent pH conditions were between 6 and 7.

Tables 6-34. Inflows and Discharges of PAC Treated Ponds

Pond	Time	Inflow Flow (L/sec)	Inflow SS (mg/L)	Inflow pH	Inflow Al (mg/L)	Outlfow Flow (L/sec)	Outlfow SS (mg/L)	Outlfow pH	Outlfow Al (mg/L)	Reduction in SS (%)
1.3.8 Over	0850	12	238	8.97	0.084	9	53	6.66	0.026	77
	1135	20	253	9.97	0.077	12	55	6.79	0.068	78
Lonely	0938	40	25,830	6.83	0.052	3	266	7.62	0.072	98
	1045	15	13,310	6.62	0.093	20	214	7.02	0.018	98
21340	0918	8	399	8.78	0.25	3	40	6.56	0.016	89
	1110	7	2,564	7.03	0.11	15	57	6.55	0.01	88
D5	0910	6	2,132	6.81	0.16	4	65	5.96	0.025	96
	1110	7	2,564	7.03	0.11	4	56	5.47	0.01	97
Untreated	1930	12	1,571	7.88	0.22	4	1,378	7.74	0.31	12
Pond	1100	9	1,522	8.02	0.17	4	1,459	7.83	0.29	4

Source: Beca Carter Hollings & Ferner Ltd, undated

The dissolved aluminum concentrations in the outflows from the treated pond samples shown in Table 6-35 were below the USEPA aquatic life chronic criterion of 0.087 mg/L (4-day average not to be exceeded; the data shown in this table are for instantaneous grab samples), and well below the acute criterion of 0.750 mg/L (1-hour average not to be exceeded). These data show very high removals of suspended solids, particularly in the ponds with high-suspended solids in the inflows. In contrast, the untreated pond had the highest concentrations of suspended solids in the outflow. The data for the Mason's Rd pond provides an example of a PAC overdose, where the pH after dosing was reduced to 4.44, and the dissolved aluminum concentration was at a high level of 1.1mg/L. The outflow data for pond 2444OW also indicates a possible PAC overdose, with a low pH of 4.70, although the dissolved aluminum was not markedly elevated.

Table 6-35. PAC Dosed Sediment Retention Pond Monitoring Data, 21.10.99

Pond	Inlet/ Outlet	Time	Flow (L/S)	pH	SS (mg/L)	Al (mg/L)	Hard (mg/L)	Reduction of SS (%)
Mason's	In	1700	3	6.44	4,704	0.02	72	
	Out	1705	3	4.44	41	1.10	49	99
OVRE	In	1720	12	8.80	23,240	0.29	65	
	Out	1725	10	9.04	272	0.07	95	98
OVRW	In	1740	8	6.86	28,845	0.02	194	
	Out	1745	10	6.89	338	0.02	85	98
2444OW	In	1750	3	-	164	0.20	58	
	Out	1745	2	4.70	15	0.34	47	90
D5	In	1815	6	7.65	770	0.03	206	
	Out	1820	5	6.15	36	0.01	159	95
2134OW	In	1825	3	10.73	128	0.31	64	
	Out	1827	4	6.84	14	0.03	81	89
Debs	In	1845	4	11.47	752	0.21	135	
	Out	1850	6	9.82	279	0.31	98	62
Lonely	In	1855	4	11.12	254	0.07	113	
	Out	1900	8	8.31	72	0.16	113	71
Untreated	Out	1835	3	8.63	712	0.06	89	

Source: Beca Carter Hollings & Ferner Ltd, undated

Design of Sediment Ponds with Aluminum Coagulant Treatment

Although chemical treatment using aluminum coagulants is capable of achieving effective sediment removal from stormwater (with relatively brief detention time for settlement in quiescent conditions), there are practical difficulties in achieving quiescent conditions in construction site ponds when high flows are being discharged into a small pond. The Auckland Regional Council recommends a minimum size of 1.5% of the drainage area (150 cubic meters per hectare) for aluminum-coagulant treated ponds. Analysis of the long-term rainfall and construction-site suspended solids data obtained during the field trials shows that more than 60% of the sediment from a construction site occurs during the two or three rainstorms per construction season that exceed 30 mm in 24 hours.

Table 6-36 shows the expected advantages of using PAC-assisted sedimentation for different sizes of wet sediment ponds in the Auckland, New Zealand, area. Chemical treatment results in a major improvement in the efficiency of sediment capture during rainstorms that exceed the hydraulic capacity of a sediment pond. This is indicated by the large improvements in sediment capture for the smaller ponds with PAC addition shown in Table 6-36.

Table 6-36. Summary of Advantages of PAC Treatment of Construction Site Runoff for Normal Catchments during a Construction Season

	Wet Sediment Pond Size (% of drainage area)		
	3%	2%	1.5%
1. Without PAC treatment:			
Total sediment discharged to receiving water (tonnes dry wt per hectare)	5.8	9.2	12.0
Efficiency of sediment removal in pond (%)	81	69	60
2. With PAC treatment:			
Total sediment discharged to receiving water (tonnes dry wt per hectare)	1.0	2.1	2.8
Efficiency of sediment removal in pond (%)	97	93	90

Polymer, or other flocculant, use may be needed to achieve low turbidity effluent concentrations, even with the best site erosion prevention practices. The polymers can be applied in dry or liquid form. Liquid use is most common for treatment at sediment ponds. The polymer can be mixed directly in the influent to the pond, as in the New Zealand example, with resulting floc being captured in the pond. However, some of the floc may still be in the effluent during periods of sediment scour (minimized if using wet ponds with suitable standing water). In other cases, polymer treatment systems may be used as a polishing treatment unit for the pond effluent. In all cases, the capture of the floc before discharge to the receiving waters is necessary. The following is a photograph of a sand filter system used to capture the flow before discharge.

Figure 6-69. Sand filters for floc removal after liquid polymer treatment at construction site (D. Lake photo)

The following sidebar is an excerpt on flocculant use in sediment ponds contained in the *Alabama Handbook* (ASWCC 2018), as an example on how current erosion control guidance documents provide information on flocculant use at construction site sediment ponds. Other discussions of chemical use at construction sites for enhanced treatment was provided in Chapter 5.

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Sidebar: “Practice Definition

Flocculation is the chemical process of causing small, suspended soil particles to be drawn together to form “flocs”. These flocs more readily settle out compared to the individual particles due to their relatively greater mass. Products that cause flocculation of suspended soil particles (Flocculants) are often used to help polish, or minimize turbidity of stormwater runoff from construction sites. These products may contain both manufactured and natural polymers.

Planning Considerations

Products containing polyacrylamide (PAM) are commonly used in construction. PAM is a term describing a wide variety of chemicals based on the acrylamide unit. Products containing chitosan have also shown to be effective in reducing turbidity in stormwater runoff and are also commonly used in the US. Chitosan is a naturally occurring polymer.

When properly applied at the recommended rates, flocculants can be used as polishing agents to remove sediments from turbid runoff water on a construction site. If conventional erosion and sediment control are not being properly implemented to the fullest extent, flocculants will have little or no effect on the quality of the runoff from a construction site. Most flocculant products are available in emulsions, powders, gel bars, logs, tablets, and socks. When including flocculant as a treatment option on a project, the following items must be addressed:

- Some states do not allow the use of flocculants for turbidity management. Flocculants are allowed in Alabama.
- Flocculant products should be tested for ecotoxicity and proven to not be toxic if used in accordance with the manufacturer’s recommended application rates.
- Material Safety Data Sheets (MSDS) should be stored and available onsite.
- Areas where flocculant is applied must drain to a sediment basin or other BMP that promotes settling for final flocculation prior to discharging from the site.
- Adequate mixing is necessary for flocculant to be fully effective. Passive treatment using the turbulent flow of water in a channel or at the outlet of a pipe as the mixing method is encouraged.
- Adequate time and laminar flow (calm flow) or ponding is necessary to promote effective and efficient flocculation.
- Flocculant must be reapplied as it becomes bound with sediment particles with each rain event or other new flow.

- Flocculants that are water soluble dissolve slowly and may require considerable agitation and time to dissolve.

- Soil tests, such the “jar test”, are required to ensure that the flocculant is properly matched with the anticipated soils suspended in the runoff.

- Manufacturer’s application or dosage rates and application instructions should be followed closely based on specific site conditions and soils.

Design Criteria
Flocculants mixed with water after heavy sediment loads and particles have been removed can greatly reduce turbidity and suspended solids concentrations. Flocculants are commonly used to passively treat construction stormwater runoff in a conveyance, within sediment basins, or with other sediment traps, barriers or other practices. Flocculants may also be used in conjunction with erosion control practices and products to better manage raindrop and rill erosion. Flocculant is also used as a part of active treatment systems. It is critical that precautions are taken to minimize the potential for over application of flocculant or the release of flocs into receiving waters.

The following basic guidelines, at a minimum, should be followed when specifying or using flocculant:

1. Completely understand any regulatory requirements concerning the use of flocculants.

2. Choose the appropriate flocculant for the soil type.

3. Choose flocculants deemed non-toxic based on toxicity reports related to the planned use.

4. Adhere to manufacturer recommendations and MSDS for specification and application.

5. Use flocculants in conjunction with other appropriate BMPs. Pretreatment to remove heavy loads and larger particles should take place in advance of flocculant introduction when possible.

6. Do not apply flocculants directly to streams, wetlands, or other waters of the state.

7. Provide provisions for capturing flocs prior to their entering receiving waters.

8. Use of multiple types of flocculants in the same watershed should be avoided. Without a full understanding of the chemical interactions of each flocculant there is a possibility the two flocculants could interact with each other, reducing the overall effectiveness.

9. Dry form (powder) may be applied by hand spreader or mechanical spreader. Mixing with dry silica sand will aid in spreading. Pre-mixing of dry form flocculants into fertilizer, seed or other soil amendments is allowable.

10. Solid forms of flocculant shall be applied following site testing results to ensure proper placement and performance and shall meet or exceed state and federal water quality requirements. Logs, blocks, and tablets must be installed up gradient from the sediment capture BMP. Solid forms of flocculant should be protected from the sun and remain hydrated if possible.

11. Some flocculants involves a two-component system and generally are provided in the form of "socks." Manufacturer recommendations for installation and matching the components should be followed closely.

Materials and Installation Requirements

One of the key factors in making a flocculant work is to ensure that it is dissolved and thoroughly mixed with the runoff water, which can be accomplished in several ways. Introducing the flocculant to the runoff at a point of high velocity will help to provide the turbulence and mixing needed to maximize the suspended sediment exposure to the flocculant. Examples include a storm drain junction box where a pipe is dropping water, inside a slope drain, or other areas of falling or fast moving water upslope from a sediment capture BMP.

Another option for introducing flocculant into runoff involves running the water over a solid form of flocculant. Powders can be sprinkled on various practices such as check dams and materials, such as jute, coir, or other geotextiles. When wet, flocculants could become very sticky, and bind to the geotextile fabric. The product binds to the material, and resists removal by flowing water rendering it ineffective for turbidity control.

Flocculant logs are designed to be placed in flowing water to dissolve the flocculant from the log somewhat proportionately to flow. While using these solid forms does not have the same challenges as liquid forms, they do have drawbacks. The amount of flocculant released is not adjustable and is generally unknown, so the user has to adjust the system by moving or adding logs to get the desired effect. Because flocculant blocks can be sticky when wet, it can accumulate materials from the runoff and become coated, releasing little flocculant. The solid forms also tend to harden when allowed to dry. This causes less flocculant to be released initially during the next storm until the log becomes moist again.

To avoid these problems, the user must do two things to ensure flocculant releases from the solid form:

- Reduce sediment load in the runoff upstream of the flocculant location. This avoids burying the flocculant under accumulated sediment.

- Create constant flow across or onto the solid flocculant. The flow will help dissolve and mix the flocculant as well as prevent suspended solids from sticking to the product."

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Case Study – New York State Route 219 Project

New York State Route 219 is a major connector route between the south Buffalo urban corridor and the popular winter recreation areas of Ellicottville 60 miles to the south. This route was upgraded over the past two decades to a four lane highway in the northern portion that extends from West Seneca, just south of Buffalo, to Springville. It is the plan of NYS Department of Transportation to complete the rest of the upgrade over a multi-phased set of contracts over the next twenty years.

The most recent construction phase, begun in 2007 and completed in 2011, is a 5.5 mile long north-south section beginning at Springville just north of NYS Route 39 extending south, bridging Cattaraugus Creek and stopping at Peters Road. A significant mile long portion of this work was planned in an area to the west of the existing route 219 and centered on a lower elevation at Scoby Road. The design for this segment was an embankment fill section. A landslide occurring during construction activities in the spring of 2008 altered these plans.

The landslide was a rotational failure that covered an area approximately 0.75 miles long and up to 600 feet in width from the top of the scarp on the east side to the toe of the slide on the west side. The width of the slide extended beyond the right of way the state had purchased for the highway. Scoby Road was basically located at the middle of the slide area. This road ran west from Route 219 and terminated at the bottom of the slope at Cattaraugus Creek. It provided access to four residences and the creek for public fishing.

The original design of the new section of Route 219 for this segment was a parallel four lane highway with a median located approximately 500 feet west of and slightly lower in elevation than the existing road. The embankment section at Scoby Road was to be approximately 30 feet high at the planned bridge. Due to the landslide, the entire segment through the slide area had to be redesigned.

Figure 6-70. NYS Route 219 slide area looking north from south end of the slide area. Note Scoby Road at the center low spot with the crane. Existing Route 219 is to the right up slope and Cattaraugus Creek is to the left down slope (D. Lake photo)

The revised design required stabilization of the slide area. This was done with a combination of horizontal drains drilled beneath the construction area to relieve groundwater pressure, buttressing excavated slopes to prevent and stabilize smaller slides within the large slide, and changing the road section from an embankment to an excavated one while balancing the amount of excavation with road sub-base fill to minimize loading and slope movement in the slide area.

Figure 6-71. Construction equipment is removing previously placed embankment material to unload the slide area north of Scoby Road. Note that all runoff drains towards the foreground (D. Lake photo)

The construction right of way limits were relatively narrow for the original design and in the slide area these limits had to be extended with additional properties taken to affect a stable remedy. These narrow limits also constrained erosion and sediment control options and made stormwater runoff control difficult. All the stormwater runoff from the bowl of the slide area, and some areas beyond, drains primarily to Scoby Road, with some small areas draining off through a few small gully areas to the west, with it all eventually reaching Cattaraugus Creek. To complicate matters further, groundwater became a large problem as soon as the excavation for the revised design was down twelve feet or so below natural ground.

Figure 6-72. Groundwater is flowing in the drainage ditch along the west side of the construction area towards Scoby Road. The flow rate from this source was a fairly constant 130 gallons per minute (D. Lake photo)

There was a constant groundwater baseflow of 130 gallons per minute for the drainage area north of Scoby Road. The baseflow south of Scoby Road draining back to the north was less than 20 gallons per minute. The constant flow from the north area, combined with small rainfall events in this relatively narrow corridor containing a large amount of disturbed area, eventually led to turbid discharges to Cattaraugus Creek. These discharges were observed by the US Army Corps of Engineers who issued a notice of non-compliance for the project. This notice required action to be taken to correct the problems.

Figure 6-73. Turbid discharge is shown here entering Cattaraugus Creek at the Scoby Road outlet approximately 400 feet to the west and down slope of the project limits (D. Lake photo)

The existing erosion and sediment control measures that were in place in the Scoby Road segment consisted of perimeter silt fence, intermittent stone check dams and two sediment basins. These, however, were not effective in preventing turbid discharges from leaving the project boundary. The disturbed soils to the north of Scoby Road were clay and silt. The gradation of this material ranged from 85 to 92 percent smaller than a #200 sieve, with 46 to 50 percent smaller than 0.002 millimeters (2 µm). The USCS classification for this soil is CL, a low plastic clay.

Figure 6-74. The soil north of Scoby Road is low plastic clay. Here it is being rapidly eroded by groundwater (D. Lake photo)

A revised erosion and sediment control plan was developed with the approach to limit the amount of exposed fine grain soil, provide stable conveyance for surface flow using one inch of runoff for design, and locate and design additional sediment trapping devices in a treatment train using the linear nature of the right of way, and provide polymer treatment (Chitosan Acetate) as a final settling stage for the fine particles north of Scoby Road.

The erosion and sediment control plan was revised weekly as the work progressed in the slide area. Practices were relocated, added and removed as the excavation and fill process continued. Ditches and swales were lined with construction grade plastic to prevent flow from eroding the fine grain soil. Stone check dams were placed in drainage ways and faced with pea gravel to slow velocity and trap sediment.

Figure 6-75. The plastic lined swale conveys groundwater through areas of fine grain soil limiting the erosion. Note the slope stabilization (D. Lake photo)

Figure 6-76. This is a stone check dam faced with pea gravel to slow water velocity and trap sediment (D. Lake photo)

All exposed areas of disturbed soil were delineated for temporary seeding with rye and a fiber mulch cover to protect the soil surface from rainfall impact and limit soil movement from the surfaces.

Figure 6-77. This exposed area has been treated with temporary seed and mulch to reduce soil erosion losses (D. Lake photo)

Linear sediment traps were constructed along the rights of way boundaries and in the median and maximized the length to width ratios to effectively trap sediment. The outlets of these traps were generally rock dams with pea gravel facing on the upstream side. After the initial installation of the linear sediment trap above the sediment basin north of Scoby Road, the turbidity of the influent sediment laden flow was 2,600 NTU. The effluent turbidity leaving this sediment trap was 40 NTU. This effluent turbidity value increased when the sediment trap filled and water and excess flow over topped the rock dam.

Figure 6-78. This linear sediment trap is located north of Scoby road upstream from a sediment pond. Its pea gravel/rock dam outlet reduced the sediment load from 2,600 NTU to 40 NTU. Constant maintenance was required (D. Lake photo)

Figure 6-79. This system of two sediment traps south of Scoby Road had two different outlet types. Together they limited the discharge to 25NTU (D. Lake photo)

The erosion and sediment control system north of Scoby Road terminated at a sediment pond from which the remaining turbid water was treated by a polymer treatment system. The operators applied the designed dosage of Chitosan Acetate (average metered dose was 0.86 lb/day, or about 0.7 mg/L), directed the flow through settling tanks, and released it to an outlet to Cattaraugus Creek. The background NTU reading for the creek was an average of 5 NTU for clear conditions. The creek was sampled twice daily and readings of the treated effluent from the sediment basin were taken every 15 minutes. The average discharge from the system was 1 NTU. As noted in the New Zealand chemical treatment discussion, effluent sediment and turbidity below natural conditions can cause unstable receiving water conditions if the water is too far below its carrying capacity. This can increased stream bank erosion and sediment transport in the receiving water.

Figure 6-80. This is the inside of the control center for the polymer operation. Constant monitoring of the NTU levels is provided by the continuous turbidity meters on the back wall (D. Lake photo)

Operation and management of the erosion and sediment control plan for this project was key to its final success. NYS DOT field engineers and staff divided the project into five segments, each with its own inspector whose duty it was to complete field compliance inspections twice a week. The contractor maintained two field maintenance crews to repair, replace, relocate, and install erosion and sediment control practices as the project landscape and the erosion and sediment control plan changed as the construction phases progressed.

Figure 6-81. This aerial view shows the erosion and sediment control system just north of Scoby Road located at the right of the photo. Note the plastic lined swales. Flow is from left to right as it works from a swale through a pipe to the linear sediment trap, the small basin with a pipe to the larger basin where the polymer system is located. The shale buttressing for slope stability and drainage is prominent in the upper portion of this part of the project (NYS DOT photo)

While the maintenance crews were doing their jobs, the seeding sub-contractor was mobilized about every three days to seed and mulch disturbed soil areas. The polymer sub-contractor was operating all days and for all hours to assure compliance of discharges from the Scoby Road drainage area. No additional water quality violations occurred after the plan was implemented.

Construction sites that have attributes and constraints, such as those encountered on the Route 219 project, become complex and need comprehensive plans with strong field management that utilize both a combination of appropriately designed practices and innovative technology to help overcome the site constraints to assure that environmental performance objectives are met.

Figure 6-82. Final grading for the pavement base layer is almost completed in the Scoby Road segment (D. Lake photo)

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Silt Fences and other Perimeter Barriers for Construction Site Sediment Control

Silt fences do not operate as filters. The fencing material is not acting as a filter, e.g., straining particles from the passing water. In fact, the silt fences operate by creating a miniature pond behind the fence, which allows runoff to slow down and pool, which allows sediment to settle in the area behind the silt fence. There are three aspects of silt fences that can be evaluated, as demonstrated in the following examples: 1) sediment capture behind the fence, 2) water flow rate reduction down slope, and 3) pressure forces on the fence from the water and resisting forces from the soil on the fence stakes. The first two aspects determine the erosion and sediment control benefits of silt fences, while the third aspect determines how silt fences may fail structurally.

Double silt fence row along toe of slope (J. Voorhees photo)

Silt fence at toe of slope (J. Voorhees photo)

Turbidity barrier silt fence around sediment delta (J. Voorhees photo)

Dewatering bag filter (J. Voorhees photo)

Perimeter protection of parking lot using silt fence (D. Lake photo)

Silt fencing surrounding stockpile (E. Hahn photo)

Figure 6-83. Uses of filter fabric material and silt fences at construction sites.

 Silt fence and ponding water	 Material trapped in ponded water area of silt fence

Figure 6-84. Silt fences accumulation of material (J. Voorhees photos)

 Sediment flowing under hay bale barrier	

Silt fences reinforced by hay bales (J. Voorhees photos)

Hay bale barrier along edge of pavement

Figure 6-85. Example use of hay bale barriers (most agencies do not allow hay bale barriers now)

Evidence of underflow erosion beneath improperly installed silt fabric fence

Holes in silt fabric fencing	Silt fabric fence installed close to construction area
 Silt fence along edge of property line (front side to left)	 Silt fence along edge of property line (back side)
 Multiple rows of silt fences and tree barriers to mark edge of disturbed zone	 Well-installed filter fabric silt fence, with bottom of fabric buried and backfilled to prevent underflow of sediment

 Large sediment load captured by silt fence, maximum load before needed maintenance (J. Voorhees photo)	 Same site as prior photo showing sediment load overtopping silt fabric fence due to lack of maintenance (J. Voorhees photo)

Figure 6-86. Problems with silt fences at construction sites.

Sediment Capture behind Silt Fences

Relatively few field investigations have been conducted to examine the effectiveness of silt fences and other controls, at construction sites. Important early tests were performed by Barrett, *et al*. (1995), Horner, *et al*. (1990), Schueler and Lugbill (1990), and Smoot, *et al.* (1992). The sidebar in Chapter 1 presents a silt fence evaluation project conducted in Alabama.

Perhaps the most comprehensive early study of silt fences was conducted by Barrett, *et al*. (1995) at Austin, TX, area highway construction sites, supplemented with controlled laboratory tests. Silt fences at six active highway construction sites were evaluated in terms of suspended solids and turbidity reduction. Two installations used non-woven fabrics, and four installations used woven fabrics. Manual grab sampling was used to obtain representative sediment samples of all size distributions during 10 rains. Uncontrolled discharges due to obvious silt fence failures (mostly undercutting flows or tears in the fabric) were excluded from sampling; only locations where the flows passed through the fabric were sampled. Samples were collected upslope of the pooled water behind the silt fence, in the pool backed up by the silt fence, and downstream of the silt fence. This sampling strategy was used to differentiate sedimentation from filtration effects, and to obtain an overall control efficiency. Because of highly variable concentrations above the pool, most of their data analysis relied on comparisons between the samples collected from the pool and the effluent from the fabric material, reflecting filtering removal and not sedimentation.

The observed suspended solids removal rates were highly variable, ranging from -61 to 54%, with a median of 0%. Typical effluent suspended solids concentrations after the silt fence were about 500 mg/L. Similar poor results were obtained for turbidity removals (-32 to 49% range, with a median removal of 2%). As indicated by the negative removal rates, the effluent from the silt fences sometimes had greater suspended solids concentrations than were found in the pool. The removal of suspended solids due to sedimentation, however, was estimated to be about 50%, based on partial field observations. At one location where the lower portion of the fabric was clogged, a shallow upstream pool lasted for an extended period and removals of about 65% were measured.

The poor removal efficiency due to filtration was explained by comparing the particle sizes of the suspended solids and the apparent opening sizes of the fabrics (typically from 100 to 1,000 μm). Silt and clay-sized particles comprised the majority of the solids collected (68 to 100%, with a median of 96%) from the pond and below the silt fences. Any large particles present in the flowing waters were thought to have been settled in the pool before the fence. The diameters of the remaining particles passing through the fence were therefore much smaller than the openings in the fabric and were able to pass through unhindered. Earlier work by Schueler and Lugbill (1990) in Maryland substantiated the small particles observed in Texas. During settling column studies on construction site runoff, Schueler and Lugbill found that 90% of the incoming sediment was smaller than 15 μm, with the largest particles observed being only 50 μm. During their sediment pond evaluation tests, however, they did observe sediment deltas forming near the influent location, indicating that sand-sized particles were transported to the sediment ponds and represented a minor portion of the total load. These larger particles were apparently not included in the grab samples as they form part of the bed load.

Barrett, *et al*. (1995) found that silt fence installations were not designed as hydraulic structures, and frequently, failures were caused by excessive runoff. Runoff around the ends of fences, and even fence over-topping of the fences was observed several times during their monitoring project. However, other downstream controls were in place to mitigate these failures. Besides failures caused by lack of hydraulic design, they also observed deficiencies in performance that were caused by improper installation and maintenance, including:

- Inadequate silt fabric splicing
- Fence failure due to sustained over-topping
- Unrepaired holes in fabric
- Flow beneath fabric due to inadequate trenching of the bottoms of the silt fences into the ground

Laboratory flume tests have also been conducted using filter fabrics, enabling flow rates and suspended solids concentrations to be controlled at specific conditions. Austin silty clay, after passing through a 3 mm sieve, was used to make a test slurry. The median particle size in this mixture was 20 μm, and 30% was finer than 3 μm. The apparent openings in the filter fabrics tested ranged from 600 to 850 μm for 3 woven fabrics and 150 μm for the one non-woven fabric tested. During testing, the woven fabrics had median suspended solids removal rates of 68 to 87% (ranges of 46 to 97%), while the non-woven fabric had a median removal rate of 93% (range of 73 to 99%). The non-woven fabric also had the longest detention times during the tests due to its lower pass-through flow rate. In comparison, a rock berm was also tested (having the highest flow rate and therefore shortest detention time) and had a median SS removal efficiency of only 42% (36 to 49% range). The suspended-solids reductions in the testing flume were 34% without any controls in place due to sedimentation of the larger test particles while flowing over the rough bed. This high background reduction level therefore significantly reduces these reported flume test measurements with controls. The corrected berm removal rate was only 7%, for example, after taking into consideration the background reductions. Similar reductions would have to be made for the filter fabric test results.

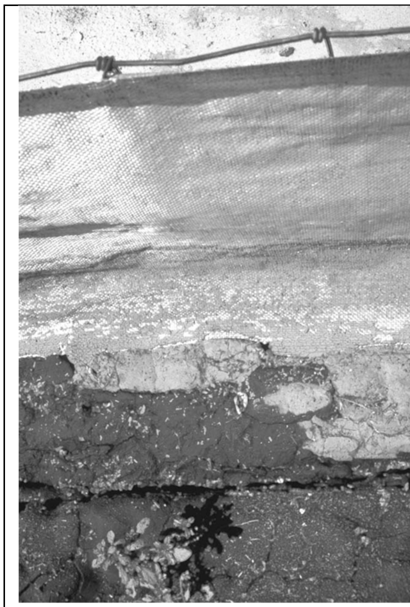
An interesting observation during the flume tests was that while the detention times increased with time since the start of the tests due to partial clogging of the fabrics, the woven fabrics all had decreased detention times after being exposed to large rains. Apparently, the rains helped wash some of the caked-on mud from the fabrics. This was not observed for the non-woven fabrics where clogging was internal and more permanent. During tests on stormwater filtration, several filter types were tested by Clark and Pitt (1999). They found that all of the fabrics examined were completely clogged after accumulating a layer of about 3 mm of silt and clay. This clogging layer preferentially forms near the bottom of the silt fence, indicating the depth of the ponding. This clogging significantly decreases the flow rates through the fabric, allowing extended detention and therefore increased sediment trapping performance.

Barrett, *et al*. (1995) concluded that the poor filtering performance of the silt fences in good condition was due to the small particles in comparison to the large fabric openings. Previously reported high filtration control efficiencies conducted during laboratory experiments were faulty due to the use of unrealistically large test particles. Median particles during field tests at construction sites indicate that almost all of the particles in the runoff are silts and clays. The relatively minor sand fractions are easily deposited during sheetflows, or in ponded areas. Sedimentation effectiveness was found to be highly dependent on the detention time in the ponded areas behind the filter fabrics. The detention time is controlled by the geometry of the upstream pond, hydraulic properties of the fabric, and maintenance of the silt fence. Holes in the fabric, under-cutting due to inadequate trenching of the fabric bottom, and overtopping or bypassing around the ends of filter fabric silt fences, all effectively decreased the detention time in the pond behind the fabrics and contributed to very low observed field performance of filter fabrics.

Test plots (with 10% slopes) at Spring Valley Farm in Georgia were used by Faucette, *et al.* (2009) to investigate different slope treatments under high intensity/durations associated with a 5-yr, 24-hr storm event. The erosion control treatments included 8 and 12 inch compost filter socks, with and without polymer, a mulch filter berm, and straw bales. The bare soil plot had runoff turbidity of 3,630 NTU. The compost filter socks with the polymer resulted in slightly reduced runoff turbidities of about 2,000 NTU, and about 2,500 to 3,000 NTU without the polymer. The mulch filter berm resulted in a turbidity of about 3,300 NTU and the straw bale resulted in a turbidity of about 3,200 NTU. Therefore, the overall turbidity reductions ranged from about 8 to 50%. Concurrent TSS concentration reductions were greater, at about 64 to 88%.

Cooke, *et al.* (2015) expressed concern about the general poor performance of silt fences to protect receiving water aquatic resources. They recommend better long-term planning, from prior to silt fence placement to after silt fence removal. They list many factors that may affect silt fence performance and see the need for detailed laboratory experiments and field monitoring. Better training and inspection is also needed. Finally, they encourage the use of comprehensive erosion controls on construction sites and not to over-rely on silt fences.

Bugg, *et al.* (2017) tested three different silt fence practices: Alabama Department of Transportation (ALDOT) Trenched silt fence, ALDOT Sliced silt fence, and Alabama Soil and Water Conservation Committee (AL-SWCC) Trenched silt fence, at the Auburn University Erosion and Sediment Control Testing Facility, AL. The sediment retention performance of these silt fence practices was 83%, 67% and 91%, respectively. Even with the large amounts of sediment retained, the downstream turbidity levels were still high. The turbidity ranged from about 4,000 to 10,000 NTU maximum levels upstream to about 3,000 to 8,000 NTU maximum levels downstream during the initial test periods. At the end of the test periods, the turbidity levels were about 1,000 NTU at both upstream and downstream locations. This study found that the structural performance of silt fences is the most important performance factor in retaining sediment. When exposed to large flows and maximum impoundments behind the silt fences, the ALDOT Trench and Sliced silt fences structurally failed, while the AL-SWCC Trenched silt fence did not. The only structural issue noted during any of the tests for the AL-SWCC Trenched silt fence was some partial and temporary undermining around one of the six posts as the water impoundment reached full height.



Silt captured on woven silt fabric

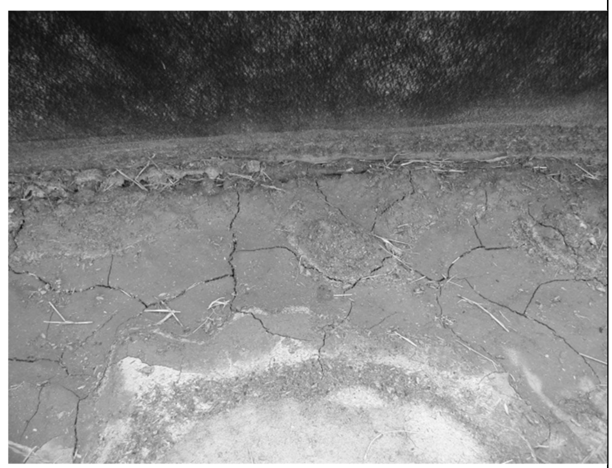
Layer of silt captured against bottom edge of newly installed silt fabric fence

Ponded area sediment accumulation and smear of silt on fence

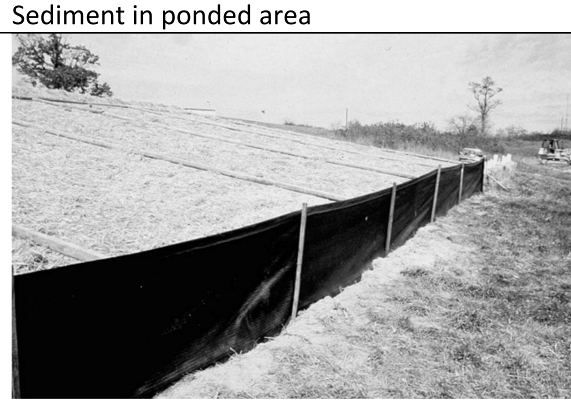
Bulk of sediment captured behind silt fence in ponded area


Heavy sediment load in ponded area

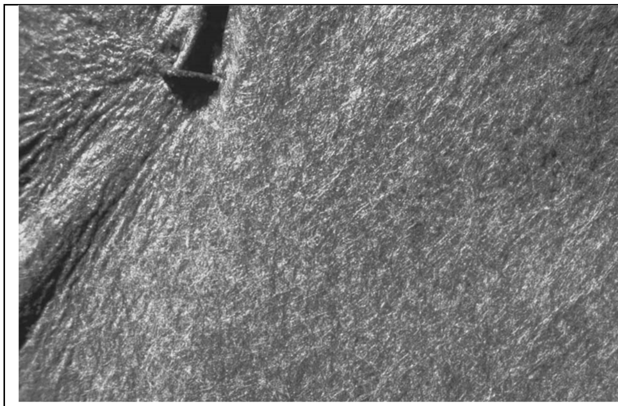
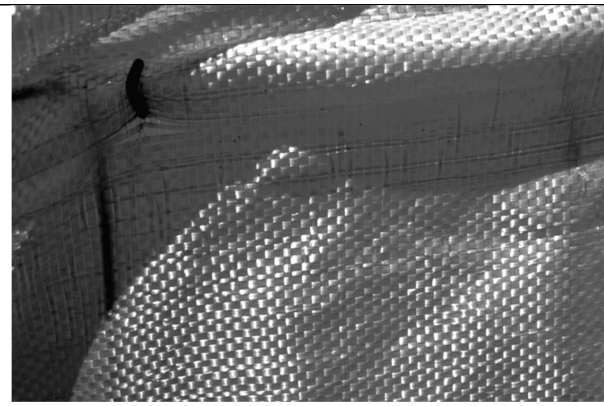

Sediment in ponded area


Sediment in ponded area


Sediment in ponded area


Silt fabric fence on mulched slope (SCS photo)

6-88. Material accumulation on silt fences.

	
Non-woven filter fabric	Woven filter fabric material

6-89. Different types of silt fence material

Example: Calculation of Sediment Capture behind Silt Fence

It is possible to calculate the expected level of control for a silt fence at a specific site using the upflow velocity concept presented earlier:

$$v = \frac{Q_{out}}{A}$$

The performance of a silt fence can therefore be calculated by knowing the ratio of the discharge through the fence divided by the surface area of the ponded area. Both of these values are directly related to the depth of water detained behind the silt fence. This value can be easily calculated assuming an even slope uphill from the fence and using the manufacturer's value for unit area flow capacity. The ponded surface area increases directly with the water depth, depending on the slope. The total outfall rate also increases directly with the water depth. Therefore, the critical particles being trapped in the pond behind the silt fence is only dependent on the slope and flow rate through the fabric. Figure 6-90 is a plot of the particle size controlled, in μm, for different ground slopes (%) and silt fabric flow rates (ft/sec), based on Stokes' law for calculating the critical particle sizes associated with the upflow velocity:

$$v = \frac{1}{18}\left[\frac{g}{\kappa}(spgr - 1)\right]d^2$$

where:
v= settling rate of particle, cm/sec
g = 981 cm/sec^2
k = kinematic viscosity = 0.01 cm^2/sec
spgr = specific gravity of particulate (often assumed to be 2.65 – the specific gravity of sand)
d = particle diameter, cm

Figure 6-90 can be used to estimate the approximate suspended solids control corresponding to the critical particle size. For example, if the calculated critical particle size is 10 μm (such as for a 2% slope and a 0.02 ft/sec filter fabric flow rate), the expected suspended-solids control would be about 25 to 45% for the size distributions likely appropriate for construction site runoff. A 5% slope and 0.25 ft/sec flow rate would result in about a 60 μm critical particle size, and the suspended-solids control would only be about 5 to 15%.

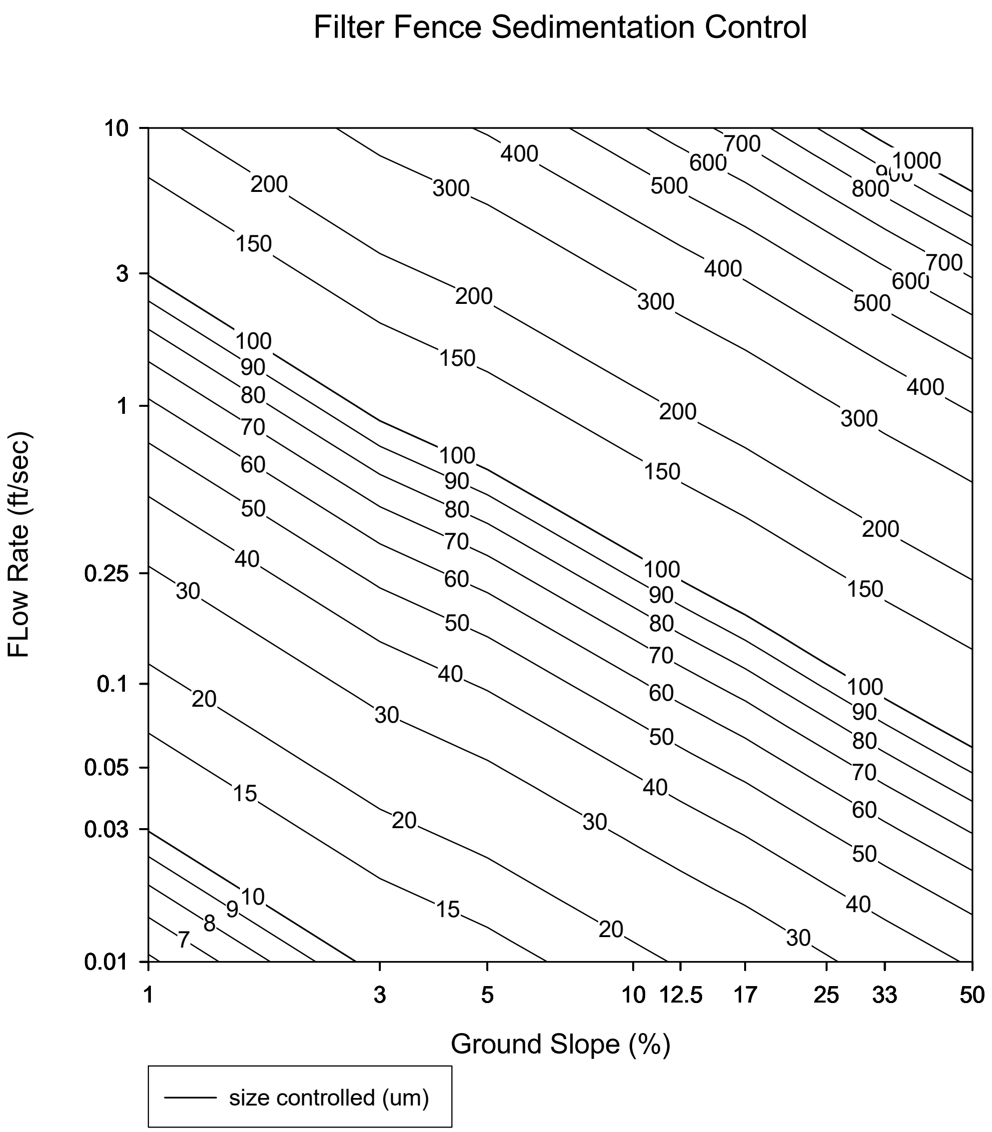


Figure 6-90. Filter fabric conditions and critical particle size controlled.

Silt Fences to Slow Water Flowing Down Critical Slopes

Silt fences intercepting sheetflows also may be used to slow the water flowing down critical slopes. The upslope length of the ponded area will be obviously protected from rain impaction and by flowing water. This length can be estimated for different water depths impounded behind a silt fence. As an example, for a 5% slope and a 1-ft water depth, the ponding would extend uphill 20 ft. In addition, some of the downslope area beneath of silt fence (if not installed on the toe of the slope, as generally recommended), will also have reduced flow velocities, compared to the same slope without the silt fence. Generally, non-woven filter fabrics have much lower flow rates compared to woven filter fabrics. The sheetflow calculation information in Chapter 4 also can be used to estimate the flow rates on slopes of different roughness and slopes. As an example, Figure 6-91 shows the sheetflow travel times for different slopes having a roughness value of 0.15, corresponding to relatively short grass. A slope of 10% that is 100 ft long would have a travel time of about 5 minutes, or a velocity of about 0.33 ft/sec. There are non-woven fabrics that have flow rates appreciably less than this value, so a silt fence could result in critical slopes having reduced periods of high flows. Of course, using multiple silt fences along a slope could help reduce the effective speed of the flowing water, but the accumulative amount of water reaching the lowest fence may be excessive, and the silt fences would have to be closely spaced, which is not a very satisfactory solution, compared to terracing or the use of coir logs on slopes, as described in Chapter 5.

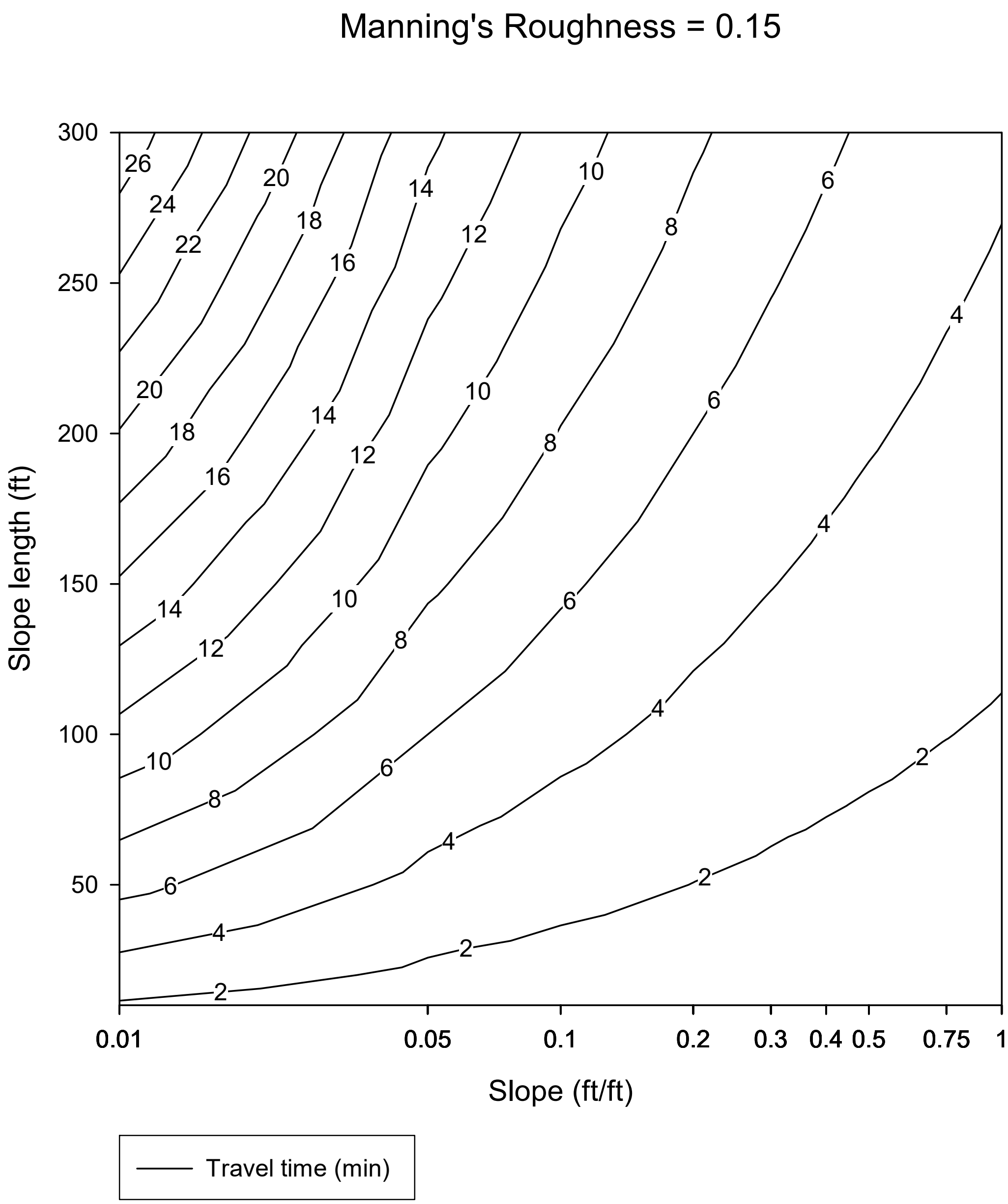


Figure 6-91. Sheetflow travel times for different slopes (NRCS and many agencies limit sheetflow length to 100 ft before shallow-concentrated flow forms).

Figure 6-92. Silt fence check dams on a construction site (practice not commonly approved; silt fences best use for sheet flows). Jamie Lyles; UA student.

Pressure Force on Silt Fences

The pressure equation can be used to calculate the forces acting on silt fences. The following calculation shows the resisting force needed for a 10 ft span of silt fence with 2 ft of standing water:

$$F_1 = \frac{\left(62.4 lb/ft^3\right)\left(\text{Cross}-\text{sectional area of flow}\right)\left(\text{Depth of flow}\right)}{2}$$

$$F_1 = \frac{\left(62.4 lb/ft^3\right)\left(20 ft^2\right)\left(2 ft\right)}{2} = 1248 lb$$

The momentum equation can be used when the flow rates should be considered:

$$F_1 - F_2 = PQ\,(V_2 - V_1)$$

Basically, the forces acting on a silt fence can be very large and the silt fence stake systems must be selected to withstand this force and prevent tipping or breaking of the support posts. In addition, the resisting forces of the soil also act on the fence stake to hold it upright, which also must be considered. Wet and soft soils may need long stakes driven deeply in the ground to resist this tipping/breaking pressure.

Guidance for Silt Fence Construction

The following sidebar is excerpted from the 2018 edition of the *Alabama Handbook for Erosion Control* (ASWCC 2018). As noted above, most failures of silt fences are associated with poor placement and maintenance. The following is an example of the typical guidance provided in regional construction site erosion control handbooks. These construction details are critical for proper operation of these common construction site controls.

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Sidebar: “Practice Description

A sediment barrier is a temporary structure used across a landscape mostly on the contour to reduce the quantity of sediment that is moving downslope. The most commonly used barrier is a silt fence (a geotextile fabric which is trenched into the ground and attached to supporting posts and possibly wire fence. Other barrier materials could include sand bags, wattles, and various man-made materials and devices that can be used in a similar manner as a silt fence.

This practice applies where sheet and rill erosion occurs on small disturbed areas. Barriers intercept runoff from upslope to form ponds that temporarily store runoff and allow sediment to settle out of the water and stay on the construction site.

Planning Considerations

Sediment barriers may be used on developing sites. It is most important that they be installed on the contour so that flow will not concentrate and cause bypassing by runoff going around the end of the barrier or overtopping because of lack of storage capacity.

The most commonly used sediment barriers are silt fences, and manufactured sediment logs (often referred to as wattles or sediment retention fiber roll). Manufactured sediment logs should be installed according to manufacturer’s recommendations.

The success of silt fences depends on a proper installation (on the contour with each end turned up slope) that causes the fence to develop maximum efficiency of sediment trapping. Silt fences should be carefully installed to meet the intended purpose.

A silt fence is specifically designed to retain sediment transported by sheet flow from disturbed areas, while allowing water to pass through the fence. Silt fences should be installed to be stable under the flows expected from the site. Silt fences should not be installed across streams, ditches, waterways, or other concentrated flow areas.

Silt fences are composed of geotextile supported between steel or wooden posts. Silt fences are commercially available with geotextile attached to the post and can be rolled out and installed by driving the post into the ground. This type of silt fence is simple to install, but more expensive than some other installations. Silt fences must be trenched in at the bottom to prevent runoff from undermining the fence and developing rills under the fence. Locations with high runoff flows or velocities should use wire fence reinforcement.

A rather recent innovation that somewhat resembles a double silt fence and referred to as a “sediment retention barrier with flocculant” is used to reduce turbidity in the runoff that will reach sensitive sites. The measure consists of a double row of netting or high flow silt fences installed parallel with loose straw, woodchips or other organic fill spread between the rows and straw or other organic material laid on the ground adjacent to the downslope row (see following picture). An approved flocculant powder is added to the material between the rows and to the organic material below the downslope row prior to runoff events. The measure is located upstream of a filter strip or buffer zone and is installed on the contour. Design professionals should get details needed to design this measure from a qualified industry representative.

Sediment retention barriers may be used as a “last line of defense” against sediment leaving the construction site in sensitive areas. Do not use it in lieu of adequate erosion and sediment control practices.

Design Criteria (only for silt fence)
Silt fence installations are normally limited to situations in which only sheet or overland flow is expected because the practice cannot pass the volumes of water generated by channel flows. Silt fences are normally constructed of synthetic fabric (geotextile) and the life is expected to be the duration of most construction projects. Silt fence fabric should conform to the requirements of geotextile meeting the requirements found in ASSHTO M288.

The drainage area behind the silt fence should not exceed ¼ acre per 100 linear feet of silt fence for non-reinforced fence and ½ acre per 100 feet of wire reinforced fence. When all runoff from the drainage area is to be stored behind the fence (i.e. there is no stormwater disposal system in place) the maximum slope length behind the fence should not exceed those shown in Table 6-37.

Table 6-37. Slope Limitations for Silt Fence

Land Slope (Percent)	Maximum Slope Length Above Fence (Feet)
<2	100
2 to 5	75
5 to 10	50
10 to 20*	25
>20	15

* In areas where the slope is greater than 10%, a flat area length of 10 feet between the toe of the slope to the fence should be provided.

Type A Silt Fence
Type A fence is at least 32” above ground with wire reinforcements and is used on sites needing the highest degree of protection by a silt fence. The wire reinforcement is necessary because this type of silt fence is used for the highest flow situations and has almost 3 times the flow rate as Type B silt fence. Type A silt fence should be used where runoff flows or velocities are particularly high or where slopes exceed a vertical height of 10 feet. Staked tie backs on each end of a Type A silt fence may be necessary to prevent overturning.

Provide a riprap splash pad or other outlet protection device for any point where flow may overtop the sediment fence.

The silt fence should be installed as shown in Figure SB-1. Materials for posts and fasteners are shown in Tables 6-38 and 6-39. Details for overlap of Type A silt fence is available from The Alabama Department of Transportation construction drawings.

Table 6-38. Post Size for Silt Fence

	Minimum Length	Type of Post	Size of Post
Type A	5'	Steel "T" Post	1.3lb./ft. min.
Type B	4'	Soft Wood Oak Steel	3" diameter or 2X4 1.5" X 1.5" 1.3lb./ft. min.
Type C	3'	Soft Wood Oak Steel	2" diameter or 2X2 1" X 1" .75lb./ft. min.

Table 6-39. Wood Post Fasteners for Silt Fence

	Gauge	Crown	Legs	Staples/Post
Wire Staples	17 min.	¾" wide	½" long	5 min.
	Gauge	Length	Button Heads	Nail/Post
Nails	14 min.	1"	¾" long	4 min.

Type B Silt Fence

This 36" wide filter fabric should be used on developments where the life of the project is greater than or equal to 6 months.

The silt fence should be installed as shown in Figure 6-93. Materials for posts and fasteners are shown in Tables 6-38 and6-39. Details for overlap of the silt fence and fastener placement are shown in Figure 6-95.

Type C Silt Fence

Though only 22" wide, this filter fabric allows the same flow rate as Type B silt fence. Type C silt fence should be limited to use on relatively minor projects, such as residential home sites or small commercial developments where permanent stabilization will be achieved in less than 6 months.

The silt fence should be installed as shown in Figure 6-94. Materials for posts and fasteners are shown in Tables 6-38 and 6-39. Details for overlap of the silt fence and fastener placement are shown in Figure 6-95.

Typical Components of the Practice

- Site Preparation
- Barrier Installation
- Reinforce Outlet Bypass. (Not always applicable)
- Erosion Control
- Construction Verification

Construction

Prior to start of construction, sediment barriers should be designed by a qualified professional. Plans and specifications should be referred to by field personnel throughout the construction process.

Note: Silt fence is the only barrier installation being covered in this handbook.

Silt Fence Installation

Fence should be installed **on the contour**, so that runoff can be intercepted as sheet flow, Ends should be flared uphill to provide temporary storage of water. Fence should be placed so that runoff from disturbed areas must pass through the fence. Fence should not be placed across concentrated flow areas such as channels or waterways. When placed near the toe of a slope, the fence should be installed far enough from the slope toe to provide a broad flat area for adequate storage capacity for sediment. Dig a trench at least 6" deep along the fence alignment as shown in Figures 6-93 and 6-94 for Types A & B fences. Type C fences require only a 4" deep trench as shown in Figure 6 95. **Please note that installation with a silt fence installation machine may permit different depths if performance is equal.**

Drive posts to the depth specified on the downslope side of the trench. Space posts a maximum of 10 feet if fence is supported by woven wire, or 6 feet if high strength fabric and no support fence is used.

Fasten support wire fence to upslope side of posts, extending 6" into the trench as shown in the appropriate figure for the type fence, see Figure 6-93, 6-94 or 6-95.

Attach continuous length of fabric to upslope side of fence posts. Minimize the number of joints and when necessary to join rolls, they should be joined by rolling the ends together using the "roll joint" method illustrated in Figure 6-96 or as detailed in the specifications. Avoid joints at low points in the fence line.

For Type A & B silt fence, place the bottom 12" of fabric in the 6" deep (minimum) trench, lapping toward the upslope side. For Type C fabric place the bottom 6" in the 4" deep (minimum) trench lapping toward the upslope side.

Install tie backs as specified on the ends of the silt fence.

Backfill the trench with compacted earth or gravel as shown in Figures 6-93, 94 and 94. Provide good access in areas of heavy sedimentation for clean out and maintenance.

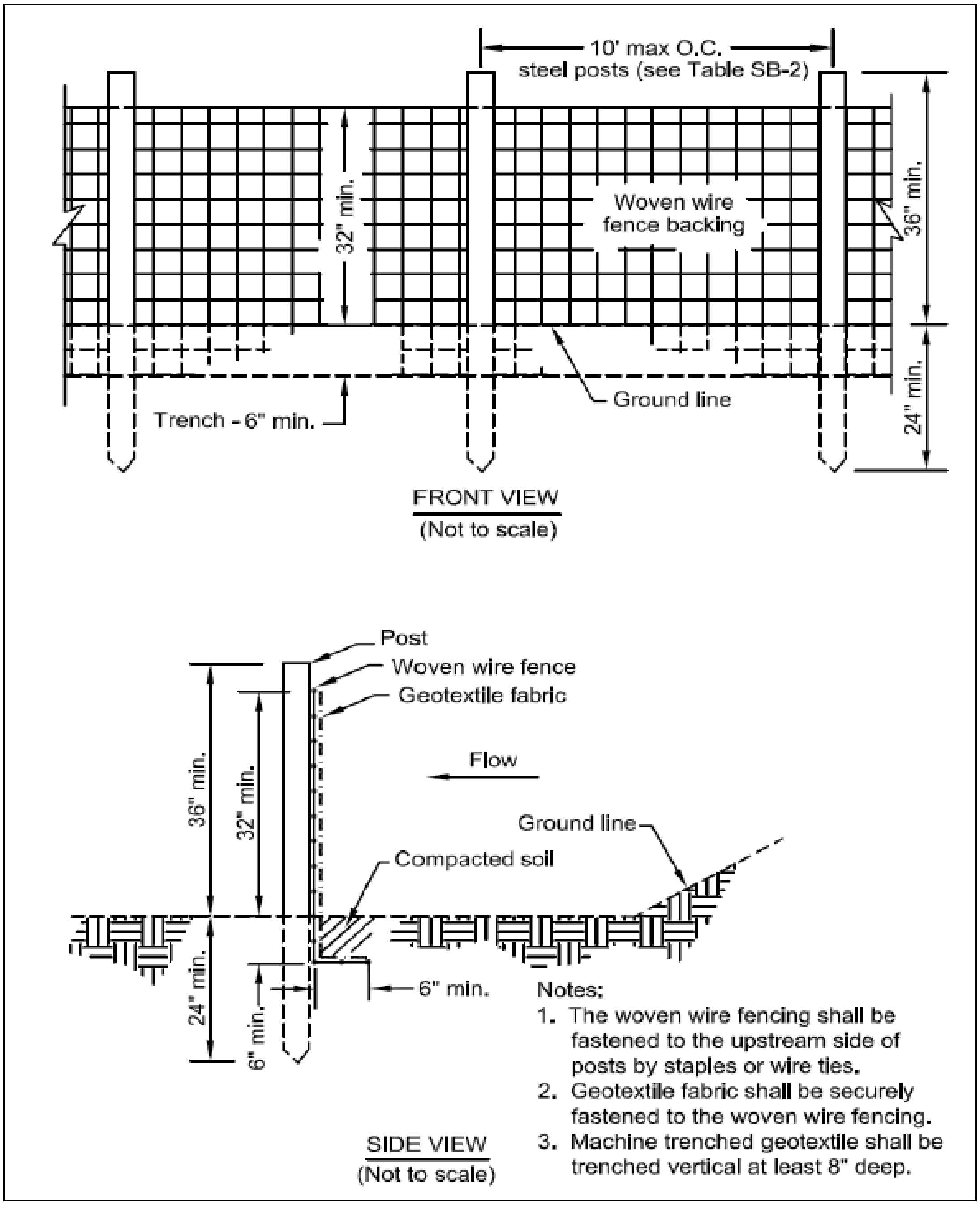

Figure 6-93. Silt Fence – Type A
(1) for post material requirements see Tables 6-38 and 6-39

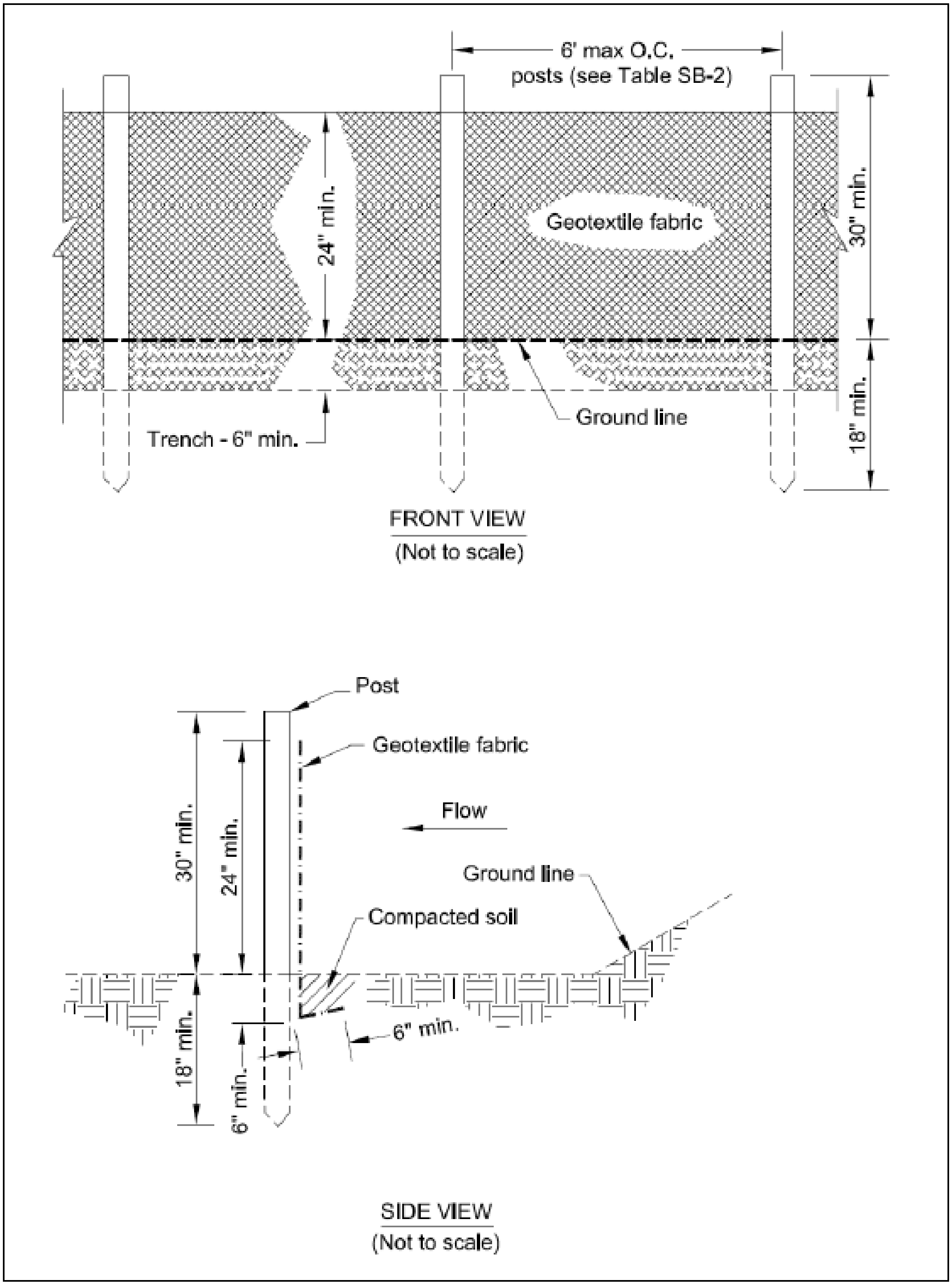

Figure 6-94. Silt Fence – Type B
(1) for post material requirements see Tables 6-38 and 6-39

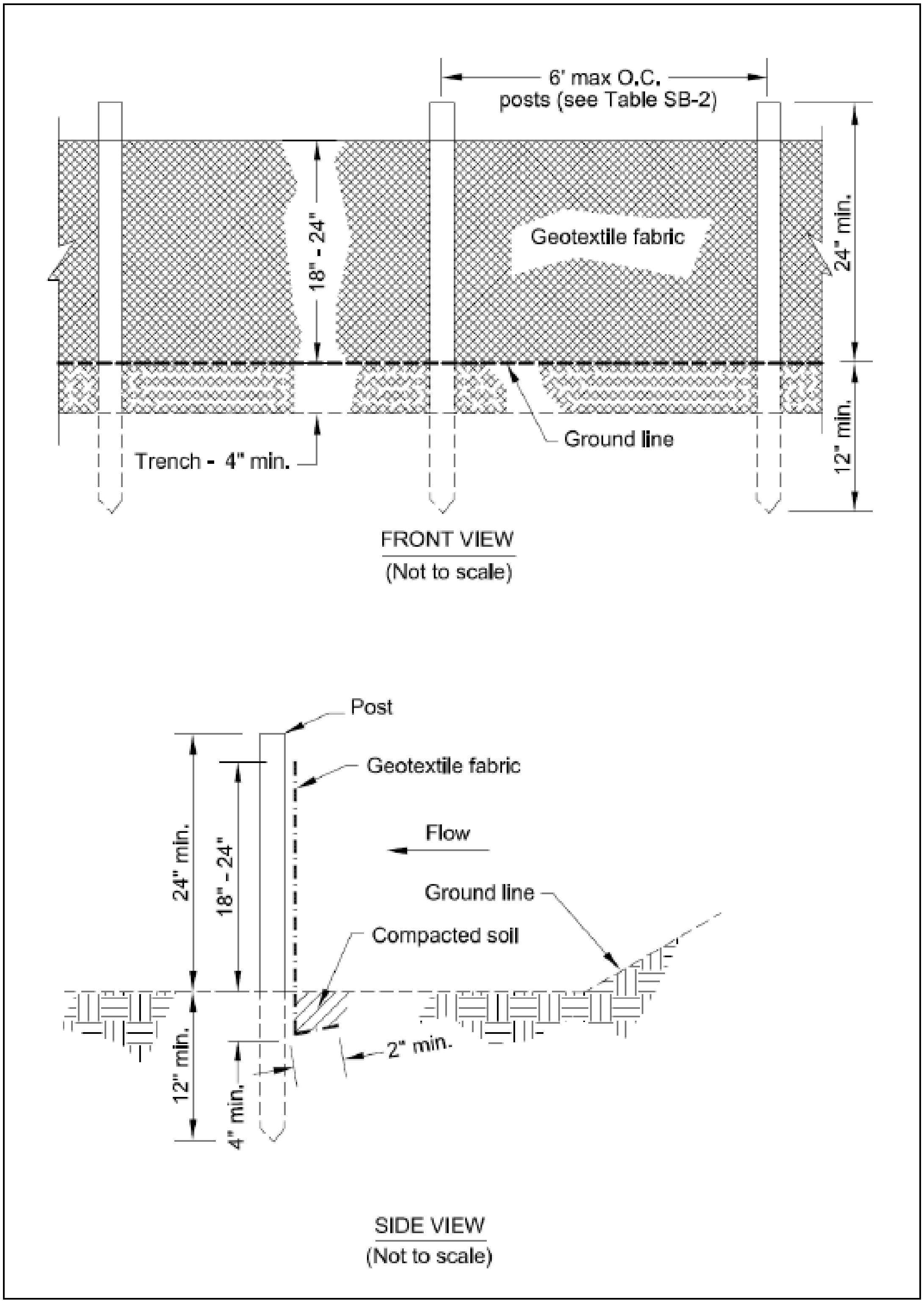

Figure 6-95. Silt Fence – Type C
(1) for post material requirements see Tables 6-38 and 6-39

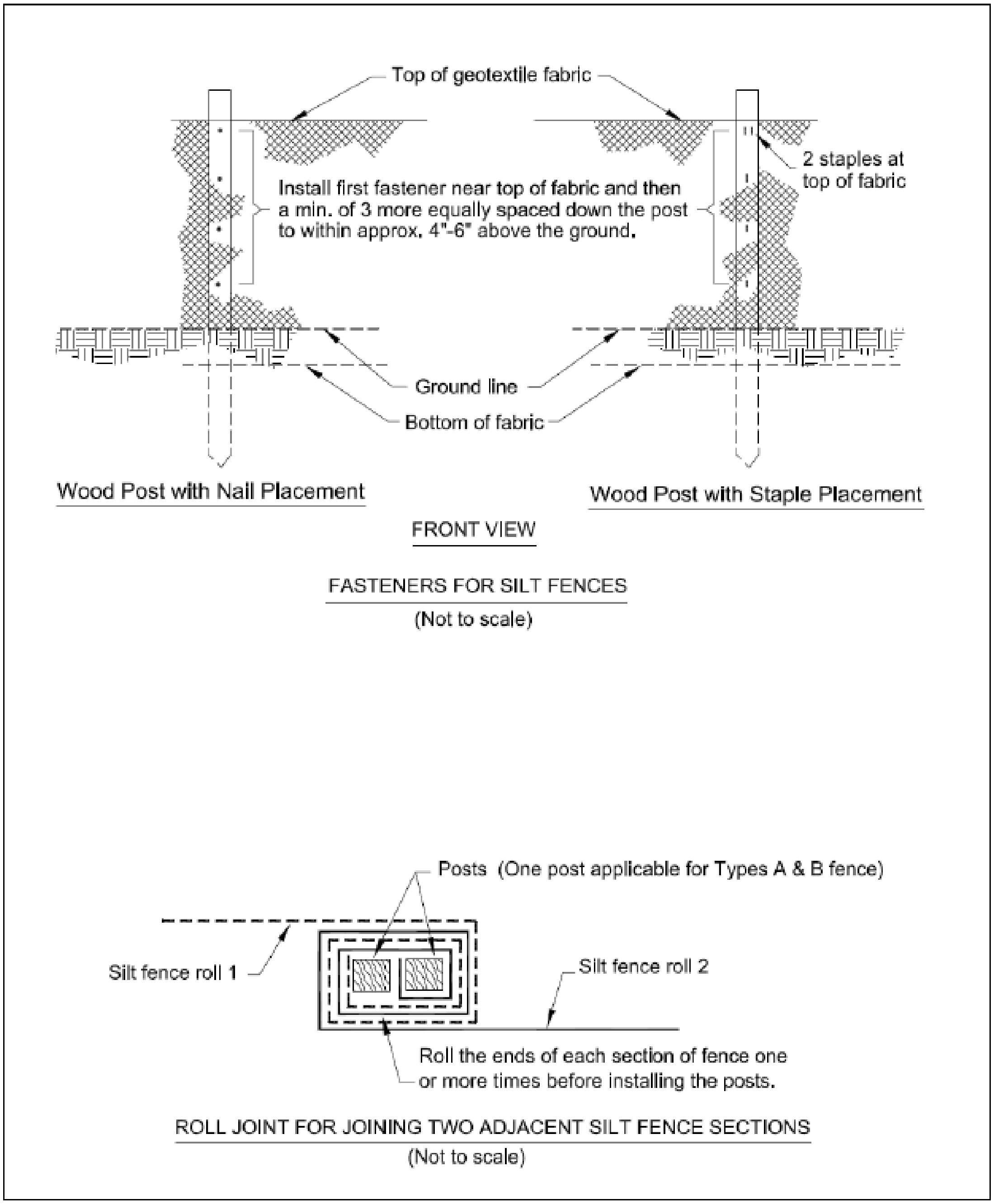

Figure 6-96. Silt Fence Installation Details

Erosion Control

Stabilize disturbed areas in accordance with vegetation plan. If no vegetation plan exists, consider planting and mulching as a part of barrier installation and select planting information from appropriate planting practice, Permanent Seeding or Temporary Seeding. Select mulching information from the Mulching practice.

Construction Verification

Check finished grades and dimensions of the sediment fence. Check materials for compliance with specifications.

Common Problems

Consult with a qualified design professional if any of the following occur:

- Variations in topography onsite indicate sediment fence will not function as intended or alignment is not on contour or fence crosses concentrated flow areas; changes in plan may be needed.

- Design specifications for filter fabric, support posts, support fence, gravel or riprap cannot be met; substitutions may be required. Unapproved substitutions could lead to failure.

- Drainage area appears to exceed ¼ acre for 100 feet of non-reinforced silt fence and ½ acre for reinforced fence.

Maintenance

Inspect silt fences at least once a week and after each significant rain event.

Make required repairs immediately.

Should the fabric of silt fence collapse, tear, decompose or become ineffective, replace it promptly.

Remove sediment deposits when they reach a depth of 15" or ½ the height of the fence as installed to provide adequate storage volume for the next rain and to reduce pressure on the fence.

After the contributing drainage area has been properly stabilized, remove all barrier materials and unstable sediment deposits, bring the area to grade and stabilize it with vegetation."

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Figure 6-97. Use of silt fences around storage pile. Caroline Sandel, UA student.


Figure 6-98. Overloaded silt fence. Caroline Sandel, UA student.

Chapter Summary

This chapter has shown that with the use of relatively-simple design criteria, construction site sediment ponds can provide excellent water quality benefits over a wide range of storm conditions. Wet detention ponds have been shown to be very effective, if their surface areas are sufficiently large in comparison to the drainage area and expected runoff volume. Dry ponds and small wet ponds are much less effective. Care must also be taken to minimize safety and environmental hazards associated with ponds.

Physical sedimentation is the main removal process occurring in wet ponds. Temporary sediment ponds at construction sites are most suitable where the area to be controlled is larger than about 10 acres (the typical upper limit for silt fencing). They have been found to be generally the most effective sediment control (after prevention), especially if augmented with floating boom discharges and the use of chemical flocculants.

Silt fences are suitable for much smaller areas than sediment ponds, but their maximum expected performance is less. They act as small detention ponds by ponding water behind the fabric material on the upslope side, allowing sedimentation. Common problems with silt fence installations include improper installation, placement, and maintenance. They frequently are not adequately secured along their bottom edges, allowing passage of water under the fabric. In many cases, the drainage areas also are too large.

Problems

1. Compute the settling velocity for the following particles: very coarse sand (diameter = 1.5 mm), medium sand (0.4 mm), very fine sand (0.075 mm), and clay (0.001 mm) assuming particle settling in laminar flow. Estimate the time for each particle to fall 3 feet in water.

2. The retention time in a stormwater management basin is 45 min. If the average water depth in the active zone is 4 ft, what proportion of fine sand (diameter = 0.1 mm) will settle to the sacrificial storage assuming the inflow is fully mixed?

3. A developer has designed a mixed-residential/commercial development for his property. The total acreage is 150 acres; 40 of which will be strip-commercial with paved parking and impervious roofs; 30 of which will be a townhome development (attached homes on 1/8 acre lots); and the remaining 80 acres, single-family homes on 1/2-acre lots. Prior to grading, the property is a forest with an average 5% slope. The developer will be grading the site as follows:

    - Strip commercial: slope approximately 0.2%. Slope length 2000 ft.
    - Townhome development: slope approximately 1.0%. Slope length 175 ft.
    - Single-family residential area: slope approximately 2%. Slope length 250 ft.

    The developer is planning to install a temporary erosion control pond at the lowest point in the watershed (which is where the parking lot of 25 acres is to be located). Answer the following questions about the pond the developer is planning to install:

    a. If the control is required for the 10-yr storm and assuming local rain conditions, what is the active water quality volume that is required for the pond? Assuming space is unlimited, what is the top area of a safe, well-designed pond for water quantity control? If only 5 acres is available for the pond, what changes have to be made to the design?

b. How much sediment is anticipated to be washed off from the site assuming it is located in your current watershed and subject to your local rain conditions? The design storm for sediment loss on this site is the 25-yr storm. Assume that the contractor removes at least the top 1 ft of soil during grading and it is the underlayer that is exposed to rain events. No cover protection is put on the site during construction, e.g., all control is occurring in the pond.

c. The development is located in a sensitive watershed, and therefore, the particle size requiring control is the 5-µm particle. For this level of control, what is the required surface area? What outlet control should be selected?

d. How much volume is required to store sediment assuming that the development construction will last for two years in your watershed?

e. Complete a final design for the pond assuming unlimited surface area.

4. Rework Problem 3, assuming that the construction is phased and cover practices are established for all areas after grading except for the area where the pond is located. The C value for the protective cover is assumed to be 0.1.

5. A house lot is being developed. The lot size is 80 ft wide by 125 ft long. The slope length occurs along the "long" side of the property. The developer plans to use silt fences as the primary erosion control measure. What is the maximum slope that the fence is recommended if the cover soil is clay? Loam? Silt? Sand?

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Appendix A. Literature Reviews and Citations of Case Studies of the Effectiveness of Construction Site Erosion and Sediment Controls

This appendix contains summaries of selected citations of case studies that have included monitoring the effectiveness of erosion and sediment control practices, published from 2000 to 2018. The controls that were reported included chemical treatment (usually with polyacrylamide, or PAM), sediment traps, silt fences, compost filter socks, sediment ponds, check dams, inlet protection, mulches, vegetative controls, and different control combinations for sediment and turbidity reduction.

The following tables summarize some of these reports that included performance monitoring.

Example Studies that Included Erosion and Sediment Control Performance Data

Article and full citation	Pollutants	Treatments Evaluated	Location of Tests (City, State, Country)	Soil Characteristics (texture)	Test Site Conditions (lab, small test plot, actual construction site)	Simulated or Actual Rain	Number of Events Monitored per Treatment
Barrett M.E., Malina J.F. Monitoring Data on Effectiveness of Sediment Control Techniques. Critical transitions in water and environmental resources management proceedings of the 2004 World Water and Environmental Resources Congress 2004: pp. 429-438	TSS, turbidity	Silt fence	Austin, Texas, USA	Soil from actual construction site	Experimental Lab scale	N/A	N/A
Benik, S. R., Wilson, B. N., Biesboer D. D., Hansen, B., Stenlund, D. Performance of Erosion Control Products on a Highway Embankment. Transactions of American Society of Agricultural Engineers. Vol. 46(4): 1113-1119	sediment	BFM, straw, wood	Minneapolis - St. Paul Metro area, Minnesota, USA	Soil from actual construction site	Field test plots on actual construction site	Simulated rain	N/A
Bharadwaj, A.K., McLaughlin, R.A. Simple Polyacrylamide Dosing Systems for Turbidity Reduction in Stilling Basins. Transactions of ASABE. 2008. 51(5): 1653-1662	TSS, turbidity	stilling basin, PAM, baffles	Raleigh, North Carolina, USA	Soil from nearby construction sites	Laboratory scale	N/A (Turbid water was pumped mixing basin into stilling basin)	N/A

Article and full citation	Pollutants	Treatments Evaluated	Location of Tests (City, State, Country)	Soil Characteristics (texture)	Test Site Conditions (lab, small test plot, actual construction site)	Simulated or Actual Rain	Number of Events Monitored per Treatment
Faucette, L.B., Governo, J., Tyler, R., Gigley, G., Jordan, C.F., and Lockaby, B.G. Performance of compost filter socks and conventional sediment control barriers used for perimeter control on construction sites. Journal of Soil and Water Conservation. January/February 2009 vol. 64 no. 1: 81-88	TSS	compost filter socks, mulch, straw bale	Athens/Clarke County, Gerogia, USA	Sandy clay loam	Small test plots	Simulated rain	1 event
Faucette, L.B., Sefton, K.A., Sadeghi, A.M., Rowland, R.A 2008. Sediment and phosphorous removal from simulated storm runoff with compost filter socks and silt fence. Journal of Soil and Water Conservation Society. 63:257-264	TSS, TP, turbidity	silt fence, filter sock, PAM	Beltsville, Maryland, USA	Silt loam	Laboratory scale test soil chambers	Simulated rain	N/A
Gharabaghi, B., Fata, A., Seters, T. V., Rudra, R. P., MacMillan, G., Smith, D., Li, J. Y., Bradford, A., Tesa, G. Evaluation of sediment control pond performance at construction sites in the Greater Toronto Area. Canadian Journal of Civil Engineering, 2006, 33(11): 1335-1344	TSS	sediment pond	Greater Toronto Area, Canada	Soil from actual construction site	Actual construction site	Actual rain events	19 events

Article and full citation	Pollutants	Treatments Evaluated	Location of Tests (City, State, Country)	Soil Characteristics (texture)	Test Site Conditions (lab, small test plot, actual construction site)	Simulated or Actual Rain	Number of Events Monitored per Treatment
Line, D. E., White, N. M. Efficiencies of Temporary Sediment Traps on Two North Carolina Construction Sites. Transactions of the American Society of Agricultural Engineers. 2001; 44(5): 1207-1215	TSS, TP, turbidity	Sediment trap	North Carolina, USA	Site 1:Sandy loam (77 % sand, 13 % silt, and 10% clay), and Site 2: Clay loam and Sandy loam (62 % sand, 22 % silt, and 16 % clay)	Actual construction site	Actual rain events	Site 1: 32 per treatment for trap 1, 10 per treatment for trap 2. Site 2: 21 per treatment
McCaleb, M.M., McLaughlin, R.A. Sediment trapping by five different sediment detention devices on construction sites. Transactions of the ASABE. 2008. 51(5): 1613-1621	TSS, turbidity	skimmer basin, desiment trap, baffles	Piedmont, North Carolina, USA	Soils from actual construction sites	Actual construction site	Actual rain events	11 to 35 events
McLaughlin R.A., Bartholomew N.2007. Soil factors influencing suspended sediment flocculation by polyacrylamide. Soil Science Society of America Journal 71:537-544	turbidity	PAM	North Carolina, USA	Soils from 13 different construction sites collected across 13 geographic regions of North Carolina	Laboratory Scale	N/A	N/A
McLaughlin, R. A., S. A. Hayes, and D. L. Osmond. Testing Polyacrylamides for turbidity and erosion control. International Erosion Control Association. 2002. Proceedings of Conf 33: 407-418	turbidity	PAM, straw mulch	North Carolina, USA	Soils from different construction sites collected across North Carolina	Field test plots	Actual rain events	8 events

Article and full citation	Pollutants	Treatments Evaluated	Location of Tests (City, State, Country)	Soil Characteristics (texture)	Test Site Conditions (lab, small test plot, actual construction site)	Simulated or Actual Rain	Number of Events Monitored per Treatment
McLaughlin, R.A. Polyacrylamide Reduces Erosion on Construction Site Slopes . Proceedings of 38th International Erosion Control Association Annual Conference 2007	turbidity	PAM, straw, excelsior, hydromulch	North Carolina, USA	Soil collected from construction sites	Small test plots	Actual rain events	3 to 6 events
McLaughlin, R.A., Brown, T.T. Evaluation of Erosion Control Products with and without Added Polyacrylamide. JAWRA Journal of the American Water Resources Association Volume 42, Issue 3, June 2006, Pages: 675–684	turbidity	PAM, straw, MBFM	Raleigh, North Carolina, USA	Sandy Clay loam (52 % sand, 24 % silt, and 24 % clay), Sandy loam (53 % sand, 39 % silt, and 8 % clay), Loam (43 % sand, 32 % silt, and 25 % clay)	Small test plots	Simulated rain	2 to 6 events (2events for groundcover/ PAM experiment, and 4 events for comparing PAM follwed by straw to straw then PAM)
McLaughlin, R.A., Hayes, S.A., Clinton, D.L., McCaleb, M.S., Jennings, G.D. Water Quality Improvements Using Modified Sediment Control Systems on Construction Sites. Transactions of ASABE. 2009. 52(6): 1859-1867	TSS, turbidity	sediment trap, PAM, baffles	Charlotte, North Carolina, USA	Sandy clay loams	Actual construction site	Actual rain events	31 events

Article and full citation	Pollutants	Treatments Evaluated	Location of Tests (City, State, Country)	Soil Characteristics (texture)	Test Site Conditions (lab, small test plot, actual construction site)	Simulated or Actual Rain	Number of Events Monitored per Treatment
McLaughlin, R.A., McCaleb, M.M. Passive Treatment to Meet the EPA Turbidity Limit. ASABE - TMDL 2010: Watershed Management to Improve Water Quality, p 71-76, 2010	turbidity	Check dams, PAM, excelsior wattles	North Carolina, USA	Soil from actual construction site	Field Scale ditch	Simulated rain	18 events (3 per treatment)
McLaughlin. R. A., King, S. E., Jennings, G. D. Improving construction site runoff quality with fiber check dams and Polyacrylamide. Journal of Soil and Water Conservation 2009 64(2):144- 154	TSS, turbidity	PAM, Check dams	North Carolina, USA	Soil from actual construction site	Experimental sections on actual construction site	Actual rain events	32 events per treatment at Site 1, and 20 events per treatment at Site 2
Roa-Espinosa, A., Bubenzer G.D., Miyashita E.S. Sediment and Runoff Control on Construction Sites Using Four Application Methods of Polyacrylamide Mix, National Conference on Tools for Urban Water Resource Management and Protection, Chicago, Feb. 7-10, 2000, p. 278-283, University of Wisconsin	sediment	PAM, mulch	Madison, Wisconsin, USA	Dodge silt loam	Small test plots	Simulated rain	3 events per treatment

Article and full citation	Pollutants	Treatments Evaluated	Location of Tests (City, State, Country)	Soil Characteristics (texture)	Test Site Conditions (lab, small test plot, actual construction site)	Simulated or Actual Rain	Number of Events Monitored per Treatment
Rounce, D., Lawler, D., Barrett, M. (2012) Reducing Turbidity of Construction Site Runoff: Factors Affecting Particle Destabilization with Polyacrylamide. World Environmental and Water Resources Congress 2012: pp. 509-519	turbidity	PAM	Texas, USA	Soils from actual construction sites	Laboratory Jar tests	Simulated rain	N/A
Soupir, M. L., Mostaghimi, S., Masters, A., Flahive, K. A., Vaughan, D. H., Mendez, A. and McClellan, P. W. (2004), Effectiveness of Polyacrylamide (PAM) in Improving Runoff Water Quality from Construction Sites. JAWRA Journal of the American Water Resources Association, 40: 53–66	TSS, TP, TN	PAM, hydroseed, straw mulch	Blacksburg, Virginia, USA	32.1 % silt, 46.1 % clay, and 21.8 % sand	Field test plots on actual construction site	Simulated rain	6 events per treatment
Tobiason, S., Jenkins, D., Molash, E., Rush, S. Polymer Use and Testing for Erosion and Sediment Control on Construction Sites: Recent experience on Pacific Northwest. Proceedings of Conference 31. International Erosion Control Association. Palm Spring, CA. February 21-25, 2000. pp 41-52	turbidity	PAM, hydromulch	Washington, USA	Silt loam(77 % sand, 16 % silt, and 7 % clay), and soil from actual construction sites	Small test plots and actual construction sites	Actual rain events	3 events for test plots and 5 and 7 events respectively for 2 construction sites

Article and full citation	Pollutants	Treatments Evaluated	Location of Tests (City, State, Country)	Soil Characteristics (texture)	Test Site Conditions (lab, small test plot, actual construction site)	Simulated or Actual Rain	Number of Events Monitored per Treatment
Wilson, W.T, Zech, W. C., Clement, T.P, Shoemaker, A.L. Polymer-Enhanced Soft Armoring: An Erosion and Sediment Control Measure for Construction Fill Slopes. 41st International Erosion Control Association Annual Conference 2010, p 150-157	turbidity	PAM, Jute matting	Auburn, Alabama, USA	Soils from actual construction sites (58.6 % sand, 12.5 % silt, and 28.9 % clay)	Experimental test plots	Simulated rain	4 events

Summary of Example Reported Performance of Construction Site Erosion and Sediment Controls

Reference	Control Practices	Type of tests and general location	Number of events X locations per treatment	TSS influent (mg/L) avg	TSS effluent (mg/L) avg	% TSS reduc	Turbidity influent (NTU) avg	Turbidity effluent (NTU) avg	% Turbidity reduc
Soupir, et al. 2004 JAWRA	control	field plots - Virginia	6	6,537	n/a	n/a			
Soupir, et al. 2004 JAWRA	dry PAM	field plots - Virginia	6	6,537	3,293	50			
Soupir, et al. 2004 JAWRA	hydroseed	field plots - Virginia	6	6,537	3,257	50			
Soupir, et al. 2004 JAWRA	low PAM	field plots - Virginia	6	6,537	5,322	19			
Soupir, et al. 2004 JAWRA	Rec. PAM	field plots - Virginia	6	6,537	4,857	26			
Soupir, et al. 2004 JAWRA	High PAM	field plots - Virginia	6	6,537	4,556	30			
Soupir, et al. 2004 JAWRA	straw mulch	field plots - Virginia	6	6,537	527	92			
Roa-Espinosa, et al. 2000 Chicago conf	control	field test trays - Wisconsin	3	6,596	n/a	n/a			
Roa-Espinosa, et al. 2000 Chicago conf	dry PAM mix dry soil	field test trays - Wisconsin	3	6,596	2,537	62			
Roa-Espinosa, et al. 2000 Chicago conf	solution PAM dry soil	field test trays - Wisconsin	3	6,596	2,072	69			
Roa-Espinosa, et al. 2000 Chicago conf	solution PAM moist soil	field test trays - Wisconsin	3	6,596	2,366	64			
Roa-Espinosa, et al. 2000 Chicago conf	solution PAM mulch dry soil	field test trays - Wisconsin	3	6,596	859	87			

Summary of Example Reported Performance of Construction Site Erosion and Sediment Controls (continued)

Reference	Control Practices	Type of tests and general location	Number of events X locations per treatment	TSS influent (mg/L) avg	TSS effluent (mg/L) avg	% TSS reduc	Turbidity influent (NTU) avg	Turbidity effluent (NTU) avg	% Turbidity reduc
McLaughlin, et al. 2009 JSWC	sediment traps and rock dams not full pools between dams	full size - North Carolina	23	15,201	n/a	n/a	3,813	n/a	n/a
McLaughlin, et al. 2009 JSWC	fiber check dam (straw wattles and coir logs)	full size - North Carolina	20	15,201	181	99	3,813	202	95
McLaughlin, et al. 2009 JSWC	fiber check dam with PAM	full size - North Carolina	27	15,201	82	99	3,813	34	99
McLaughlin, et al. 2009 JSWC	standard practice 2 (sediment traps and rock dams spaced for pools)	full size - North Carolina	19	1,694	n/a	n/a	867	n/a	n/a
McLaughlin, et al. 2009 JSWC	fiber check dam with PAM 2	full size - North Carolina	9	1,694	260	85	867	115	87
Wilson, et al. 2010 IECA	control	lab erosion tray	4	n/a	n/a	n/a	3,500	n/a	n/a
Wilson, et al. 2010 IECA	jute matting	lab erosion tray	4	n/a	n/a	98	3,500	900	74
Wilson, et al. 2010 IECA	jute matting with PAM	lab erosion tray	4	n/a	n/a	100	3,500	0	100

Summary of Example Reported Performance of Construction Site Erosion and Sediment Controls (continued)

Reference	Control Practices	Type of tests and general location	Number of events X locations per treatment	TSS influent (mg/L) avg	TSS effluent (mg/L) avg	% TSS reduc	Turbidity influent (NTU) avg	Turbidity effluent (NTU) avg	% Turbidity reduc
Tobiason, et al. 2000 IECA	PAM only	full size - Seattle. WA	5						88 - 90
Tobiason, et al. 2000 IECA	hydromulch and PAM	full size - Seattle. WA	5						94 - 99
Tobiason, et al. 2000 IECA	hydromulch	full size - Seattle. WA	5						22 - 95
Tobiason, et al. 2000 IECA	straw and PAM	full size - Seattle. WA	7						57 - 82
Tobiason, et al. 2000 IECA	wet pond outlet after polymers	full size - Seattle. WA	225				226	7	97
Gharabaghi, et al. 2006 CJCE	wet pond (L:W 8:1; 48 hr drawdown time)	full size - Toronto	14	about 3,500	177	>90			
Gharabaghi, et al. 2006 CJCE	wet pond (L:W 2:1; 83 hr drawdown time)	full size - Toronto	12	n/a (much less than 3,500)	37	>90			
Line and White 2001 ASAE	sed trap with rock outlet	full size - North Carolina	34	2,145	665	69			
Line and White 2001 ASAE	U-shaped sed trap with rock outlet	full size - North Carolina	42	4,685	1,921	59			

Summary of Example Reported Performance of Construction Site Erosion and Sediment Controls (continued)

Reference	Control Practices	Type of tests and general location	Number of events X locations per treatment	TSS influent (mg/L) avg	TSS effluent (mg/L) avg	% TSS reduc	Turbidity influent (NTU) avg	Turbidity effluent (NTU) avg	% Turbidity reduc
Faucette, et al. 2009 JSWCS	bare soil control	field test plots and controlled flow - North Georgia	1	4,252	n/a	n/a	3,628	n/a	n/a
Faucette, et al. 2009 JSWCS	8 inch compost filter sock	field test plots and controlled flow - North Georgia	1	4,252	1,027	76	3,628	2,592	29
Faucette, et al. 2009 JSWCS	12 inch compost filter sock	field test plots and controlled flow - North Georgia	1	4,252	1,213	71	3,628	2,934	19
Faucette, et al. 2009 JSWCS	8 in compost filter sock + polymer	field test plots and controlled flow - North Georgia	1	4,252	1,028	76	3,628	1,847	49
Faucette, et al. 2009 JSWCS	12 in compost filter sock + polymer	field test plots and controlled flow - North Georgia	1	4,252	718	83	3,628	2,113	42
Faucette, et al. 2009 JSWCS	mulch fiber berm	field test plots and controlled flow - North Georgia	1	4,252	2,069	51	3,628	3,334	8
Faucette, et al. 2009 JSWCS	straw bale	field test plots and controlled flow - North Georgia	1	4,252	1,964	54	3,628	3,201	12

Summary of Example Reported Performance of Construction Site Erosion and Sediment Controls (continued)

Reference	Control Practices	Type of tests and general location	Number of events X locations per treatment	TSS influent (mg/L) avg	TSS effluent (mg/L) avg	% TSS reduc	Turbidity influent (NTU) avg	Turbidity effluent (NTU) avg	% Turbidity reduc
McCaleb, et al. 2008 ASABE	Dry skimmer basin with coir baffles SkB	full size - Piedmont North Carolina	35	260000 (?)	1,040	99.6	n/a	1,070	n/a
McCaleb, et al. 2008 ASABE	Dry standard 10-yr trap 10ST	full size - Piedmont North Carolina	18	1,665	1,080	35	n/a	2,090	n/a
McCaleb, et al. 2008 ASABE	Wet pond standard 10-yr trap with standing pool STSP	full size - Piedmont North Carolina	17	120 (?)	79	34	n/a	130	n/a
McCaleb, et al. 2008 ASABE	Dry pond standard 25-yr trap 25ST	full size - Piedmont North Carolina	29	6,927	3,810	45	n/a	4,410	n/a
McCaleb, et al. 2008 ASABE	Dry standard trap with silt fence baffles STSFB	full size - Piedmont North Carolina	11	12,200	8,420	31	n/a	12,640	n/a

Summary of Example Reported Performance of Construction Site Erosion and Sediment Controls (continued)

Reference	Control Practices	Type of tests and general location	Number of events X locations per treatment	TSS influent (mg/L) avg	TSS effluent (mg/L) avg	% TSS reduc	Turbidity influent (NTU) avg	Turbidity effluent (NTU) avg	% Turbidity reduc
McLaughlin and McCaleb 2010 ASABE	Rock check dam	field controlled tests - North Carolina	3				2000 (est)	910	55
McLaughlin and McCaleb 2010 ASABE	Rock check dam with PAM	field controlled tests - North Carolina	3				2000 (est)	120	94
McLaughlin and McCaleb 2010 ASABE	Rock check dam with excelsior blanket	field controlled tests - North Carolina	3				2000 (est)	410	80
McLaughlin and McCaleb 2010 ASABE	rock check dam with excelsior blanket and PAM	field controlled tests - North Carolina	3				2000 (est)	88	96
McLaughlin and McCaleb 2010 ASABE	Excelsior wattle	field controlled tests - North Carolina	3				2000 (est)	450	78
McLaughlin and McCaleb 2010 ASABE	Excelsior wattle with PAM	field controlled tests - North Carolina	3				2000 (est)	100	95

Summary of Example Reported Performance of Construction Site Erosion and Sediment Controls (continued)

Reference	Control Practices	Type of tests and general location	Number of events X locations per treatment	TSS influent (mg/L) avg	TSS effluent (mg/L) avg	% TSS reduc	Turbidity influent (NTU) avg	Turbidity effluent (NTU) avg	% Turbidity reduc
McLaughlin and Brown 2006 JAWRA	bare soil control	field fescue test plots - North Carolina	5	6,770	n/a	n/a	2,279	n/a	n/a
McLaughlin and Brown 2006 JAWRA	bare soil with PAM	field fescue test plots - North Carolina	5	6,770	3,520	48	2,279	1,950	14
McLaughlin and Brown 2006 JAWRA	straw mulch	field fescue test plots - North Carolina	5	6,770	1,220	82	2,279	763	67
McLaughlin and Brown 2006 JAWRA	straw mulch with PAM	field fescue test plots - North Carolina	5	6,770	950	86	2,279	371	84
McLaughlin and Brown 2006 JAWRA	straw erosion control mat ECB	field fescue test plots - North Carolina	5	6,770	3,320	61	2,279	1,350	41
McLaughlin and Brown 2006 JAWRA	straw erosion control mat ECB wit PAM	field fescue test plots - North Carolina	5	6,770	750	89	2,279	570	75
McLaughlin and Brown 2006 JAWRA	bonded fiber matrix MBFM	field fescue test plots - North Carolina	5	6,770	950	86	2,279	349	85
McLaughlin and Brown 2006 JAWRA	bonded fiber matrix MBFM with PAM	field fescue test plots - North Carolina	5	6,770	2,170	68	2,279	142	94

Summary of Example Reported Performance of Construction Site Erosion and Sediment Controls (continued)

Reference	Control Practices	Type of tests and general location	Number of events X locations per treatment	TSS influent (mg/L) avg	TSS effluent (mg/L) avg	% TSS reduc	Turbidity influent (NTU) avg	Turbidity effluent (NTU) avg	% Turbidity reduc
McLaughlin and Brown 2006 JAWRA	bare soil control	lab erosion tray	3				3,530	n/a	n/a
McLaughlin and Brown 2006 JAWRA	bare soil with PAM	lab erosion tray	3				3,530	2,400	32
McLaughlin and Brown 2006 JAWRA	straw, with or without PAM	lab erosion tray	3				3,530	857	76
McLaughlin and Brown 2006 JAWRA	wood fiber, with or without PAM	lab erosion tray	3				3,530	664	81
McLaughlin and Brown 2006 JAWRA	bonded fiber matrix MBFM, with or without PAM	lab erosion tray	3				3,530	142	96
McLaughlin, et al. 2009 ASABE	standard sediment trap wth rock dam outlets ST	large construction site - Charlotte, NC	26	n/a	3,950	n/a	n/a	4,320	n/a
McLaughlin, et al. 2009 ASABE	standard sediment trap with forebay, rock dam outlet and block PAM STFBPam	large construction site - Charlotte, NC	31	n/a	740	n/a	n/a	740	n/a
McLaughlin, et al. 2009 ASABE	sediment trap with surface skimmer outlet, forebay, and block PAM SkFBPam	large construction site - Charlotte, NC	17	n/a	820	n/a	n/a	1,560	n/a

Summary of Example Reported Performance of Construction Site Erosion and Sediment Controls (continued)

Reference	Control Practices	Type of tests and general location	Number of events X locations per treatment	TSS influent (mg/L) avg	TSS effluent (mg/L) avg	% TSS reduc	Turbidity influent (NTU) avg	Turbidity effluent (NTU) avg	% Turbidity reduc
Bharadwaj and McLaughlin 2008 ASABE	dry standard pond	field controlled tests - Raleigh, NC	2	230	220	5	150	140	8
Bharadwaj and McLaughlin 2008 ASABE	dry standard pond with coir porous baffles	field controlled tests - Raleigh, NC	2	360	301	17	250	215	14
Bharadwaj and McLaughlin 2008 ASABE	dry standard pond with pumped PAM	field controlled tests - Raleigh, NC	2	270	68	75	260	30	88
Bharadwaj and McLaughlin 2008 ASABE	dry standard pond with coir porous baffles and pumped PAM	field controlled tests - Raleigh, NC	2	200	40	80	150	50	66
Bharadwaj and McLaughlin 2008 ASABE	dry standard pond with passive block PAM	field controlled tests - Raleigh, NC	2	190	66	65	150	30	78
Bharadwaj and McLaughlin 2008 ASABE	dry standard pond with coir porous baffles and passive block PAM	field controlled tests - Raleigh, NC	2	200	111	45	260	30	88

Summary of Example Reported Runoff Volume Changes with Erosion and Sediment Controls

Reference	Control Practices	Type of tests and general location	number of events X locations per treatment	control runoff (in)	treated runoff (in)	% runoff reduction
Soupir, et al. 2004 JAWRA	control	field plots - Virginia	6	1.21	n/a	n/a
Soupir, et al. 2004 JAWRA	dry PAM	field plots - Virginia	6	1.21	1.46	-21
Soupir, et al. 2004 JAWRA	hydroseed	field plots - Virginia	6	1.21	1.67	-38
Soupir, et al. 2004 JAWRA	low PAM	field plots - Virginia	6	1.21	1.15	5
Soupir, et al. 2004 JAWRA	Rec. PAM	field plots - Virginia	6	1.21	1.16	4
Soupir, et al. 2004 JAWRA	High PAM	field plots - Virginia	6	1.21	1.48	-22
Soupir, et al. 2004 JAWRA	straw mulch	field plots - Virginia	6	1.21	1.4	-16
Roa-Espinosa. Et al. 2000 Chicago conf	control	field test trays - Wisconsin	3	1.58	n/a	n/a
Roa-Espinosa. Et al. 2000 Chicago conf	dry PAM mix dry soil	field test trays - Wisconsin	3	1.58	1.5	5
Roa-Espinosa. Et al. 2000 Chicago conf	solution PAM dry soil	field test trays - Wisconsin	3	1.58	1.59	-1
Roa-Espinosa. Et al. 2000 Chicago conf	solution PAM moist soil	field test trays - Wisconsin	3	1.58	1.81	-15
Roa-Espinosa. Et al. 2000 Chicago conf	solution PAM mulch dry soil	field test trays - Wisconsin	3	1.58	1.62	-3

Summary of Example Reported Runoff Volume Changes with Erosion and Sediment Controls (continued)

McLaughlin and Brown 2006 JAWRA	bare soil control	field fescue test plots - North Carolina	5	2.55	n/a	n/a
McLaughlin and Brown 2006 JAWRA	bare soil with PAM	field fescue test plots - North Carolina	5	2.55	2.04	20
McLaughlin and Brown 2006 JAWRA	straw mulch	field fescue test plots - North Carolina	5	2.55	0.67	74
McLaughlin and Brown 2006 JAWRA	straw mulch with PAM	field fescue test plots - North Carolina	5	2.55	0.75	71
McLaughlin and Brown 2006 JAWRA	straw erosion control mat ECB	field fescue test plots - North Carolina	5	2.55	1.26	51
McLaughlin and Brown 2006 JAWRA	straw erosion control mat ECB wit PAM	field fescue test plots - North Carolina	5	2.55	0.83	67
McLaughlin and Brown 2006 JAWRA	bonded fiber matrix MBFM	field fescue test plots - North Carolina	5	2.55	0.67	74
McLaughlin and Brown 2006 JAWRA	bonded fiber matrix MBFM with PAM	field fescue test plots - North Carolina	5	2.55	0.55	78

Summary of Example Reported Nutrient Removals with Erosion and Sediment Controls

Reference	Control Practices	Type of tests and general location	number of events X locations per treatment	TP influent (mg/L)	TP effluent (mg/L)	% TP reduction	TN influent (mg/L)	TN effluent (mg/L)	TN % reduction
Soupir, et al. 2004 JAWRA	control	field plots - Virginia	6	5.6	n/a	n/a	58	n/a	n/a
Soupir, et al. 2004 JAWRA	dry PAM	field plots - Virginia	6	5.6	3.5	38	58	45	21
Soupir, et al. 2004 JAWRA	hydroseed	field plots - Virginia	6	5.6	10.8	-93	58	91	-58
Soupir, et al. 2004 JAWRA	low PAM	field plots - Virginia	6	5.6	3.9	31	58	12	80
Soupir, et al. 2004 JAWRA	Rec. PAM	field plots - Virginia	6	5.6	3.8	33	58	28	51
Soupir, et al. 2004 JAWRA	High PAM	field plots - Virginia	6	5.6	3.8	32	58	24	59
Soupir, et al. 2004 JAWRA	straw mulch	field plots - Virginia	6	5.6	2.1	63	58	30	48
Line and White 2001 ASAE	sed trap with rock outlet	full size - North Carolina	34	0.4	0.4	9			
Line and White 2001 ASAE	U-shaped sed trap with rock outlet	full size - North Carolina	42	0.3	0.2	30			

Selected Abstracts of Recent Publications on Construction Site Erosion and Sediment Control

It is recommended that the complete publications be obtained to review the details of the sites and practices associated with the erosion and sediment controls examined.

Babcock, D.L. and R.A. McLaughlin. "Erosion control effectiveness of straw, hydromulch, and polyacrylamide in a rainfall simulator." ***Journal of Soil and Water Conservation*****. Vol. 68, no. 3, pp. 221 – 227. May/June 2013.**

Babcock and McLaughlin (2013) tested several hydromulches and straw applications, with and without polyacrylamide during small-scale controlled tests. Soil was packed to a depth of 0.06 m (0.2 ft) into 1 by 2 m (3.3 by 6.6 ft) boxes, which were placed under a rainfall simulator at a slope of 18° and tested for several artificial rainfall applications. The straw had the highest turbidity (about 1,000 to 1,500 NTU), while the lowest turbidity was observed with the hydromulch plus PAM (about 60 to 150 NTU). Turbidity was highest for the straw alone treatment at 1,500 and 1,040 NTU for first and second events, respectively. The lowest turbidity was in the hydromulch plus PAM treatments, ranging from 62 to 151 NTU. No tests were conducted on bare soil. Adding PAM to the straw mulch was less expensive and had similar turbidity results as the hydromulch without PAM. However, the hydromulch with PAM was found to provide the lowest turbidity and best erosion protection. Adding PAM would cost about $600 per ha ($250/ac), which is about 10% of the typical costs of the total application of seed, fertilizer, lime, and straw, based on local erosion control bids. During these controlled tests with relatively high rain intensity (1.5 in/hr), the dissolved forms of PAM provided the best initial protection, as the granular forms required some time to dissolve. The granular forms performed best during later tests. Suring earlier field tests, the researchers did not find any significant differences between dissolved and granular PAM applications, probably due to lower natural rain intensities allowed the granular forms to dissolve more completely before runoff was initiated.

Bharadwaj, A.K., McLaughlin, R.A. "Simple Polyacrylamide dosing systems for turbidity reduction in stilling basins." ***Transactions of ASABE*****. 51(5): 1653-1662. 2008.**

Bharadwaj, *et al.* (2008) evaluated different PAM dosing methods along with the use of porous baffles (900 gm^{-3} coir material) in pilot-scale sediment ponds constructed at the Sediment and Erosion Control Research and Evaluation Facility at North Carolina State University. The passive PAM dosage method used a solid block of PAM (APS Floc Log 706b) which dissolved water flowed over it. The active dosage PAM system pumped a concentrated PAM solution (made from a powder of APS Silt Stop 705) at the intake. Turbidity and TSS concentrations were not reduced in the pond having no baffles with 1.5 and 24 hour detention times. Porous baffles which were installed to reduce turbulence had little benefit on performance. However, both the active and the passive PAM dosing methods reduced the turbidity by up to 88%, with the active dosing system being slightly more effective.

Bugg, R.A., W. Donald, W. Zech, and M. Perez. "Performance evaluations of three silt fence practices using a full-scale testing apparatus. *Water*. 9, 502. 15 Pgs. July 2017.

Three different silt fence practices were tested to evaluate performance: Alabama Department of Transportation (ALDOT) Trenched Silt Fence, ALDOT Sliced Silt Fence, and Alabama Soil and Water Conservation Committee (AL-SWCC) Trenched Silt Fence at the Auburn University Erosion and Sediment Control Testing Facility. This paper also reviewed several standard methods used to evaluate silt fence installations which were all small-scale. This paper used a larger-scale installation for comparison testing. The sediment retention performance of these silt fence practices was 83%, 67% and 91%, respectively. Even with the large amounts of sediment retained, the upstream and downstream turbidity levels did not appear to be substantially different (ranging from about 4,000 to 10,000 NTU maximum levels upstream to about 3,000 to 8,000 NTU maximum levels downstream during initial test periods to about 1,000 NTU in both upstream and downstream locations near the end of the test periods). This study indicated that the structural performance of silt fences is the most important performance factor in retaining sediment. When exposed to large flows and maximum impoundments behind the silt fences, the ALDOT Trench and Sliced Silt Fence practices structurally failed, while the AL-SWCC Trenched Silt Fence did not. The only structural issue noted during any of the tests for the AL-SWCC Trenched Silt Fence was some partial and temporary undermining around one of the six posts as the water impoundment reached full height.

Cooke, S.J., J.M. Chapman, and J.C. Vermaire. "On the apparent failure of silt fences to protect freshwater ecosystems from sedimentation: A call for improvements in science, technology, training and compliance monitoring." *Journal of Environmental Management*. 164, pgs. 67 – 73. 2015.

Cooke, *et al.* (2015) expressed concern about the general poor performance of silt fences to protect receiving water aquatic resources. They recommend better long-term planning, extending from prior to fence installation to after silt fence removal. They list many factors that may affect silt fence performance and see the need for detailed laboratory experiments and field monitoring. Better training and inspection is also needed. Finally, they encourage the use of comprehensive erosion controls on construction sites and not to over-rely on silt fences.

Donald, W.N., W.C. Zech, X. Fang, and J.J. LaMondia. "Evaluation of wheat straw wattles for velocity reduction in ditch check installations." *Transportation Research Record*. No. 2358, pp. 69-78. 2013.

Donald, *et al.* (2013) conducted controlled channel tests of different installation configurations of wattle ditch check installations at the Auburn University Erosion and Sediment Control Testing Facility, mainly to investigate the effects of staking patterns and filter fabric underlay. Seven wattle installations were tested to measure velocity reductions, impoundment length, and installation structural integrity. The main objective was to reduce the flow length of highly erosive supercritical flows. They examined staking on the downstream side of the wattle, which pierces the netting, to an alternative method of driving stakes into the ground on both upstream and downstream sides, which does not pierce the netting. They also examined the use of a stapled filter fabric underlay that protects the channel bottom from scour beneath the wattles. Three replicates were conducted for each installation option. They used a multiple regression method to identify the significant installation variables.

- Staking patterns did not significantly affect the subcritical flow length.
- Trenching the wattle had a significantly detrimental effect on performance.

• The filter fabric stapled underlay significantly improved performance by increasing the subcritical flow length.

Donald, W.N., W.C. Zech, and X. Fang. "Comparative evaluation of wattle ditch checks composed of differing materials and properties." ***J. Irrig. Drain. Eng.*** **Vol 141, no. 2, pp. 04014051-1 to 9. 2015.**

Donald, *et al.* (2015) used the Auburn test facility to evaluate the hydraulic performance of several wattle check dams. They measured the impoundment depth upgradient of the check dams as the measure of performance. The data indicated an apparent similar trend within each material group for various flow conditions. During high flows, the excelsior and wheat straw wattles were similar when the wattle density to impoundment ratio was considered, while the synthetic wattle (composed of recycled carpet fibers) created a much greater impounding depth, even though it has a lower density in comparison with the other material groups. This was likely due to the synthetic wattle being able to absorb water and swell, causing a greater flow restriction. During low flows, the excelsior and wheat straw wattles did perform significantly differently because flow was not restricted by the high flow-through properties of the excelsior.

Fang, X., W.C. Zech, and C.P. Logan. "Stormwater field evaluation and its challenges of a sediment basin with skimmer and baffles at a highway construction site." ***Water*****. No. 7, pp. 3407 – 3420. 2015.**

Fang, *et al.* (2015) studied enhanced performance in a shallow sediment basin at a highway construction site using skimmers and baffles. The skimmer was the primary water quality outlet capturing effluent water from the surface of the ponded water. The basin also had three coir baffles, along with polyacrylamide flocculant blocks and check dams on the inflow channel. During two monitored events, the average influent turbidity was reduced from 6,830 and 2,024 NTU to 478 and 793 NTU, indicating turbidity removals of 93 and 61%, respectively, while the sediment load reductions were 98 and 84%. Resuspension of deposited sediments from previous rainfall events resulted in higher turbidity in the sediment basin and reduced its effectiveness.

Faucette, L.B., Sefton, K.A., Sadeghi, A.M., Rowland, R.A "Sediment and phosphorous removal from simulated storm runoff with compost filter socks and silt fence." ***Journal of Soil and Water Conservation Society.*** **63:257-264. 2008.**

Faucette, *et al.* (2008) evaluated the sediment removal efficiency of silt fences and compost filter socks, and to determine if the addition of polymers to the compost filter socks could improve the reduction of sediment and phosphorous loads. Four experiments were set up at the Environmental Quality Laboratory, USDA, Agricultural Research Service, Beltsville, MD. The soil test plots used in the tests had 10% slopes and were exposed to a 2.9 in/hr simulated rainfall event for 30 minutes. All the experiments were tested for five treatment conditions, including the bare soil control. The runoff samples were analyzed for TSS, soluble P, total P, and turbidity. The filter socks were able to reduce the TSS concentration between 62% and 87%, and the silt fence achieved TSS reductions greater than 71%. The addition of polymers to the filter socks significantly increased the reduction of TSS concentration to greater than 87%. Silt fences reduced the turbidity in the runoff between 45% and 76%, and the filter socks reduced the turbidity between 53% and 78%. The addition of polymers to the filter socks increased the turbidity reductions to between 79% and 98%.

Faucette, L.B., Governo, J., Tyler, R., Gigley, G., Jordan, C.F., and Lockaby, B.G. "Performance of compost filter socks and conventional sediment control barriers used for perimeter control on construction sites." ***Journal of Soil and Water Conservation*****. vol. 64 no. 1: 81-88. January/February 2009.**

Test plots (with 10% slopes) at Spring Valley Farm in Georgia were used by Faucette, *et al.* (2009) to investigate different slope treatments under high intensity/duration single 5-yr, 24-hr storm event conditions using a rainfall simulator. The erosion control treatments included 8 and 12 inch compost filter socks with and without polymer, a mulch filter berm, and straw bales. The bare soil plot had a turbidity of 3,630 NTU. The compost filter socks with the polymer resulted in turbidities of about 2,000 NTU, and about 2,500 to 3,000 NTU without the polymer. The mulch filter berm resulted in a turbidity of about 3,300 NTO and the straw bale resulted in a turbidity of about 3,200 NTU. Therefore, the overall turbidity reductions ranged from about 8 to 50%. Concurrent TSS concentration reductions were greater, at about 64 to 88%.

Fulazzaky, M.A., M.H. Khumidun, and B. Yusof. "Sediment traps from synthetic construction site stormwater runoff by grassed filter strip." ***Journal of Hydrology*****. 502. Pgs. 53 – 61. 2013.**

Fulazzaky, *et al.* (2013) conducted a series of laboratory flume tests to investigate grass filter strip retention of synthetic construction site runoff particulates. The regression model developed relating runoff flow rate and sediment trapping efficiency was verified at a construction site in Kuala Lumpur. Typical laboratory inlet SS concentrations were in the order of 1,200 mg/L and the observed outlet SS concentrations after grass filtering was about 200 to 400 mg/L. The outlet concentrations increased with increasing flow rates. Maximum sediment trapping efficiencies were about 75 to 85% for 2% slopes and reduced to about 55 to 65% for 8% slopes.

Garcia, C.B., J. Monical, R. Bhattarai, and P.K. Kalita. "Field evaluation of sediment retention devices under concentrated flow conditions." ***J. Soils Sediments*****, No. 15, pp. 2022 – 2031. 2015.**

Garcia, *et al.* (2015) tested several types of ditch check dams during controlled tests at the University of Illinois Erosion Control Research and Training Center. The upgradient total sediment average concentration was about 700 to 800 mg/L, while the downgradient average concentrations ranged from about 443 to 556 mg/L for the three products during three flow rates, although statistical tests did indicate significant differences between the three products. The Triangular Silt Dike performed better under all flow conditions, while the GeoRidge and the Sediment Log performed similarly. The GeoRidge was found to be able to retain more sediment upstream compared to the other two products.

Gharabaghi, B., Fata, A., Seters, T. V., Rudra, R. P., MacMillan, G., Smith, D., Li, J. Y., Bradford, A., Tesa, G. "Evaluation of sediment control pond performance at construction sites in the Greater Toronto Area." ***Canadian Journal of Civil Engineering*****. 33(11): 1335-1344. 2006.**

Gharabaghi, *et al.* (2006) evaluated sediment pond performance at two construction sites in the Toronto area. A numerical model was used to calculate the sediment removal efficiencies based on various pond geometries. The ponds were also monitored to verify the calculations. The pond effluent particle sizes had more than 50% less than 3.7 µm, showing good removal of fine-grain particles. Although both ponds were both designed based on the same design criteria, significant differences in pond performance were observed, although both the ponds showed more than 90% removal of total suspended solids. The main difference between the two ponds is that the better performing pond has a length-to-width ratio of 8:1, while the poorer operating pond has a length-to-width ratio of 2:1.

Hopkinson, L.C., E. Davis, and G. Hilvers. "Vegetation cover at right of way locations." ***Transportation Research Part D: Transport and Environment.*** **Vol. 43. Pgs. 28 – 39. January 2016.**

Hopkinson, *et al.* (2016) evaluated 29 vegetated roadside and median highway locations to compare quality of grass establishment to site factors (soil type, elevation, vegetation establishment and cover, seed mixture, slope, aspect, time since planting, and climate). About half of the sites met the 70% cover criterion necessary to terminate the NPDES permit for the West Virginia Division of Highways. The sites having the worst cover had soils with high soluble salts or low organic matter. The salt content was associated with de-icing operations, while organic matter content was associated with the native soil material. Neither of these factors were considered amenable to changes in management, as adding mulches to increase organic matter is not feasible for large projects and deicing chemical use was used for safety considerations, and alternative chemical use was not considered warranted. Nitrogen soil levels was the only nutrient that had a positive correlation with vegetation cover. Soil tests to indicate needed fertilization were therefore recommended. They did not find any significant relationships between physical site characteristics and vegetation cover. The test location vegetation was mostly tall fescue (Festuca arundinacea) and crownvetch (Coronilla varia L.), which are considered invasive, although included in the seed mixtures used for highway projects. They conclude that site specific seed mixtures should be used at highway projects. Based on this study, these mixtures should be able to better withstand high salt exposures and soils with low organic matter. There are also concerns about using non-native plants in many areas of the country.

Kang, J., M.M. McCaleb, and R.A. McLaughlin. "Check dam and polyacrylamide performance under simulated stormwater runoff." ***Journal of Environmental Management*****. No. 129, pp. 593 – 598. 2013.**

Kang, *et al.* (2013) investigated turbidity reductions through several types of check dams, both with and without polyacrylamide additions, in a lined channel test facility at North Carolina State University. The check dams investigated were: 1) rock check dam representing the standard installation in the state, 2) excelsior wattle representing a fiber check dam (FCD), and 3) rock check dam wrapped with excelsior erosion control blanket representing an alternative FCD. The check dams were installed in a lined, 24-m long channel on a 5 to 7% slope. Additional tests were conducted after manually sprinkling granular polyacrylamide (PAM) on the check dams. The granular PAM applied on the excelsior wattles was able to maintain effluent turbidity well below the 280 NTU turbidity levels. The hydrated PAM on the surface of the excelsior formed a gelatinous pad, which still appeared to be active after the end of the repeated storm event tests. The PAM addition to the bare rock check dams was not as effective (washed out easier), but still reduced the turbidity significantly. The effluent turbidity in the ditch outlet was reduced by 78 to 93% when PAM was applied to any check dam type compared to identical tests with no PAM treatment. They also found that wrapping rocks with an ECB can achieve turbidity reductions comparable to the excelsior wattle in situations where rock check dams are used.

Kang, J. and R.A. McLaughlin. "Simple systems for treating pumped, turbid water with flocculants and a geotextile dewatering bag." ***Journal of Environmental Management*****. 182, pp. 208 – 213. 2016.**

Controlled tests were conducted to investigate the benefits of adding a biopolymer (chitosan) or polyacrylamide (PAM) to simulated construction site runoff water (about 3,000 NTU) before discharging through a conventional bag filter. The dewatering bag resulted in relatively high removals, but the effluent water turbidity was remained higher than desired (about 1,000 NTU). Additions of the chitosan or PAM reduced the effluent turbidity to much lower levels (<100 NTU). The chemical additions did not adversely affect clogging of the dewatering bag during the short duration of the experiments.

Line, D. E., White, N. M. Efficiencies of Temporary Sediment Traps on Two North Carolina Construction Sites. Transactions of the American Society of Agricultural Engineers. 2001; 44(5): 1207-1215

Line and White (2001) evaluated the effectiveness of check dams at two different construction sites in North Carolina having different soil types and slopes. A washed stone and rock check dam was used at one site (43 storms) and a horseshoe-shaped berm, with the open side facing upstream, was used at the other site (13 storms). The overall sediment trapping efficiency at the two sites were about 60 to 70%.

McCaleb, M.M., McLaughlin, R.A. "Sediment trapping by five different sediment detention devices on construction sites." ***Transactions of the ASABE*****. 51(5): 1613-1621. 2008.**

McCaleb and McLaughlin (2008) monitored several sediment trapping devices on construction sites in North Carolina. Three devices were basins with outlets designed for 10-year recurrence storms with following differences: one was excavated to have a 1m standing pool, one had silt fence baffles with weirs, and one was open and fully drained. The fourth basin had a rock outlet and was fully open and drained, but was sized for 25-year recurrence storm. The fifth device had a floating surface outlet and solid riser spillways plus porous baffles within basin, and is designed for a 25-year recurrence storm. The three devices with rock dam outlets retained less than 45% of the sediment entering the traps over the monitoring period. The skimmer outlet device with surface outlets, stable sides and inlets, and porous baffles retained more than 99% of the sediment, but the efficiency dropped when the floating outlet mired in sediment, which resulted in discharge from bottom.

McLaughlin, R. A., S. A. Hayes, and D. L. Osmond. "Testing Polyacrylamides for turbidity and erosion control." ***International Erosion Control Association, Proceedings of Conf 33*****. pgs 407-418. 2002.**

McLaughlin, *et al.* (2002) tested 11 different PAMs on 13 different sediment sources from North Carolina highway construction sites in the laboratory. Field tests were also performed using two PAMs (Soilfix and Silt Stop 705) at two rates, with and without straw much and seeding, on a 2:1 fill slope, applied at the recommended rate and at half of the recommended rate. These field tests were conducted with and without straw mulch seeding, straw mulch and seed only, and bare soil. Eight rain events were recorded during the 5 week testing period with total rainfall for each event varying from 0.08 to 2.24cm. Turbidity reductions of 80%, or more, was achieved at higher doses for all the flocculants. Turbidity reductions of 95% or more were achieved for many PAM and soil combinations, showing that PAM is effective in right combinations. PAM only had marginal effects on severe 2:1 slopes.

McLaughlin, R.A., Brown, T.T. "Evaluation of erosion control products with and without added Polyacrylamide." ***Journal of the American Water Resources Association*****. Volume 42, Issue 3, pp 675 – 684. June 2006.**

McLaughlin, *et al.* (2006) evaluated the use of anionic PAM on bare soil and in combinations with different ground covers (straw, straw erosion control blanket, wood fiber, and mechanically bonded fiber matrix). Natural rainfall and vegetation (fescue) was tested on a 4% slope and other tests were conducted with a rainfall simulator on 10 and 20% slopes. The ground covers were applied with and without PAM (Siltstop 705 at 19 kg/ha) after seeding. The ground covers significantly reduced runoff volume, turbidity losses and sediment losses compared to bare soil at the 4% slope test site, as shown in the table above. Straw produced better vegetative cover than either bare soil or the fiber matrix on the steeper slopes. PAM with straw was effective in reducing turbidity during the 20% slope tests.

McLaughlin R.A., Bartholomew N. "Soil factors influencing suspended sediment flocculation by polyacrylamide." ***Soil Science Society of America Journal*****. 71:537-544. 2007.**

McLaughlin, *et al.* (2007) conducted laboratory tests to determine the effect of soil physical and chemical properties on flocculation by PAMs. Soil samples were collected from 13 construction sites in North Carolina. Eleven different PAM products were tested, having i varying molecular weights (14 to 28 $Mgmol^{-1}$) and charge densities (0 to 50%). The flocculation tests used 5 g of subsoil mixed with 100 mL of distilled water. The PAM was then added to bring the PAM concentrations from 0 to 2 mg PAM/L. They concluded: "Three patterns of turbidity response to increase in PAM dosage were observed in this study: steady decline to 1 to 2 mg L^{-1}, steady decline with a stabilization (increased turbidity) response initiating at or below 1 mg L^{-1}, and low or erratic changes. The optimal dose appeared to be between 1 and 2 mg L^{-1}. Subsoils that demonstrated the greatest turbidity reduction with PAM has several common properties. They all were greater than 14 % clay and 22 % silt content. The most responsive subsoils had the highest CBD-extractable Fe. Anionic PAM flocculated the kaolinite-dominated soils more readily than subsoils with significant smectite or vermiculite. The relationships between PAM effectiveness and subsoil properties were found to be strong for particle size distribution, with increasing sand content having a negative effect on turbidity reduction."

McLaughlin, R.A. "Polyacrylamide reduces erosion on construction site slopes." ***Proceedings of 38th International Erosion Control Association Annual Conference.*** **2007.**

McLaughlin, *et al.* (2007) studied 18 erosion control treatment plots at four locations in North Carolina. The plots were treated with fertilizer and lime and a fescue, Bermuda, a centipede seed mixtures. Straw and asphalt tackifiers and Polymer Systems 705 PAM powder were also applied at some test plots. They found that the runoff turbidity from straw treated plots was substantially reduced, while the Excelsior matting had a smaller reduction in runoff turbidity. A large turbidity reduction with PAM was noted for one site, but not at another. They concluded that PAM applications of 20 kg/ha were needed on slopes from 5 to 45% for consistent turbidity reductions.

McLaughlin. R. A., King, S. E., Jennings, G. D. Improving construction site runoff quality with fiber check dams and Polyacrylamide. Journal of Soil and Water Conservation 2009 64(2): 144-154

McLaughlin, *et al.* (2009a) studied erosion control test options at two roadway construction projects in North Carolina. The controls investigated included: standard narrow sediment traps in the ditch along with rock check dams; fiber check dams consisting of a mix of straw wattles and coir logs; or fiber check dams with granulated anionic PAM (Siltstop 705). The fiber check dams resulted in greater reductions in sediment losses compared to the standard rock check dams. The use of the PAM further increased the performance of the fiber check dams.

McLaughlin, R.A., Hayes, S.A., Clinton, D.L., McCaleb, M.S., Jennings, G.D. "Water quality improvements using modified sediment control systems on construction sites." ***Transactions of ASABE*****. 52(6): 1859-1867. 2009**

McLaughlin, *et al.* (2009b) evaluated three different sediment pond alternatives (standard sediment trap, modified standard sediment trap with forebay and PAM, and skimmer basin with forebay and PAM) on a large construction site in North Carolina, during 11 rains. The skimmer pond had the largest turbidity improvement, with influent turbidities ranging from about 110 to 4,400 NTU while the surface outlet turbidities from the skimmer discharge ranged from about 30 to 780 NTU. The other changes (forebays and use of PAM) did not result in obvious turbidity reductions.

McLaughlin, R.A., McCaleb, M.M. "Passive treatment to meet the EPA turbidity limit." ***ASABE - TMDL 2010: Watershed Management to Improve Water Quality.*** **pp 71-76, 2010.**

McLaughlin, *et al.* (2010) investigated the turbidity reduction performance of three check dam types in combination with PAM (rock only, rock with PAM, rock wrapped with excelsior, rock wrapped with excelsior with PAM, excelsior wattle, and excelsior wattle with PAM). During three tests, the rock alone resulted in about 400, 1050, and 1300 NTU (the highest for any control combination). PAM additions significantly reduced the turbidity for all dam materials (by about 60 to 90% compared to tests without PAM). For the higher NTU runs, the excelsior blankets (wrapped rocks or wattles) reduced the turbidities by about 60% without PAM.

Perez, M.A., W.C. Zech, W.N. Donald, and X, Fang. "Methodology for evaluating inlet protection practices using large-scale testing techniques." ***J. Hydrol. Eng*****., Vol. 20, no. 4 pp. 04014049 –1 to -9. 2015.**

Perez, *et al.* (2015) developed protocols and examined inlet protection practices under controlled large-scale tests at the Auburn University Erosion and Sediment Control Testing Facility. This 0.9 ha facility was developed for testing, evaluating, and improving erosion and sediment control practices and products typically used on highway construction projects. A wattle barrier inlet protection practice was installed according to ALDOT standards. During the tests, measured parameters indicating performance included erosion losses around the barrier, deposition outside and inside the barrier ring, ponding depth and duration, flows, turbidity, and TSS levels. The erosion and deposition volumes were measured using a Trimble S6 Robotic Total Station. The ALDOT standard installation resulted in about a 70% capture of total solids behind the barrier, while an enhanced barrier retained about 85% of the total solids.

Roa-Espinosa, A., Bubenzer G.D., Miyashita E.S. "Sediment and runoff control on construction sites using four application methods of Polyacrylamide mix." ***National Conference on Tools for Urban Water Resource Management and Protection*****. Chicago, Feb. 7-10, 2000, p. 278-283, University of Wisconsin. 2000.**

Roa-Espinosa, *et al.* (2000) conducted erosion tests at 15 test plots at a construction site in Madison, WI. They applied a simulated 6.3 cm/hr rain after the plots were treated with a Polyacrylamide mix (PAM-mix CFM 2000, applied at a rate of 22.5 kg/ha). The PAM treatments resulted in sediment reductions of 63% to 81% when applied to dry soil, and 36% to 97% when applied to moist soil.

Rounce, D. R., Eck, B. J., Lawler, D. F., Barrett, M. E. Reducing Turbidity of Construction Site Runoff: Coagulation with Polyacrylamide. Journal of Transportation Research Board, No. 2309. Transportation Research Board of the National Academics, Washington, D.C., 2012. pp 171-177

This study was performed to evaluate the effective use of PAM for sediment control and to understand how properties of PAM and soil affect flocculation. For this study, seven soil samples were collected from different highway construction sites across the state of Texas. A modified synthetic stormwater runoff was created for each sample such that a turbidity of 1500 NTU (+/- 300 NTU) is attained. Seven PAM products were used in this study, with varying ranges of molecular weights (0.2 to 14 $Mgmol^{-1}$) and charge densities (0% to 50%). Jar tests were performed to determine the effectiveness of a variety of PAMs and different doses of each PAM on each of the selected soils. The jar tests comprised a rapid mix, slow mix, and settling period. Jar tests were run with modified synthetic stormwater runoff with each type of PAM with varying doses (0.03 to 10 mg/L). Hardness tests were performed to determine if calcium was actually participating in the reaction and being removed with particles in jar test. Electrophoretic tests were also conducted to determine the effect that each flocculent had on the surface charge of particles. The PAM which had the lowest molecular weight was ineffective for all the modified synthetic stormwater runoffs, while the other high molecular weight PAMs were more effective. Hardness and electrophoretic mobility tests indicated interparticle bridging to be the bonding mechanism. The increase in charge density for high molecular weight PAMs has shown negative effects in flocculation.

Rounce, D., Lawler, D., Barrett, M. "Reducing turbidity of construction site runoff: Factors affecting particle destabilization with Polyacrylamide." ***World Environmental and Water Resources Congress 2012*****. pp. 509-519. 2012.**

Rounce, *et al.* (2012) conducted jar tests using seven different PAM products and seven soil samples collected from Texas construction sites. The initial turbidities were 1500 NTU (+/- 300 NTU). The PAM products were used in this study had molecular weights of 0.2 to 14 $Mgmol^{-1}$ and charge densities of 0% to 50%. The PAM dosages varied from 0.03 to 10 mg/L. Hardness tests were performed to determine if calcium was participating in the reaction. Electrophoretic tests were also conducted to determine the effect that each flocculent had on the surface charge of particles. The PAM which had the lowest molecular weight was ineffective during all tests. The hardness and electrophoretic mobility tests indicated that interparticle bridging was the dominant bonding mechanism.

Sidhu, R.S., M. Dougherty, W.C. Zech, and B. Guertal. "Cost effectiveness of erosion control covers during vegetation establishment under simulated rainfall." ***Journal of Water Resource and Protection*****. 7. Pgs. 119 – 129. 2015.**

Sidhu, *et al.* (2015) investigated runoff volume and sediment delivery reductions associated with different surface treatments. Pilot-scale 1.2 m × 0.6 m test plots were used with 2-year 15 minute and 2-year 30 minute rain intensities at the Turfgrass Research Unit (TGRU) at Auburn University, Auburn, AL. The test plots were filled with sandy clay soils. The ground covers tested were bare soil with polyacrylamide (PAM, EnviroPAM® polyacrylamide distributed by Innovative Turf Solutions, Cincinnati, OH), wheat straw and PAM with and without seed; and engineered fiber matrix with and without seed. The fiber mat with the seed was found to be the most effective treatment for turbidity and suspended solids reductions (>98% reductions). The runoff volume reductions ranged from about 16% for the bare soil plus PAM to 68% for the fiber mat plus seed. The wheat straw plus pam and seed was recommended as the most cost effective method for sediment delivery reductions.

Soupir, M. L., Mostaghimi, S., Masters, A., Flahive, K. A., Vaughan, D. H., Mendez, A. and McClellan, P. W. "Effectiveness of Polyacrylamide (PAM) in improving runoff water quality from construction sites." ***Journal of the American Water Resources Association*****, 40: 53–66. 2004.**

Twenty-one test plots were studied at a Virginia Tech construction site. All were fertilized and PAM was applied at three rates on different plots by Soupir, *et al.* (2004). A hydromulch-cellulose-seed mixture was applied with the fertilizer. Rainfall simulations were used one month apart to test the short- and long-term effects of the different combinations. They found that the most effective treatments in reducing TSS concentrations were straw mulch, then the hydroseed, and then the dry PAM. The straw mulch, followed by dry PAM, were the most effective treatments in reducing TP concentrations, while the low PAM application rate was most effective in reducing TN concentrations.

Tobiason, S., Jenkins, D., Molash, E., Rush, S. "Polymer use and testing for erosion and sediment control on construction sites: Recent experience on Pacific Northwest." ***Proceedings of Conference 31, International Erosion Control Association*****. Palm Spring, CA. pp 41-52. February 21 – 25, 2000.**

Tobiason, *et al.* (2000) investigated different PAM application rates at three sites in Washington state. At the first site, slopes of test boxes were 3.5H to 1V. Chemco™ 9836A granular anionic Polyacrylamide was used in these tests, along with Vanson™ Chitosan (at a single concentration). Construction sites of 0.4 to 13.5 acres with slopes ranging from 6H to 3H to 1V were also investigated at a second location. The third location was a large construction project where hydroseeding was used along with geotextile-lined interceptor ditches that drained to a sedimentation pond. A polymer batch treatment system was used at this location as an experimental control for post treatment. The sediment pond effluent was dosed with Catfloc 2953, a poly-aluminum-based conventional water treatment polymer. Observation from the first test facility indicated that a PAM dosage in the range of 40-80 mg/L was more effective for the soils and slopes. At the second site, turbidity reductions high (up to > 90%) with PAM alone and in combinations with hydromulch. At the third site, turbidity reductions of >90% in the pond effluent were obtained with a 2 hour contact time.

Vasconcelos, J.G., M. Perez, J. Want. W.C. Zech, and X. Fang. *Evaluation of High-rate Settling Technology for Sediment Control in Roadway Construction Sites*. Department of Civil Engineering, Auburn University, for Alabama Department of Transportation, Montgomery, AL. 67 pgs. 2017.

Vacconcelos, *et al.* (2017) describe a series of controlled erosion control evaluations conducted at the Auburn University Erosion and Sediment Control Testing Facility to enhance sediment pond performance. Their goal, using a 17 by 9 m pilot-scale pond configuration, was to examine the benefits of the following on sediment pond performance:

- Having a forebay prior to a sediment basin;
- Changing thickness of coir fiber baffles;
- Adding high-rate lamella settlers in the sediment basin; and
- Adding a small-scale high-rate lamella settler to treat skimmer outflow from basins.

Measured infiltration losses from the test pond was about 2.2 cm/hr (0.9 in/hr) averaged over 24 hrs. Automatic water samplers were located at several locations in the pond between porous baffles, indicating turbidity gradients along the water flow path in the pond. A surface skimmer was used to withdraw the water from the surface of the pond to minimize bottom scour. The pond was designed based on the ALDOT (Alabama Department of Transportation) pond sizing criterion of 250 m^3/ha (3,600 ft^3/acre). Another ALDOT sizing option is to completely contain the runoff from a 2-yr, 24-hr rain event. The test flows were selected to be 0.042 m^3/sec (1.5 ft^3/sec), corresponding to the average flow rate over 30 min of the design storm. The influent sediment concentration was calculated to be about 8,000 mg/L using MUSLE (the Modified Universal Soil Loss Equation). The median size (D50) of the added medium sand (sieved local soil) was about 1 mm in diameter, while the D10 was about 0.1 mm. Most of the larger particles were trapped in the influent channel and did not enter the pond. The following figure shows the water and sediment inlets for the tests. The initial tests using porous baffles resulted in 30 minute average turbidity levels of about 770 NTU during the filling period. The initial turbidity levels in the other bays were about the same, but decreased to about 300 NTU at the end of the filling of the pond. During one hour quiescent settling, lower turbidity levels of between 220 and 270 NTU in the different chambers were noted, At 12 hours, the turbidity level was the same in all three bays, at 113 NTU. The baffles were therefore found to only be important during the initial filling period. Tests were also conducted using an excavated sump forebay. However, no turbidity reduction was observed with the sump. In fact, sediment from the forebay became resuspended during the later tests. Tests conducted using the lamella plate systems had clear positive on the water quality. The following plot shows the particle size distribution changes as the water flowed through the pond and lamella plate treatment (labelled HRS). The lamella plates resulted in effluent median particle sizes of about 7 µm, compared to about 20 µm without using the plates. They also tested the use of polyacrylamide (PAM) flocculants to further reduce the effluent turbidity. They tested the use of small blocks of PAM at the pond outlet as a polishing treatment of small particles after most of the sediment had been captured in the pond. The observed outlet turbidity levels were all less than 100 NTU with the use of the PAM, four times less than the untreated skimmer flows. Other observations during the tests found that the pond had greater removal rates with deeper water, indicating scour protection through dissipation of the energy of the flowing water. They also observed significant reductions in settling rates during cold weather, resulting in reduced performance.

Wilson, W.T, Zech, W. C., Clement, T.P, Shoemaker, A.L. "Polymer-enhanced soft armoring: An erosion and sediment control measure for construction fill slopes." ***41st International Erosion Control Association Annual Conference*****. pp 150-157. 2010.**

Wilson, *et al.* (2010) tested soil from a construction site in Auburn, AL under controlled rainfall simulations at 4.4 in/hr (the local 2-yr, 24-hr rainfall intensity). Dry PAM (Silt Stop^{TM} 712) was applied at a rate of 31.2 kg/ha with an open weave jute matting installed on bare soil. The jute matting was found to be effective in reducing soil losses, while the addition of the dry PAM resulted in reduced soil loss and turbidity.

Xu, X., K. Zang, J. Chen, and B. Yu. "Effectiveness of erosion control measures along the Qinghai-Tibet highway, Tibetan plateau, China." ***Transportation Research Part D: Transport and Environment.*** **Vol. 11, Issue 4, pgs. 302 – 309. July 2006.**

Xu, *et al.* (2006) studied a range of erosion control measures to reduce runoff and soil losses along the Qinghai–Tibet highway near Tuotuo river in the summers of 2003 and 2004. The test locations are characterized by high elevations, low summer rainfall, and poor vegetation cover. They found that engineering erosion controls can be effective during short periods, but established vegetation on the steep slopes is the most effective during the long term. They found that a combination of lattice structures and establishing vegetation was the most effective overall.

Zhang, C., W. Chen, C. Li, Y. Pu, and H. Sun. "Effects of polyacrylamide on soil erosion and nutrient losses from substrate material in steep rocky slope stabilization projects." ***Science of the Total Environment*****. 554-555, pp. 26 – 22. 2016.**

Zhang, *et al.* (2016) note that PAM is adsorbed by soil through cationic bridges between soil and polymer anionic groups, and multivalent cations in the soil solution would bridge the negatively charged soil particles and polymers together. Nine types of anionic polyacrylamide (PAM) were studied during twenty-seven simulated rainfall events in a greenhouse. They found that:

(1) PAM reduced total nitrogen and total phosphorus losses from the 3 mm test aggregate by about 35% to 50% compared to the control group.

(2) The losses of total nitrogen and total phosphorus had significant correlation with the molecular weight of the PAM.

Citations Containing Erosion and Sediment Control Effectiveness Data

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Appendix B. Tools Included in Erosion and Sediment Control Guidelines

Erosion Controls (U.S. Manuals) (URLs will likely change with time; use search tools to locate most recent manuals)

Jurisdiction	Preferred Erosion Controls													
	Land Grading	**Topsoiling**	**Surface Roughening**	**Preserving Natural Vegetation**	**Chemical Stabilization (PAM)**		**Erosion Control Blanket/ Geotextiles**	**Mulching**	**Soil Binders**	**Permanent Seeding**	**Groundcover Planting**	**Sodding**	**Temporary seeding**	**Tree Planting**
U.S. Sources					**Land Application**	**Water Application**								
State of Alabama (http://swcc.alabama.gov/pages/erosion_handbook.aspx)	Yes	Yes		Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
State of Alaska (http://www.dec.state.ak.us/water/wnpspc/stormwater/Guidance.html)			Yes	Yes	Yes	Yes	Yes	Yes					Yes	
State of Arizona (DOT) for Highway Construction (http://www.azdot.gov/inside_adot/OES/Water_Quality/Stormwater/Manuals.asp)			Yes	Yes			Yes	Yes	Yes					
County of Maricopa, AZ (http://www.fcd.maricopa.gov/Pub/manuals/erosionControl.aspx)			Yes				Yes	Yes					Yes	
State of Arkansas (DOT) for Highway Construction (http://www.arkansashighways.com/stormwater/erosion_sediment_manual.aspx)			Yes				Yes	Yes					Yes	
State of California (http://www.dot.ca.gov/manuals.htm)				Yes			Yes	Yes	Yes				Yes	
City of Morro Bay, CA (http://www.morro-bay.ca.us/index.aspx?NID=689)				Yes			Yes	Yes					Yes	
San Francisco Bay Region, CA (http://www.co.monterey.ca.us/building/grade/forms%202005/Erosion%20Control%20Handbook.pdf)			Yes	Yes			Yes	Yes		Yes			Yes	
Urban Drainage Flood Control District, Denver, CO (http://www.udfcd.org/downloads/down_critmanual_home.htm)			Yes				Yes	Yes	Yes	Yes			Yes	

Jurisdiction	Preferred Erosion Controls (Contd.)													
	Land Grading	Topsoiling	Surface Roughening	Preserving Natural Vegetation	Chemical Stabilization (PAM)		Erosion Control Blanket/ Geotextiles	Mulching	Soil Binders	Permanent Seeding	Groundcover Planting	Sodding	Temporary seeding	Tree Planting
					Land Application	Water Application								
State of Colorado (DOT) for Highway Construction (http://www.coloradodot.info/programs/environmental/water-quality/documents/erosion-storm-quality)	Yes						Yes	Yes	Yes				Yes	
Jefferson County, CO (https://www.co.jefferson.co.us/planning/planning_T59_R35.htm)				Yes			Yes	Yes					Yes	
State of Connecticut (http://www.ct.gov/deep/cwp/view.asp?a=2720&q=325660)	Yes	Yes	Yes	Yes			Yes	Yes		Yes	Yes		Yes	Yes
State of Delaware (http://www.dnrec.delaware.gov/swc/pages/sedimentstormwater.aspx)	Yes	Yes					Yes	Yes				Yes	Yes	
District of Columbia (http://ddoe.dc.gov/soil-erosion-and-sediment-control-handbook)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes		Yes	Yes	
State of Florida (http://stormwater.ucf.edu)	Yes	Yes	Yes	Yes			Yes	Yes	Yes	Yes		Yes	Yes	
State of Georgia (http://www.gaepd.org/Documents/esc_manual.html)		Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Commonwealth of Northern Marina Islands and Guam (http://www.deq.gov.mp/article.aspx?secID=6&artID=199)	Yes	Yes	Yes				Yes	Yes		Yes			Yes	
State of Hawaii (DOT) for Highway Construction (http://stormwaterhawaii.com/contractors/contractors_design.aspx)			Yes				Yes	Yes			Yes		Yes	
City and County of Honolulu, HI (http://www.cleanwaterhonolulu.com/storm/)	Yes	Yes	Yes	Yes			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Jurisdiction	Preferred Erosion Controls (Contd.)													
	Land Grading	Topsoiling	Surface Roughening	Preserving Natural Vegetation	Chemical Stabilization (PAM)		Erosion Control Blanket/ Geotextiles	Mulching	Soil Binders	Permanent Seeding	Groundcover Planting	Sodding	Temporary seeding	Tree Planting
					Land Application	Water Application								
Kauai County, HI (http://www.kauai.gov/Government/Departments/PublicWorks/Engineering/DesignampPermitting/tabid/133/Default.aspx)			Yes	Yes			Yes	Yes		Yes			Yes	
State of Idaho (http://www.deq.idaho.gov/water-quality/wastewater/stormwater.aspx)		Yes	Yes				Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State of Illinois (http://www.aiswcd.org/Programs/ium.html)	Yes	Yes	Yes				Yes	Yes		Yes	Yes	Yes	Yes	Yes
State of Indiana (http://www.in.gov/idem/4899.htm)		Yes	Yes	Yes			Yes	Yes		Yes		Yes	Yes	
State of Iowa (http://www.iowadnr.gov/InsideDNR/RegulatoryWater/StormWater/GuidanceApplicationForms.aspx)			Yes				Yes	Yes		Yes		Yes	Yes	
States of Kansas and Missouri (http://www.dnr.mo.gov/env/wpp/wpcp-guide.htm)	Yes	Yes	Yes	Yes			Yes	Yes		Yes		Yes	Yes	
City of Crestwood, MO (http://www.ci.crestwood.mo.us/business/permits-licenses/)			Yes				Yes	Yes	Yes	Yes		Yes	Yes	
City of West Plains, MO (http://wpstormwater.weebly.com/publications.html)			Yes				Yes	Yes		Yes			Yes	
State of Kentucky (http://water.ky.gov/permitting/Lists/Working%20in%20Streams%20and%20Wetlands/DispForm.aspx?ID=14)		Yes	Yes		Yes	Yes	Yes	Yes		Yes		Yes	Yes	

Jurisdiction	Preferred Erosion Controls (Contd.)														
	Land Grading	Topsoiling	Surface Roughening	Preserving Natural Vegetation	Chemical Stabilization (PAM)		Erosion Control Blanket/ Geotextiles	Mulching	Soil Binders	Permanent Seeding	Groundcover Planting	Sodding	Temporary seeding	Tree Planting
					Land Application	Water Application								
State of Louisiana Coastal Zone (http://dnr.louisiana.gov/index.cfm?md=pagebuilder&tmp=home&pid=109)		Yes		Yes			Yes	Yes		Yes	Yes	Yes	Yes	Yes
State of Maine (http://www.maine.gov/dep/land/erosion/escbmps/index.html)	Yes	Yes	Yes				Yes	Yes	Yes	Yes	Yes		Yes	
State of Maryland (http://www.mde.maryland.gov/programs/water/stormwatermanagementprogram/soilerosionandsedimentcontrol/pages/programs/waterprograms/sedimentandstormwater/erosionsedimentcontrol/esc_standards.aspx)	Yes	Yes					Yes	Yes		Yes	Yes		Yes	
State of Massachusetts (http://www.mass.gov/eea/agencies/massdep/water/regulations/water-resources-policies-and-guidance-documents.html)	Yes	Yes	Yes	Yes			Yes	Yes		Yes	Yes	Yes	Yes	Yes
State of Michigan (MDOT) for Highway Construction (http://www.michigan.gov/deq/0,4561,7-135-3311_4113---,00.html), (http://macdc.us/index.php)			Yes				Yes			Yes	Yes	Yes	Yes	Yes
State of Minnesota (http://www.pca.state.mn.us/index.php/water/water-types-and-programs/stormwater/stormwater-management/stormwater-best-management-practices-manual.html)	Yes	Yes	Yes				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
State of Mississippi (http://deq.state.ms.us/MDEQ.nsf/page/NPS_Publications_Literature?OpenDocument)	Yes	Yes		Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes

Jurisdiction	Preferred Erosion Controls (Contd.)													
	Land Grading	Topsoiling	Surface Roughening	Preserving Natural Vegetation	Chemical Stabilization (PAM)		Erosion Control Blanket/ Geotextiles	Mulching	Soil Binders	Permanent Seeding	Groundcover Planting	Sodding	Temporary seeding	Tree Planting
					Land Application	Water Application								
State of Montana (http://www.mdt.mt.gov/research/projects/env/erosion.shtml)	Yes		Yes				Yes	Yes		Yes			Yes	
City of Billings, MT (http://mt-billings.civicplus.com/index.aspx?NID=567)				Yes			Yes	Yes	Yes	Yes			Yes	
State of Nebraska (NDOR) for Roadways Construction (http://www.transportation.nebraska.gov/environment/swppp.htm)							Yes	Yes		Yes	Yes	Yes	Yes	
City of Omaha and Paio-Missouri River Natural Resources District, NE (http://www.papiopartnership.org/stormwater/construction_site_runoff_control.shtml)		Yes					Yes			Yes		Yes	Yes	
City of Lincoln, NE (http://www.lincoln.ne.gov/city/pworks/watrshed/require/drainage/)		Yes	Yes				Yes	Yes		Yes		Yes	Yes	
City of Scottsbluff, NE (http://www.scottsbluff.org/departments/public_works/stormwater/web_resources.php)			Yes				Yes	Yes						
State of Nevada (http://ndep.nv.gov/bwqp/bmp05.htm)		Yes		Yes			Yes	Yes	Yes	Yes			Yes	
State of Nevada (DOT) for Highway Construction (http://www.nevadadot.com/About_NDOT/NDOT_Divisions/Engineering/Hydraulics/Water_Quality_BMP_Manuals.aspx)				Yes			Yes	Yes	Yes	Yes			Yes	
Las Vegas Valley, NV (http://www.lvstormwater.com/)		Yes	Yes	Yes			Yes	Yes					Yes	
City of Elko, NV (http://www.ci.elko.nv.us/commdev/dev_eng.html)		Yes	Yes	Yes			Yes	Yes	Yes	Yes		Yes	Yes	

Jurisdiction	Preferred Erosion Controls (Contd.)													
	Land Grading	Topsoiling	Surface Roughening	Preserving Natural Vegetation	Chemical Stabilization (PAM)		Erosion Control Blanket/ Geotextiles	Mulching	Soil Binders	Permanent Seeding	Groundcover Planting	Sodding	Temporary seeding	Tree Planting
					Land Application	Water Application								
State of New Hampshire (http://des.nh.gov/organization/divisions/water/stormwater/manual.htm)	Yes		Yes				Yes	Yes		Yes			Yes	
State of New Jersey (NJDOT) for Highway Construction (http://www.state.nj.us/transportation/eng/documents/SESC/)	Yes			Yes			Yes	Yes		Yes	Yes		Yes	Yes
State of New York (http://www.dec.ny.gov/chemical/29066.html)	Yes	Yes	Yes	Yes			Yes	Yes		Yes	Yes	Yes	Yes	Yes
State of North Carolina (http://portal.ncdenr.org/web/lr/publications#espubs)	Yes	Yes	Yes	Yes			Yes	Yes		Yes	Yes	Yes	Yes	Yes
State of North Dakota (http://www.ndhealth.gov/WQ/publications.asp?DivisionID=18&ShowSectionHeading=no)							Yes			Yes			Yes	
State of Ohio (http://www.dnr.state.oh.us/tabid/9186/default.aspx)	Yes	Yes	Yes	Yes			Yes	Yes		Yes		Yes	Yes	
Clermont County, OH (http://www.clermontstorm.net/escbmps.aspx)			Yes		Yes	Yes	Yes	Yes		Yes		Yes	Yes	
City of Oklahoma City, OK (http://www.okc.gov/pw/SWQ/storm15.html)							Yes	Yes						
State of Oregon (http://www.deq.state.or.us/wq/stormwater/constappl.htm)		Yes	Yes	Yes			Yes	Yes	Yes	Yes	Yes	Yes	Yes	
City of Corvallis, OR (http://www.corvallisoregon.gov/index.aspx?page=366)				Yes			Yes	Yes		Yes		Yes	Yes	

Jurisdiction	Preferred Erosion Controls (Contd.)													
	Land Grading	Topsoiling	Surface Roughening	Preserving Natural Vegetation	Chemical Stabilization (PAM)		Erosion Control Blanket/ Geotextiles	Mulching	Soil Binders	Permanent Seeding	Groundcover Planting	Sodding	Temporary seeding	Tree Planting
					Land Application	Water Application								
City of Gresham, OR (https://www.greshamoregon.gov/city/city-departments/environmental-services/watershed-management/template.aspx?id=20715)		Yes	Yes	Yes			Yes	Yes	Yes	Yes	Yes	Yes	Yes	
City of Portland, OR (http://www.portlandonline.com/auditor/index.cfm?a=81661&c=28044)		Yes	Yes				Yes	Yes		Yes	Yes	Yes	Yes	
State of Pennsylvania (http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-8299)	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes	
State of Rhode Island (http://www.dem.ri.gov/programs/benviron/water/permits/swcoord/)	Yes	Yes	Yes	Yes			Yes	Yes		Yes	Yes	Yes	Yes	Yes
State of South Carolina (https://www.scdhec.gov/environment/water/swater/BMPhandbook.htm)			Yes		Yes	Yes	Yes	Yes		Yes		Yes	Yes	
State of South Dakota (SDDOT) (http://www.sddot.com/resources/manuals/)		Yes	Yes				Yes	Yes		Yes		Yes	Yes	
Pennington County, SD (http://www.co.pennington.sd.us/stormwater/smp.html)			Yes				Yes	Yes		Yes			Yes	
State of Tennessee (http://www.tn.gov/environment/wpc/sed_ero_controlhandbook/)		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
State of Texas (http://www.tceq.texas.gov/assets/public/permitting/waterquality/attachments/401certification/erosion.pdf)							Yes	Yes				Yes	Yes	
North Central Texas (http://iswm.nctcog.org/)					Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes	

Jurisdiction	Preferred Erosion Controls (Contd.)													
	Land Grading	Topsoiling	Surface Roughening	Preserving Natural Vegetation	Chemical Stabilization (PAM)		Erosion Control Blanket/ Geotextiles	Mulching	Soil Binders	Permanent Seeding	Groundcover Planting	Sodding	Temporary seeding	Tree Planting
					Land Application	Water Application								
State of Utah (UDOT) for Highway Construction (http://www.udot.utah.gov/main/f?p=100:pg:0::::V,T:,2122)				Yes			Yes	Yes		Yes				
Salt Lake County, UT (http://www.pweng.slco.org/stormwater/html/guide.html)	Yes		Yes	Yes			Yes	Yes		Yes			Yes	
State of Vermont (http://www.vtwaterquality.org/stormwater/htm/sw_cgp.htm)		Yes	Yes	Yes			Yes	Yes		Yes		Yes	Yes	
Virgin Islands (http://www.coralreef.gov/transportation/)	Yes			Yes			Yes	Yes	Yes	Yes	Yes		Yes	
State of Virginia (http://www.dcr.virginia.gov/stormwater_management/e_and_s.shtml)		Yes	Yes	Yes			Yes	Yes		Yes	Yes	Yes	Yes	Yes
City of Seattle, WA (http://web1.seattle.gov/dpd/dirrulesviewer/List.aspx?leg=GD&t=Stormwater,%20Grading,%20and%20Drainage%20Control%20Code%20%28Ch.%2022.800%29)		Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	
King County, WA (http://www.kingcounty.gov/environment/waterandland/stormwater/documents/surface-water-design-manual.aspx)			Yes		Yes	Yes	Yes	Yes		Yes		Yes	Yes	
Eastern Washington (https://fortress.wa.gov/ecy/publications/summarypages/0410076.html)		Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes		Yes	Yes	
Western Washington (http://www.ecy.wa.gov/programs/wq/stormwater/manual.html)		Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes		Yes	Yes	
State of West Virginia (http://www.dep.wv.gov/WWE/Programs/stormwater/csw/Pages/ESC_BMP.aspx)		Yes	Yes	Yes			Yes	Yes		Yes	Yes	Yes	Yes	
Jurisdiction	Preferred Erosion Controls (Contd.)													

	Land Grading	Topsoiling	Surface Roughening	Preserving Natural Vegetation	Chemical Stabilization (PAM)		Erosion Control Blanket/ Geotextiles	Mulching	Soil Binders	Permanent Seeding	Groundcover Planting	Sodding	Temporary seeding	Tree Planting
					Land Application	Water Application								
State of Wisconsin (http://dnr.wi.gov/topic/stormwater/standards/const_standards.html)	Yes				Yes	Yes	Yes	Yes		Yes			Yes	
Dane County, WI (http://www.danewaters.com/business/stormwater.aspx)			Yes	Yes			Yes	Yes		Yes		Yes	Yes	Yes
City of Casper, WY (http://www.casperwy.gov/PublicWorks/StormWaterManagement/ErosionandSediment/tabid/531/Default.aspx)				Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Erosion Controls (Non – U.S. Manuals)

Jurisdiction	Preferred Erosion Controls (Contd.)													
	Land Grading	Topsoiling	Surface Roughening	Preserving Natural Vegetation	Chemical Stabilization (PAM)		Erosion Control Blanket/ Geotextiles	Mulching	Soil Binders	Permanent Seeding	Groundcover Planting	Sodding	Temporary seeding	Tree Planting
					Land Application	Water Application								
Non – U.S. Sources														
Singapore (http://www.pub.gov.sg/ecm/download/Pages/default.aspx)							Yes			Yes			Yes	
Malaysia (http://www.water.gov.my/urban-stormwater-mainmenu-564/188), (http://msmam.com/msma-chapters/)				Yes			Yes	Yes		Yes	Yes		Yes	Yes
Scotland and Northern Ireland (http://www.ciria.org/service/AM/ContentManagerNet/Default.aspx?template=/TaggedPage/TaggedPageDisplay.cfm&TPLID=66&ContentID=16011&TPPID=5891&AspNetFlag=1&Section=free_publications&ThisPage=2)	Yes	Yes					Yes	Yes		Yes	Yes		Yes	Yes
City of Calgary, Canada (http://www.calgary.ca/UEP/Water/Pages/Watersheds-and-rivers/Erosion-and-sediment-control/Erosion-and-Sediment-Control.aspx?redirect=/wqs)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	
City of Edmonton, Canada (http://www.edmonton.ca/city_government/utilities/erosion-and-sedimentation-control.aspx)	Yes		Yes	Yes			Yes	Yes		Yes			Yes	
City of Moncton, Canada (http://www.moncton.ca/Government/Departments/Engineering_and_Environmental_Services.htm)			Yes				Yes	Yes		Yes		Yes	Yes	

Jurisdiction	Preferred Erosion Controls (Contd.)													
	Land Grading	Topsoiling	Surface Roughening	Preserving Natural Vegetation	Chemical Stabilization (PAM)		Erosion Control Blanket/ Geotextiles	Mulching	Soil Binders	Permanent Seeding	Groundcover Planting	Sodding	Temporary seeding	Tree Planting
					Land Application	Water Application								
City of Winnipeg, Canada (for Activities around Waterways and Watercourses) (http://www.winnipeg.ca/ppd/riverbank.stm)	Yes		Yes	Yes			Yes	Yes		Yes	Yes		Yes	
Credit Valley Conservation, Mississauga, Canada (http://www.creditvalleyca.ca/planning-permits/planning-services/engineering-plan-review/erosion-and-sediment-control-during-construction/)		Yes	Yes	Yes			Yes	Yes		Yes		Yes	Yes	
Nova Scotia, Canada (http://www.gov.ns.ca/nse/surface.water/guidelines.asp#guidelines)	Yes	Yes	Yes				Yes							
Darling Range, Perth, Australia (http://www.agric.wa.gov.au/PC_92445.html)		Yes					Yes	Yes		Yes	Yes		Yes	
New South Wales, Australia (http://www.landcom.nsw.gov.au/news/publications-and-programs/the-blue-book.aspx), (http://www.environment.nsw.gov.au/resources/stormwater/erosionsediment0642.pdf)		Yes	Yes	Yes			Yes	Yes		Yes	Yes		Yes	
South west of Western Australia, Australia (http://www.amrshire.wa.gov.au/environment/links/)							Yes			Yes	Yes		Yes	

Jurisdiction	Preferred Erosion Controls (Contd.)													
	Land Grading	Topsoiling	Surface Roughening	Preserving Natural Vegetation	Chemical Stabilization (PAM)		Erosion Control Blanket/ Geotextiles	Mulching	Soil Binders	Permanent Seeding	Groundcover Planting	Sodding	Temporary seeding	Tree Planting
					Land Application	Water Application								
Sunshine Coast Council, Queensland, Australia (http://www.sunshinecoast.qld.gov.au/sitePage.cfm?code=erosion-sediment-control)							Yes	Yes		Yes	Yes		Yes	
IECA- Australia- Principles of Construction Site Erosion and Sediment Control (http://www.austieca.com.au/publications/best-practice-erosion-and-sediment-control-bpesc-document)		Yes					Yes	Yes		Yes	Yes		Yes	
Auckland Council, New Zealand (http://www.aucklandcouncil.govt.nz/EN/planspoliciesprojects/reports/technicalpublications/Pages/technicalpublications51-100.aspx)		Yes	Yes				Yes	Yes		Yes		Yes	Yes	

Runoff Conveyance Controls (U.S. Manuals)

Jurisdiction	Preferred Runoff Conveyance Controls										
U.S. Sources	Check Dam	Diversion/Berm	Drop Structure	Level Spreader	Grass Swale	Lined Swale	Rock Outlet Protection	Riprap-lined Swale	Temporary Stream Crossing	Rock Flume	Subsurface Drain	Temporary Slope Drain
State of Alabama (http://swcc.alabama.gov/pages/erosion_handbook.aspx)	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes		Yes	Yes
State of Alaska (http://www.dec.state.ak.us/water/wnpspc/stormwater/Guidance.html)	Yes	Yes		Yes			Yes	Yes		Yes		Yes
State of Arizona (DOT) for Highway Construction (http://www.azdot.gov/inside_adot/OES/Water_Quality/Stormwater/Manuals.asp)	Yes				Yes	Yes	Yes	Yes				Yes
County of Maricopa, AZ (http://www.fcd.maricopa.gov/Pub/manuals/erosionControl.aspx)		Yes			Yes	Yes	Yes	Yes	Yes			Yes
State of Arkansas (DOT) for Highway Construction (http://www.arkansashighways.com/stormwater/erosion_sediment_manual.aspx)	Yes	Yes									Yes	Yes
State of California (http://www.dot.ca.gov/manuals.htm)	Yes				Yes	Yes	Yes	Yes	Yes			Yes
City of Morro Bay, CA (http://www.morro-bay.ca.us/index.aspx?NID=689)												
San Francisco Bay Region, CA (http://www.co.monterey.ca.us/building/grade/forms%202005/Erosion%20Control%20Handbook.pdf)	Yes						Yes		Yes			
Urban Drainage Flood Control District, Denver, CO (http://www.udfcd.org/downloads/down_critmanual_home.htm)	Yes				Yes	Yes		Yes	Yes			Yes
State of Colorado (DOT) for Highway Construction (http://www.coloradodot.info/programs/environmental/water-quality/documents/erosion-storm-quality)	Yes	Yes			Yes	Yes	Yes	Yes	Yes			

Jurisdiction	Preferred Runoff Conveyance Controls (cont.)											
U.S. Sources	Check Dam	Diversion/Berm	Drop Structure	Level Spreader	Grass Swale	Lined Swale	Rock Outlet Protection	Riprap-lined Swale	Temporary Stream Crossing	Rock Flume	Subsurface Drain	Temporary Slope Drain
Jefferson County, CO (https://www.co.jefferson.co.us/planning/planning_T59_R35.htm)												
State of Connecticut (http://www.ct.gov/deep/cwp/view.asp?a=2720&q=325660)	Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes
State of Delaware (http://www.dnrec.delaware.gov/swc/pages/sedimentstormwater.aspx)	Yes	Yes			Yes	Yes	Yes	Yes	Yes		Yes	Yes
District of Columbia (http://ddoe.dc.gov/soil-erosion-and-sediment-control-handbook)	Yes	Yes			Yes	Yes		Yes	Yes		Yes	Yes
State of Florida (http://stormwater.ucf.edu)	Yes	Yes			Yes	Yes	Yes	Yes	Yes			Yes
State of Georgia (http://www.gaepd.org/Documents/esc_manual.html)	Yes		Yes	Yes	Yes		Yes		Yes			
Commonwealth of Northern Marina Islands and Guam (http://www.deq.gov.mp/article.aspx?secID=6&artID=199)	Yes	Yes		Yes	Yes		Yes		Yes			
State of Hawaii (DOT) for Highway Construction (http://stormwaterhawaii.com/contractors/contractors_design.aspx)	Yes	Yes		Yes	Yes		Yes	Yes	Yes		Yes	Yes
Kauai County, HI (http://www.kauai.gov/Government/Departments/PublicWorks/Engineering/DesignampPermitting/tabid/133/Default.aspx)	Yes	Yes		Yes	Yes		Yes					Yes
State of Idaho (http://www.deq.idaho.gov/water-quality/wastewater/stormwater.aspx)	Yes	Yes			Yes	Yes		Yes	Yes			
State of Illinois (http://www.aiswcd.org/Programs/ium.html)	Yes	Yes		Yes	Yes	Yes	Yes		Yes			Yes
State of Indiana (http://www.in.gov/idem/4899.htm)	Yes	Yes			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Jurisdiction	Preferred Runoff Conveyance Controls (cont.)											
U.S. Sources	Check Dam	Diversion/Berm	Drop Structure	Level Spreader	Grass Swale	Lined Swale	Rock Outlet Protection	Riprap-lined Swale	Temporary Stream Crossing	Rock Flume	Subsurface Drain	Temporary Slope Drain
State of Iowa (http://www.iowadnr.gov/InsideDNR/RegulatoryWater/StormWater/GuidanceApplicationForms.aspx)	Yes	Yes		Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes
States of Kansas and Missouri (http://www.dnr.mo.gov/env/wpp/wpcp-guide.htm)	Yes	Yes			Yes		Yes		Yes		Yes	Yes
City of Crestwood, MO (http://www.ci.crestwood.mo.us/business/permits-licenses/)	Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes			Yes
City of West Plains, MO (http://wpstormwater.weebly.com/publications.html)		Yes							Yes			Yes
State of Kentucky (http://water.ky.gov/permitting/Lists/Working%20in%20Streams%20and%20Wetlands/DispForm.aspx?ID=14)	Yes	Yes			Yes	Yes	Yes	Yes	Yes			Yes
State of Louisiana Coastal Zone (http://dnr.louisiana.gov/index.cfm?md=pagebuilder&tmp=home&pid=109)	Yes	Yes			Yes	Yes	Yes	Yes	Yes		Yes	Yes
State of Maine (http://www.maine.gov/dep/land/erosion/escbmps/index.html)	Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes			Yes
State of Maryland (http://www.mde.maryland.gov/programs/water/stormwatermanagementprogram/soilerosionandsedimentcontrol/pages/programs/waterprograms/sedimentandstormwater/erosionsedimentcontrol/esc_standards.aspx)	Yes	Yes			Yes		Yes	Yes	Yes		Yes	Yes
State of Massachusetts (http://www.mass.gov/eea/agencies/massdep/water/regulations/water-resources-policies-and-guidance-documents.html)		Yes		Yes	Yes	Yes	Yes	Yes	Yes			Yes

Jurisdiction	Preferred Runoff Conveyance Controls (cont.)

U.S. Sources	**Check Dam**	**Diversion/Berm**	**Drop Structure**	**Level Spreader**	**Grass Swale**	**Lined Swale**	**Rock Outlet Protection**	**Riprap-lined Swale**	**Temporary Stream Crossing**	**Rock Flume**	**Subsurface Drain**	**Temporary Slope Drain**
State of Michigan (MDOT) for Highway Construction (http://www.michigan.gov/deq/0,4561,7-135-3311_4113---,00.html), (http://macdc.us/index.php)	Yes	Yes	Yes		Yes			Yes				Yes
State of Minnesota (http://www.pca.state.mn.us/index.php/water/water-types-and-programs/stormwater/stormwater-management/stormwater-best-management-practices-manual.html)	Yes	Yes					Yes		Yes			Yes
State of Mississippi (http://deq.state.ms.us/MDEQ.nsf/page/NPS_Publications_Literature?OpenDocument)	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes		Yes	Yes
State of Montana (http://www.mdt.mt.gov/research/projects/env/erosion.shtml)	Yes	Yes										Yes
City of Billings, MT (http://mt-billings.civicplus.com/index.aspx?NID=567)	Yes	Yes			Yes	Yes	Yes					Yes
State of Nebraska (NDOR) for Roadways Construction (http://www.transportation.nebraska.gov/environment/swppp.htm)	Yes	Yes	Yes			Yes		Yes				Yes
City of Omaha and Paio-Missouri River Natural Resources District, NE (http://www.papiopartnership.org/stormwater/construction_site_runoff_control.shtml)	Yes	Yes		Yes					Yes			Yes
City of Lincoln, NE (http://www.lincoln.ne.gov/city/pworks/watrshed/require/drainage/)	Yes	Yes		Yes	Yes		Yes		Yes		Yes	Yes
City of Scottsbluff, NE (http://www.scottsbluff.org/departments/public_works/stormwater/web_resources.php)	Yes	Yes					Yes		Yes			Yes
State of Nevada (http://ndep.nv.gov/bwqp/bmp05.htm)	Yes	Yes			Yes	Yes	Yes	Yes	Yes			Yes

Jurisdiction	Preferred Runoff Conveyance Controls (cont.)											
U.S. Sources	Check Dam	Diversion/Berm	Drop Structure	Level Spreader	Grass Swale	Lined Swale	Rock Outlet Protection	Riprap-lined Swale	Temporary Stream Crossing	Rock Flume	Subsurface Drain	Temporary Slope Drain
State of Nevada (DOT) for Highway Construction (http://www.nevadadot.com/About_NDOT/NDOT_Divisions/Engineering/Hydraulics/Water_Quality_BMP_Manuals.aspx)	Yes	Yes			Yes	Yes	Yes					Yes
Las Vegas Valley, NV (http://www.lvstormwater.com/)	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes			Yes
City of Elko, NV (http://www.ci.elko.nv.us/commdev/dev_eng.html)	Yes	Yes				Yes	Yes	Yes	Yes			Yes
State of New Hampshire (http://des.nh.gov/organization/divisions/water/stormwater/manual.htm)	Yes	Yes										Yes
State of New Jersey (NJDOT) for Highway Construction (http://www.state.nj.us/transportation/eng/documents/SESC/)		Yes			Yes	Yes	Yes	Yes	Yes		Yes	Yes
State of New York (http://www.dec.ny.gov/chemical/29066.html)	Yes	Yes		Yes	Yes		Yes	Yes	Yes		Yes	Yes
State of North Carolina (http://portal.ncdenr.org/web/lr/publications#espubs)	Yes	Yes		Yes	Yes		Yes	Yes	Yes		Yes	Yes
State of North Dakota (http://www.ndhealth.gov/WQ/publications.asp?DivisionID=18&ShowSectionHeading=no)	Yes							Yes				
State of Ohio (http://www.dnr.state.oh.us/tabid/9186/default.aspx)	Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes
Clermont County, OH (http://www.clermontstorm.net/escbmps.aspx)	Yes	Yes			Yes			Yes	Yes			Yes
City of Oklahoma City, OK (http://www.okc.gov/pw/SWQ/storm15.html)	Yes	Yes						Yes				

Jurisdiction	Preferred Runoff Conveyance Controls (Contd.)											
	Check Dam	**Diversion/Berm**	**Drop Structure**	**Level Spreader**	**Grass Swale**	**Lined Swale**	**Rock Outlet Protection**	**Riprap-lined Swale**	**Temporary Stream Crossing**	**Rock Flume**	**Subsurface Drain**	**Temporary Slope Drain**
State of Oregon (http://www.deq.state.or.us/wq/stormwater/constappl.htm)	Yes	Yes			Yes	Yes						Yes
City of Corvallis, OR (http://www.corvallisoregon.gov/index.aspx?page=366)	Yes	Yes			Yes	Yes	Yes					Yes
City of Gresham, OR (https://www.greshamoregon.gov/city/city-departments/environmental-services/watershed-management/template.aspx?id=20715)	Yes	Yes			Yes	Yes		Yes				Yes
City of Portland, OR (http://www.portlandonline.com/auditor/index.cfm?a=81661&c=28044)	Yes	Yes			Yes	Yes		Yes				Yes
State of Pennsylvania (http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-8299)	Yes	Yes		Yes	Yes		Yes	Yes	Yes			Yes
State of Rhode Island (http://www.dem.ri.gov/programs/benviron/water/permits/swcoord/)	Yes	Yes			Yes	Yes	Yes	Yes	Yes			Yes
State of South Carolina (https://www.scdhec.gov/environment/water/swater/BMPhandbook.htm)	Yes	Yes		Yes			Yes	Yes	Yes		Yes	Yes
State of South Dakota (SDDOT) (http://www.sddot.com/resources/manuals/)	Yes	Yes						Yes				Yes
Pennington County, SD (http://www.co.pennington.sd.us/stormwater/smp.html)	Yes	Yes					Yes					Yes
State of Tennessee (http://www.tn.gov/environment/wpc/sed_ero_controlhandbook/)	Yes	Yes		Yes		Yes	Yes	Yes	Yes			Yes
State of Texas (http://www.tceq.texas.gov/assets/public/permitting/waterquality/attachments/401certification/erosion.pdf)		Yes			Yes			Yes				
North Central Texas (http://iswm.nctcog.org/)	Yes	Yes			Yes	Yes		Yes				Yes

Jurisdiction	Preferred Runoff Conveyance Controls (Contd.)											
	Check Dam	Diversion/Berm	Drop Structure	Level Spreader	Grass Swale	Lined Swale	Rock Outlet Protection	Riprap-lined Swale	Temporary Stream Crossing	Rock Flume	Subsurface Drain	Temporary Slope Drain
State of Utah (UDOT) for Highway Construction (http://www.udot.utah.gov/main/f?p=100:pg:0::::V,T:,2122)	Yes				Yes	Yes	Yes	Yes				Yes
Salt Lake County, UT (http://www.pweng.slco.org/stormwater/html/guide.html)	Yes	Yes			Yes	Yes	Yes		Yes			Yes
State of Vermont (http://www.vtwaterquality.org/stormwater/htm/sw_cgp.htm)	Yes	Yes		Yes	Yes	Yes	Yes	Yes				Yes
Virgin Islands (http://www.coralreef.gov/transportation/)	Yes	Yes			Yes	Yes	Yes	Yes				
State of Virginia (http://www.dcr.virginia.gov/stormwater_management/e_and_s.shtml)	Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes
City of Seattle, WA (http://web1.seattle.gov/dpd/dirrulesviewer/List.aspx?leg=GD&t=Stormwater,%20Grading,%20and%20Drainage%20Control%20Code%20%28Ch.%2022.800%29)	Yes	Yes		Yes	Yes	Yes	Yes	Yes			Yes	Yes
King County, WA (http://www.kingcounty.gov/environment/waterandland/stormwater/documents/surface-water-design-manual.aspx)				Yes	Yes	Yes	Yes	Yes			Yes	Yes
Eastern Washington (https://fortress.wa.gov/ecy/publications/summarypages/0410076.html)	Yes	Yes		Yes	Yes	Yes	Yes	Yes			Yes	Yes
Western Washington (http://www.ecy.wa.gov/programs/wq/stormwater/manual.html)	Yes	Yes		Yes	Yes	Yes	Yes	Yes			Yes	Yes
State of West Virginia (http://www.dep.wv.gov/WWE/Programs/stormwater/csw/Pages/ESC_BMP.aspx)	Yes	Yes		Yes		Yes	Yes	Yes	Yes			Yes
State of Wisconsin (http://dnr.wi.gov/topic/stormwater/standards/const_standards.html)	Yes	Yes										

Jurisdiction	Preferred Runoff Conveyance Controls (Contd.)											
	Check Dam	Diversion/Berm	Drop Structure	Level Spreader	Grass Swale	Lined Swale	Rock Outlet Protection	Riprap-lined Swale	Temporary Stream Crossing	Rock Flume	Subsurface Drain	Temporary Slope Drain
Dane County, WI (http://www.danewaters.com/business/stormwater.aspx)	Yes	Yes			Yes	Yes	Yes					Yes
City of Casper, WY (http://www.casperwy.gov/PublicWorks/StormWaterManagement/ErosionandSediment/tabid/531/Default.aspx)					Yes	Yes	Yes	Yes				

Runoff Conveyance Controls (Non – U.S. Manuals)

Non – U.S. Sources												
Jurisdiction	**Preferred Runoff Conveyance Controls**											
	Check Dam	**Diversion/Berm**	**Drop Structure**	**Level Spreader**	**Grass Swale**	**Lined Swale**	**Rock Outlet Protection**	**Riprap-lined Swale**	**Temporary Stream Crossing**	**Rock Flume**	**Subsurface Drain**	**Temporary Slope Drain**
Singapore (http://www.pub.gov.sg/ecm/download/Pages/default.aspx)												
Malaysia (http://www.water.gov.my/urban-stormwater-mainmenu-564/188), (http://msmam.com/msma-chapters/)	Yes	Yes					Yes	Yes	Yes			Yes
Scotland and Northern Ireland (http://www.ciria.org/service/AM/ContentManagerNet/Default.aspx?template=/TaggedPage/TaggedPageDisplay.cfm&TPLID=66&ContentID=16011&TPPID=5891&AspNetFlag=1&Section=free_publications&ThisPage=2)		Yes			Yes		Yes					Yes
City of Calgary, Canada (http://www.calgary.ca/UEP/Water/Pages/Watersheds-and-rivers/Erosion-and-sediment-control/Erosion-and-Sediment-Control.aspx?redirect=/wqs)	Yes	Yes			Yes	Yes	Yes	Yes				Yes
City of Edmonton, Canada (http://www.edmonton.ca/city_government/utilities/erosion-and-sedimentation-control.aspx)	Yes				Yes	Yes		Yes				
City of Moncton, Canada (http://www.moncton.ca/Government/Departments/Engineering_and_Environmental_Services.htm)	Yes	Yes			Yes	Yes		Yes				
City of Winnipeg, Canada (for Activities around Waterways and Watercourses) (http://www.winnipeg.ca/ppd/riverbank.stm)	Yes	Yes			Yes	Yes		Yes				

Jurisdiction	Preferred Runoff Conveyance Controls (cont.)											
	Check Dam	Diversion/Berm	Drop Structure	Level Spreader	Grass Swale	Lined Swale	Rock Outlet Protection	Riprap-lined Swale	Temporary Stream Crossing	Rock Flume	Subsurface Drain	Temporary Slope Drain
Credit Valley Conservation, Mississauga, Canada (http://www.creditvalleyca.ca/planning-permits/planning-services/engineering-plan-review/erosion-and-sediment-control-during-construction/)	Yes	Yes			Yes		Yes	Yes				
Nova Scotia, Canada (http://www.gov.ns.ca/nse/surface.water/guidelines.asp#guidelines)	Yes	Yes	Yes		Yes	Yes	Yes	Yes			Yes	Yes
Darling Range, Perth, Australia (http://www.agric.wa.gov.au/PC_92445.html)		Yes	Yes					Yes				
New South Wales, Australia (http://www.landcom.nsw.gov.au/news/publications-and-programs/the-blue-book.aspx), (http://www.environment.nsw.gov.au/resources/stormwater/erosionsediment0642.pdf)	Yes	Yes			Yes		Yes	Yes	Yes		Yes	Yes
South west of Western Australia, Australia (http://www.amrshire.wa.gov.au/environment/links/)		Yes										
Sunshine Coast Council, Queensland, Australia (http://www.sunshinecoast.qld.gov.au/sitePage.cfm?code=erosion-sediment-control)	Yes	Yes		Yes	Yes		Yes	Yes	Yes		Yes	Yes
IECA- Australia- Principles of Construction Site Erosion and Sediment Control (http://www.austieca.com.au/publications/best-practice-erosion-and-sediment-control-bpesc-document)	Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes			
Auckland Council, New Zealand (http://www.aucklandcouncil.govt.nz/EN/planspoliciesprojects/reports/technicalpublications/Pages/technicalpublications51-100.aspx)	Yes	Yes	Yes	Yes			Yes		Yes			Yes

Sediment Controls I (U.S. Manuals)

Jurisdiction	Preferred Sediment Controls I									
U.S. Sources	**Block and Gravel Inlet Protection**	**Brush/Fabric Barrier**	**Construction Entrance/Exit**	**Silt Fence**	**Straw Wattles**	**Fabric Drop Inlet Protection**	**Sod Drop Inlet Protection**	**Gravel and Mesh Wire Inlet Protection**	**Excavated Drop Inlet Protection**	**Filter Strip**
State of Alabama (http://swcc.alabama.gov/pages/erosion_handbook.aspx)	Yes	Yes				Yes				Yes
State of Alaska (http://www.dec.state.ak.us/water/wnpspc/stormwater/Guidance.html)	Yes	Yes	Yes	Yes	Yes	Yes		Yes		
State of Arizona (DOT) for Highway Construction (http://www.azdot.gov/inside_adot/OES/Water_Quality/Stormwater/Manuals.asp)	Yes		Yes	Yes	Yes					
County of Maricopa, AZ (http://www.fcd.maricopa.gov/Pub/manuals/erosionControl.aspx)		Yes	Yes	Yes	Yes	Yes			Yes	
State of Arkansas (DOT) for Highway Construction (http://www.arkansashighways.com/stormwater/erosion_sediment_manual.aspx)			Yes	Yes						
State of California (http://www.dot.ca.gov/manuals.htm)		Yes	Yes	Yes		Yes			Yes	
City of Morro Bay, CA (http://www.morro-bay.ca.us/index.aspx?NID=689)	Yes		Yes	Yes	Yes					
San Francisco Bay Region, CA (http://www.co.monterey.ca.us/building/grade/forms%202005/Erosion%20Control%20Handbook.pdf)	Yes	Yes	Yes	Yes	Yes					
Urban Drainage Flood Control District, Denver, CO (http://www.udfcd.org/downloads/down_critmanual_home.htm)	Yes	Yes		Yes		Yes			Yes	
State of Colorado (DOT) for Highway Construction (http://www.coloradodot.info/programs/environmental/water-quality/documents/erosion-storm-quality)	Yes	Yes	Yes	Yes		Yes		Yes	Yes	

Jurisdiction	Preferred Sediment Controls I (cont.)									
U.S. Sources	Block and Gravel Inlet Protection	Brush/Fabric Barrier	Construction Entrance/Exit	Silt Fence	Straw Wattles	Fabric Drop Inlet Protection	Sod Drop Inlet Protection	Gravel and Mesh Wire Inlet Protection	Excavated Drop Inlet Protection	Filter Strip
Jefferson County, CO (https://www.co.jefferson.co.us/planning/planning_T59_R35.htm)				Yes						
State of Connecticut (http://www.ct.gov/deep/cwp/view.asp?a=2720&q=325660)			Yes	Yes						Yes
State of Delaware (http://www.dnrec.delaware.gov/swc/pages/sedimentstormwater.aspx)	Yes		Yes	Yes		Yes				
District of Columbia (http://ddoe.dc.gov/soil-erosion-and-sediment-control-handbook)	Yes	Yes	Yes	Yes	Yes	Yes				
State of Florida (http://stormwater.ucf.edu)	Yes	Yes	Yes	Yes						Yes
State of Georgia (http://www.gaepd.org/Documents/esc_manual.html)			Yes	Yes		Yes			Yes	
Commonwealth of Northern Marina Islands and Guam (http://www.deq.gov.mp/article.aspx?secID=6&artID=199)	Yes		Yes	Yes		Yes			Yes	
State of Hawaii (DOT) for Highway Construction (http://stormwaterhawaii.com/contractors/contractors_design.aspx)	Yes	Yes	Yes	Yes		Yes		Yes	Yes	
City and County of Honolulu, HI (http://www.cleanwaterhonolulu.com/storm/)	Yes			Yes		Yes	Yes		Yes	
Kauai County, HI (http://www.kauai.gov/Government/Departments/PublicWorks/Engineering/DesignampPermitting/tabid/133/Default.aspx)	Yes		Yes	Yes		Yes			Yes	
State of Idaho (http://www.deq.idaho.gov/water-quality/wastewater/stormwater.aspx)	Yes			Yes	Yes		Yes	Yes		
State of Illinois (http://www.aiswcd.org/Programs/ium.html)	Yes		Yes	Yes	Yes	Yes	Yes	Yes	Yes	

Jurisdiction	Preferred Sediment Controls I (cont.)									
U.S. Sources	**Block and Gravel Inlet Protection**	**Brush/Fabric Barrier**	**Construction Entrance/Exit**	**Silt Fence**	**Straw Wattles**	**Fabric Drop Inlet Protection**	**Sod Drop Inlet Protection**	**Gravel and Mesh Wire Inlet Protection**	**Excavated Drop Inlet Protection**	**Filter Strip**
State of Indiana (http://www.in.gov/idem/4899.htm)	Yes		Yes	Yes		Yes			Yes	Yes
State of Iowa (http://www.iowadnr.gov/InsideDNR/RegulatoryWater/StormWater/GuidanceApplicationForms.aspx)	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes
States of Kansas and Missouri (http://www.dnr.mo.gov/env/wpp/wpcp-guide.htm)	Yes	Yes	Yes	Yes	Yes	Yes			Yes	
City of Crestwood, MO (http://www.ci.crestwood.mo.us/business/permits-licenses/)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes
City of West Plains, MO (http://wpstormwater.weebly.com/publications.html)	Yes		Yes	Yes		Yes				
State of Kentucky (http://water.ky.gov/permitting/Lists/Working%20in%20Streams%20and%20Wetlands/DispForm.aspx?ID=14)	Yes	Yes	Yes	Yes	Yes	Yes				
State of Louisiana Coastal Zone (http://dnr.louisiana.gov/index.cfm?md=pagebuilder&tmp=home&pid=109)	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes
State of Maine (http://www.maine.gov/dep/land/erosion/escbmps/index.html)	Yes	Yes	Yes	Yes		Yes	Yes	Yes		Yes
State of Maryland (http://www.mde.maryland.gov/programs/water/stormwatermanagementprogram/soilerosionandsedimentcontrol/pages/programs/waterprograms/sedimentandstormwater/erosionsedimentcontrol/esc_standards.aspx)	Yes		Yes	Yes		Yes				
State of Massachusetts (http://www.mass.gov/eea/agencies/massdep/water/regulations/water-resources-policies-and-guidance-documents.html)		Yes	Yes	Yes			Yes	Yes	Yes	Yes

Jurisdiction	Preferred Sediment Controls I (Contd.)									
	Block and Gravel Inlet Protection	Brush/Fabric Barrier	Construction Entrance/Exit	Silt Fence	Straw Wattles	Fabric Drop Inlet Protection	Sod Drop Inlet Protection	Gravel and Mesh Wire Inlet Protection	Excavated Drop Inlet Protection	Filter Strip
State of Michigan (MDOT) for Highway Construction (http://www.michigan.gov/deq/0,4561,7-135-3311_4113---,00.html), (http://macdc.us/index.php)		Yes	Yes	Yes		Yes				
State of Minnesota (http://www.pca.state.mn.us/index.php/water/water-types-and-programs/stormwater/stormwater-management/stormwater-best-management-practices-manual.html)	Yes		Yes	Yes		Yes	Yes	Yes		
State of Mississippi (http://deq.state.ms.us/MDEQ.nsf/page/NPS_Publications_Literature?OpenDocument)	Yes	Yes	Yes	Yes		Yes	Yes		Yes	Yes
State of Montana (http://www.mdt.mt.gov/research/projects/env/erosion.shtml)	Yes			Yes	Yes			Yes		
City of Billings, MT (http://mt-billings.civicplus.com/index.aspx?NID=567)	Yes		Yes	Yes	Yes	Yes				
State of Nebraska (NDOR) for Roadways Construction (http://www.transportation.nebraska.gov/environment/swppp.htm)				Yes						
City of Omaha and Paio-Missouri River Natural Resources District, NE (http://www.papiopartnership.org/stormwater/construction_site_runoff_control.shtml)	Yes		Yes	Yes		Yes	Yes	Yes	Yes	
City of Lincoln, NE (http://www.lincoln.ne.gov/city/pworks/watrshed/require/drainage/)	Yes		Yes	Yes		Yes	Yes	Yes	Yes	Yes
City of Scottsbluff, NE (http://www.scottsbluff.org/departments/public_works/stormwater/web_resources.php)	Yes		Yes	Yes		Yes	Yes	Yes		
State of Nevada (http://ndep.nv.gov/bwqp/bmp05.htm)	Yes		Yes	Yes	Yes	Yes		Yes		

Jurisdiction	Preferred Sediment Controls I (Contd.)									
	Block and Gravel Inlet Protection	Brush/Fabric Barrier	Construction Entrance/Exit	Silt Fence	Straw Wattles	Fabric Drop Inlet Protection	Sod Drop Inlet Protection	Gravel and Mesh Wire Inlet Protection	Excavated Drop Inlet Protection	Filter Strip
State of Nevada (DOT) for Highway Construction (http://www.nevadadot.com/About_NDOT/NDOT_Divisions/Engineering/Hydraulics/Water_Quality_BMP_Manuals.aspx)	Yes		Yes	Yes		Yes			Yes	
Las Vegas Valley, NV (http://www.lvstormwater.com/)	Yes		Yes	Yes	Yes	Yes			Yes	
City of Elko, NV (http://www.ci.elko.nv.us/commdev/dev_eng.html)	Yes	Yes	Yes	Yes		Yes			Yes	
State of New Hampshire (http://des.nh.gov/organization/divisions/water/stormwater/manual.htm)	Yes		Yes	Yes				Yes		
State of New Jersey (NJDOT) for Highway Construction (http://www.state.nj.us/transportation/eng/documents/SESC/)			Yes	Yes						
State of New York (http://www.dec.ny.gov/chemical/29066.html)	Yes	Yes	Yes	Yes	Yes	Yes			Yes	
State of North Carolina (http://portal.ncdenr.org/web/lr/publications#espubs)	Yes		Yes	Yes		Yes	Yes	Yes	Yes	
State of North Dakota (http://www.ndhealth.gov/WQ/publications.asp?DivisionID=18&ShowSectionHeading=no)	Yes			Yes		Yes	Yes	Yes		
State of Ohio (http://www.dnr.state.oh.us/tabid/9186/default.aspx)	Yes		Yes	Yes		Yes		Yes	Yes	
Clermont County, OH (http://www.clermontstorm.net/escbmps.aspx)	Yes		Yes	Yes	Yes		Yes		Yes	
City of Oklahoma City, OK (http://www.okc.gov/pw/SWQ/storm15.html)	Yes		Yes	Yes	Yes	Yes				

Jurisdiction	Preferred Sediment Controls I (Contd.)									
	Block and Gravel Inlet Protection	Brush/Fabric Barrier	Construction Entrance/Exit	Silt Fence	Straw Wattles	Fabric Drop Inlet Protection	Sod Drop Inlet Protection	Gravel and Mesh Wire Inlet Protection	Excavated Drop Inlet Protection	Filter Strip
State of Oregon (http://www.deq.state.or.us/wq/stormwater/constappl.htm)	Yes	Yes	Yes	Yes	Yes	Yes				
City of Corvallis, OR (http://www.corvallisoregon.gov/index.aspx?page=366)	Yes	Yes	Yes	Yes	Yes					
City of Gresham, OR (https://www.greshamoregon.gov/city/city-departments/environmental-services/watershed-management/template.aspx?id=20715)	Yes	Yes	Yes	Yes	Yes	Yes				
City of Portland, OR (http://www.portlandonline.com/auditor/index.cfm?a=81661&c=28044)	Yes		Yes	Yes	Yes	Yes				
State of Pennsylvania (http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-8299)	Yes		Yes	Yes	Yes					
State of Rhode Island (http://www.dem.ri.gov/programs/benviron/water/permits/swcoord/)	Yes		Yes	Yes	Yes	Yes			Yes	
State of South Carolina (https://www.scdhec.gov/environment/water/swater/BMPhandbook.htm)	Yes		Yes	Yes	Yes	Yes			Yes	
State of South Dakota (SDDOT) (http://www.sddot.com/resources/manuals/)	Yes		Yes	Yes	Yes	Yes				
Pennington County, SD (http://www.co.pennington.sd.us/stormwater/smp.html)				Yes	Yes					Yes
State of Tennessee (http://www.tn.gov/environment/wpc/sed_ero_controlhandbook/)	Yes		Yes	Yes	Yes	Yes	Yes		Yes	
State of Texas (http://www.tceq.texas.gov/assets/public/permitting/waterquality/attachments/401certification/erosion.pdf)		Yes		Yes						Yes

Jurisdiction	Preferred Sediment Controls I (Contd.)									
	Block and Gravel Inlet Protection	**Brush/Fabric Barrier**	**Construction Entrance/Exit**	**Silt Fence**	**Straw Wattles**	**Fabric Drop Inlet Protection**	**Sod Drop Inlet Protection**	**Gravel and Mesh Wire Inlet Protection**	**Excavated Drop Inlet Protection**	**Filter Strip**
North Central Texas (http://iswm.nctcog.org/)	Yes		Yes	Yes		Yes		Yes	Yes	Yes
State of Utah (UDOT) for Highway Construction (http://www.udot.utah.gov/main/f?p=100:pg:0::::V,T:,2122)	Yes	Yes	Yes	Yes	Yes					
Salt Lake County, UT (http://www.pweng.slco.org/stormwater/html/guide.html)	Yes		Yes	Yes	Yes	Yes	Yes		Yes	Yes
State of Vermont (http://www.vtwaterquality.org/stormwater/htm/sw_cgp.htm)	Yes	Yes		Yes		Yes			Yes	
Virgin Islands (http://www.coralreef.gov/transportation/)	Yes		Yes	Yes				Yes	Yes	Yes
State of Virginia (http://www.dcr.virginia.gov/stormwater_management/e_and_s.shtml)	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	
City of Seattle, WA (http://web1.seattle.gov/dpd/dirrulesviewer/List.aspx?leg=GD&t=Stormwater,%20Grading,%20and%20Drainage%20Control%20Code%20%28Ch.%2022.800%29)	Yes	Yes		Yes	Yes	Yes				Yes
King County, WA (http://www.kingcounty.gov/environment/waterandland/stormwater/documents/surface-water-design-manual.aspx)	Yes	Yes	Yes	Yes	Yes			Yes	Yes	Yes
Eastern Washington (https://fortress.wa.gov/ecy/publications/summarypages/0410076.html)	Yes	Yes	Yes	Yes	Yes					Yes
Western Washington (http://www.ecy.wa.gov/programs/wq/stormwater/manual.html)	Yes	Yes	Yes	Yes	Yes			Yes	Yes	Yes
State of West Virginia (http://www.dep.wv.gov/WWE/Programs/stormwater/csw/Pages/ESC_BMP.aspx)	Yes		Yes	Yes	Yes	Yes		Yes	Yes	

Jurisdiction	Preferred Sediment Controls I (Contd.)									
	Block and Gravel Inlet Protection	Brush/Fabric Barrier	Construction Entrance/Exit	Silt Fence	Straw Wattles	Fabric Drop Inlet Protection	Sod Drop Inlet Protection	Gravel and Mesh Wire Inlet Protection	Excavated Drop Inlet Protection	Filter Strip
State of Wisconsin (http://dnr.wi.gov/topic/stormwater/standards/const_standards.html)	Yes			Yes		Yes		Yes		
Dane County, WI (http://www.danewaters.com/business/stormwater.aspx)	Yes			Yes					Yes	
City of Casper, WY (http://www.casperwy.gov/PublicWorks/StormWaterManagement/ErosionandSediment/tabid/531/Default.aspx)	Yes		Yes	Yes		Yes			Yes	

Sediment Controls I (Non – U.S. Manuals)

Jurisdiction	Preferred Sediment Controls I									
	Block and Gravel Inlet Protection	Brush/Fabric Barrier	Construction Entrance/Exit	Silt Fence	Straw Wattles	Fabric Drop Inlet Protection	Sod Drop Inlet Protection	Gravel and Mesh Wire Inlet Protection	Excavated Drop Inlet Protection	Filter Strip
Singapore (http://www.pub.gov.sg/ecm/download/Pages/default.aspx)			Yes	Yes						
Malaysia (http://www.water.gov.my/urban-stormwater-mainmenu-564/188), (http://msmam.com/msma-chapters/)	Yes	Yes	Yes	Yes		Yes		Yes	Yes	
Scotland and Northern Ireland (http://www.ciria.org/service/AM/ContentManagerNet/Default.aspx?template=/TaggedPage/TaggedPageDisplay.cfm&TPLID=66&ContentID=16011&TPPID=5891&AspNetFlag=1&Section=free_publications&ThisPage=2)			Yes	Yes						
City of Calgary, Canada (http://www.calgary.ca/UEP/Water/Pages/Watersheds-and-rivers/Erosion-and-sediment-control/Erosion-and-Sediment-Control.aspx?redirect=/wqs)	Yes	Yes	Yes	Yes	Yes					
City of Edmonton, Canada (http://www.edmonton.ca/city_government/utilities/erosion-and-sedimentation-control.aspx)		Yes	Yes	Yes	Yes	Yes				
City of Moncton, Canada (http://www.moncton.ca/Government/Departments/Engineering_and_Environmental_Services.htm)	Yes			Yes		Yes	Yes			
City of Winnipeg, Canada (for Activities around Waterways and Watercourses) (http://www.winnipeg.ca/ppd/riverbank.stm)				Yes	Yes					
Credit Valley Conservation, Mississauga, Canada (http://www.creditvalleyca.ca/planning-permits/planning-services/engineering-plan-review/erosion-and-sediment-control-during-construction/)				Yes	Yes					Yes

Jurisdiction	Preferred Sediment Controls I (cont.)									
	Block and Gravel Inlet Protection	Brush/Fabric Barrier	Construction Entrance/Exit	Silt Fence	Straw Wattles	Fabric Drop Inlet Protection	Sod Drop Inlet Protection	Gravel and Mesh Wire Inlet Protection	Excavated Drop Inlet Protection	Filter Strip
Nova Scotia, Canada (http://www.gov.ns.ca/nse/surface.water/guidelines.asp#guidelines)		Yes		Yes	Yes					
Darling Range, Perth, Australia (http://www.agric.wa.gov.au/PC_92445.html)			Yes	Yes		Yes				
New South Wales, Australia (http://www.landcom.nsw.gov.au/news/publications-and-programs/the-blue-book.aspx), (http://www.environment.nsw.gov.au/resources/stormwater/erosionsediment0642.pdf)		Yes	Yes	Yes		Yes		Yes		Yes
South west of Western Australia, Australia (http://www.amrshire.wa.gov.au/environment/links/)			Yes	Yes						
Sunshine Coast Council, Queensland, Australia (http://www.sunshinecoast.qld.gov.au/sitePage.cfm?code=erosion-sediment-control)			Yes	Yes	Yes					Yes
IECA- Australia- Principles of Construction Site Erosion and Sediment Control (http://www.austieca.com.au/publications/best-practice-erosion-and-sediment-control-bpesc-document)				Yes		Yes				Yes
Auckland Council, New Zealand (http://www.aucklandcouncil.govt.nz/EN/planspoliciesprojects/reports/technicalpublications/Pages/technicalpublications51-100.aspx)	Yes		Yes	Yes		Yes		Yes	Yes	

Sediment Controls II (U.S. Manuals)

Jurisdiction	Preferred Sediment Controls II									
U.S. Sources	Compost Socks and Berms	Floating Turbidity Barrier	Roc k Filter Dam	Sediment Barrier	Sediment Basin/Trap	Straw Bale Sediment Trap	Vegetated Buffer Strips	Treatment/ Coagulation Unit	Perimeter Drain	InletSoxx for Inlet Protection
State of Alabama (http://swcc.alabama.gov/pages/erosion_handbook.aspx)		Yes	Yes	Yes	Yes	Yes				
State of Alaska (http://www.dec.state.ak.us/water/wnpspc/stormwater/Guidance.html)					Yes		Yes			
State of Arizona (DOT) for Highway Construction (http://www.azdot.gov/inside_adot/OES/Water_Quality/Stormwater/Manuals.asp)				Yes	Yes					
County of Maricopa, AZ (http://www.fcd.maricopa.gov/Pub/manuals/erosionControl.aspx)			Yes	Yes	Yes					
State of Arkansas (DOT) for Highway Construction (http://www.arkansashighways.com/stormwater/erosion_sediment_manual.aspx)					Yes					
State of California (http://www.dot.ca.gov/manuals.htm)			Yes	Yes	Yes					
City of Morro Bay, CA (http://www.morro-bay.ca.us/index.aspx?NID=689)										
San Francisco Bay Region, CA (http://www.co.monterey.ca.us/building/grade/forms%202005/Erosion%20Control%20Handbook.pdf)			Yes	Yes	Yes					
Urban Drainage Flood Control District, Denver, CO (http://www.udfcd.org/downloads/down_critmanual_home.htm)				Yes	Yes		Yes			
State of Colorado (DOT) for Highway Construction (http://www.coloradodot.info/programs/environmental/water-quality/documents/erosion-storm-quality)				Yes	Yes					

Jurisdiction	Preferred Sediment Controls II (cont.)

U.S. Sources	Compost Socks and Berms	Floating Turbidity Barrier	Roc k Filter Dam	Sediment Barrier	Sediment Basin/Trap	Straw Bale Sediment Trap	Vegetated Buffer Strips	Treatment/ Coagulation Unit	Perimeter Drain	InletSoxx for Inlet Protection
Jefferson County, CO (https://www.co.jefferson.co.us/planning/planning_T59_R35.htm)				Yes						
State of Connecticut (http://www.ct.gov/deep/cwp/view.asp?a=2720&q=325660)		Yes		Yes	Yes		Yes			
State of Delaware (http://www.dnrec.delaware.gov/swc/pages/sedimentstormwater.aspx)		Yes		Yes	Yes					
District of Columbia (http://ddoe.dc.gov/soil-erosion-and-sediment-control-handbook)				Yes	Yes					
State of Florida (http://stormwater.ucf.edu)		Yes		Yes	Yes		Yes			
State of Georgia (http://www.gaepd.org/Documents/esc_manual.html)			Yes	Yes	Yes		Yes			
Commonwealth of Northern Marina Islands and Guam (http://www.deq.gov.mp/article.aspx?secID=6&artID=199)		Yes			Yes		Yes			
State of Hawaii (DOT) for Highway Construction (http://stormwaterhawaii.com/contractors/contractors_design.aspx)			Yes	Yes	Yes		Yes			
City and County of Honolulu, HI (http://www.cleanwaterhonolulu.com/storm/)	Yes			Yes	Yes		Yes			
Kauai County, HI (http://www.kauai.gov/Government/Departments/PublicWorks/Engineering/DesignampPermitting/tabid/133/Default.aspx)					Yes		Yes			
State of Idaho (http://www.deq.idaho.gov/water-quality/wastewater/stormwater.aspx)	Yes			Yes	Yes		Yes			
State of Illinois (http://www.aiswcd.org/Programs/ium.html)				Yes	Yes					
State of Indiana (http://www.in.gov/idem/4899.htm)	Yes			Yes	Yes					

Jurisdiction	Preferred Sediment Controls II (cont.)									
U.S. Sources	Compost Socks and Berms	Floating Turbidity Barrier	Roc k Filter Dam	Sediment Barrier	Sediment Basin/Tra p	Straw Bale Sediment Trap	Vegetate d Buffer Strips	Treatment/ Coagulation Unit	Perimeter Drain	InletSoxx for Inlet Protection
State of Iowa (http://www.iowadnr.gov/InsideDNR/RegulatoryWater/StormWater/GuidanceApplicationForms.aspx)	Yes	Yes		Yes	Yes					
States of Kansas and Missouri (http://www.dnr.mo.gov/env/wpp/wpcp-guide.htm)	Yes	Yes	Yes	Yes	Yes		Yes			
City of Crestwood, MO (http://www.ci.crestwood.mo.us/business/permits-licenses/)					Yes					
City of West Plains, MO (http://wpstormwater.weebly.com/publications.html)				Yes	Yes					
State of Kentucky (http://water.ky.gov/permitting/Lists/Working%20in%20Streams%20and%20Wetlands/DispForm.aspx?ID=14)				Yes	Yes		Yes			
State of Louisiana Coastal Zone (http://dnr.louisiana.gov/index.cfm?md=pagebuilder&tmp=home&pid=109)	Yes	Yes	Yes		Yes	Yes	Yes			
State of Maine (http://www.maine.gov/dep/land/erosion/escbmps/index.html)				Yes	Yes		Yes			
State of Maryland (http://www.mde.maryland.gov/programs/water/stormwatermanagementprogram/soilerosionandsedimentcontrol/pages/programs/waterprograms/sedimentandstormwater/erosionsedimentcontrol/esc_standards.aspx)	Yes		Yes	Yes	Yes					
State of Massachusetts (http://www.mass.gov/eea/agencies/massdep/water/regulations/water-resources-policies-and-guidance-documents.html)		Yes	Yes		Yes	Yes	Yes			

Jurisdiction	Preferred Sediment Controls II (Contd.)									
	Compost	Floating	Roc k Filter	Sediment	Sediment	Straw Bale	Vegetate	Treatment/	Perimeter	InletSoxx for

	Socks and Berms	Turbidity Barrier	Dam	Barrier	Basin/Trap	Sediment Trap	d Buffer Strips	Coagulation Unit	Drain	Inlet Protection
State of Michigan (MDOT) for Highway Construction (http://www.michigan.gov/deq/0,4561,7-135-3311_4113---,00.html), (http://macdc.us/index.php)		Yes	Yes		Yes	Yes	Yes			
State of Minnesota (http://www.pca.state.mn.us/index.php/water/water-types-and-programs/stormwater/stormwater-management/stormwater-best-management-practices-manual.html)		Yes		Yes	Yes	Yes				
State of Mississippi (http://deq.state.ms.us/MDEQ.nsf/page/NPS_Publications_Literature?OpenDocument)		Yes	Yes	Yes	Yes	Yes				
State of Montana (http://www.mdt.mt.gov/research/projects/env/erosion.shtml)					Yes		Yes			
City of Billings, MT (http://mt-billings.civicplus.com/index.aspx?NID=567)				Yes	Yes					
State of Nebraska (NDOR) for Roadways Construction (http://www.transportation.nebraska.gov/environment/swppp.htm)			Yes			Yes				
City of Omaha and Paio-Missouri River Natural Resources District, NE (http://www.papiopartnership.org/stormwater/construction_site_runoff_control.shtml)		Yes		Yes	Yes					
City of Lincoln, NE (http://www.lincoln.ne.gov/city/pworks/watrshed/require/drainage/)		Yes		Yes	Yes					
City of Scottsbluff, NE (http://www.scottsbluff.org/departments/public_works/stormwater/web_resources.php)				Yes	Yes					
State of Nevada (http://ndep.nv.gov/bwqp/bmp05.htm)	Yes			Yes	Yes		Yes			

Jurisdiction	Preferred Sediment Controls II (Contd.)									
	Compost	Floating	Roc k Filter	Sediment	Sediment	Straw Bale	Vegetate	Treatment/	Perimeter	InletSoxx for

	Socks and Berms	Turbidity Barrier	Dam	Barrier	Basin/Trap	Sediment Trap	d Buffer Strips	Coagulation Unit	Drain	Inlet Protection
State of Nevada (DOT) for Highway Construction (http://www.nevadadot.com/About_NDOT/NDOT_Divisions/Engineering/Hydraulics/Water_Quality_BMP_Manuals.aspx)			Yes	Yes	Yes					
Las Vegas Valley, NV (http://www.lvstormwater.com/)			Yes	Yes	Yes		Yes			
City of Elko, NV (http://www.ci.elko.nv.us/commdev/dev_eng.html)	Yes		Yes	Yes	Yes					
State of New Hampshire (http://des.nh.gov/organization/divisions/water/stormwater/manual.htm)	Yes			Yes	Yes					
State of New Jersey (NJDOT) for Highway Construction (http://www.state.nj.us/transportation/eng/documents/SESC/)		Yes		Yes	Yes					
State of New York (http://www.dec.ny.gov/chemical/29066.html)	Yes	Yes	Yes		Yes					
State of North Carolina (http://portal.ncdenr.org/web/lr/publications#espubs)			Yes		Yes		Yes			
State of North Dakota (http://www.ndhealth.gov/WQ/publications.asp?DivisionID=18&ShowSectionHeading=no)				Yes	Yes					
State of Ohio (http://www.dnr.state.oh.us/tabid/9186/default.aspx)	Yes		Yes		Yes					
Clermont County, OH (http://www.clermontstorm.net/escbmps.aspx)				Yes	Yes		Yes			
City of Oklahoma City, OK (http://www.okc.gov/pw/SWQ/storm15.html)					Yes					
State of Oregon (http://www.deq.state.or.us/wq/stormwater/constappl.htm)	Yes		Yes	Yes	Yes					

Jurisdiction	Preferred Sediment Controls II (Contd.)									
	Compost	Floating	Roc k Filter	Sediment	Sediment	Straw Bale	Vegetate	Treatment/	Perimeter	InletSoxx for

	Socks and Berms	Turbidity Barrier	Dam	Barrier	Basin/Trap	Sediment Trap	d Buffer Strips	Coagulation Unit	Drain	Inlet Protection
City of Corvallis, OR (http://www.corvallisoregon.gov/index.aspx?page=366)			Yes	Yes	Yes					
City of Gresham, OR (https://www.greshamoregon.gov/city/city-departments/environmental-services/watershed-management/template.aspx?id=20715)	Yes		Yes	Yes	Yes					
City of Portland, OR (http://www.portlandonline.com/auditor/index.cfm?a=81661&c=28044)	Yes		Yes	Yes	Yes		Yes			
State of Pennsylvania (http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-8299)	Yes	Yes	Yes	Yes	Yes		Yes			
State of Rhode Island (http://www.dem.ri.gov/programs/benviron/water/permits/swcoord/)	Yes	Yes			Yes					
State of South Carolina (https://www.scdhec.gov/environment/water/swater/BMPhandbook.htm)				Yes	Yes					
State of South Dakota (SDDOT) (http://www.sddot.com/resources/manuals/)		Yes								
Pennington County, SD (http://www.co.pennington.sd.us/stormwater/smp.html)	Yes				Yes					
State of Tennessee (http://www.tn.gov/environment/wpc/sed_ero_controlhandbook/)	Yes	Yes	Yes		Yes					
State of Texas (http://www.tceq.texas.gov/assets/public/permitting/waterquality/attachments/401certification/erosion.pdf)	Yes			Yes	Yes					
North Central Texas (http://iswm.nctcog.org/)	Yes	Yes			Yes		Yes			
State of Utah (UDOT) for Highway Construction (http://www.udot.utah.gov/main/f?p=100:pg:0::::V,T:,2122)	Yes			Yes	Yes					

Jurisdiction	Preferred Sediment Controls II (Contd.)									
	Compost Socks and Berms	Floating Turbidity Barrier	Roc k Filter Dam	Sediment Barrier	Sediment Basin/Tra p	Straw Bale Sediment Trap	Vegetate d Buffer Strips	Treatment/ Coagulation Unit	Perimeter Drain	InletSoxx for Inlet Protection
Salt Lake County, UT (http://www.pweng.slco.org/stormwater/html/guide.html)		Yes		Yes	Yes		Yes			
State of Vermont (http://www.vtwaterquality.org/stormwater/htm/sw_cgp.htm)			Yes	Yes						
Virgin Islands (http://www.coralreef.gov/transportation/)					Yes					
State of Virginia (http://www.dcr.virginia.gov/stormwater_management/e_and_s.shtml)		Yes		Yes	Yes					
City of Seattle, WA (http://web1.seattle.gov/dpd/dirrulesviewer/List.aspx?leg=GD&t=Stormwater,%20Grading,%20and%20Drainage%20Control%20Code%20%28Ch.%2022.800%29)	Yes	Yes	Yes	Yes	Yes		Yes			
King County, WA (http://www.kingcounty.gov/environment/waterandland/stormwater/documents/surface-water-design-manual.aspx)	Yes				Yes		Yes			
Eastern Washington (https://fortress.wa.gov/ecy/publications/summarypages/0410076.html)			Yes	Yes	Yes		Yes			
Western Washington (http://www.ecy.wa.gov/programs/wq/stormwater/manual.html)			Yes	Yes	Yes		Yes			
State of West Virginia (http://www.dep.wv.gov/WWE/Programs/stormwater/csw/Pages/ESC_BMP.aspx)					Yes		Yes			
State of Wisconsin (http://dnr.wi.gov/topic/stormwater/standards/const_standards.html)		Yes		Yes	Yes		Yes			
Dane County, WI (http://www.danewaters.com/business/stormwater.aspx)					Yes		Yes			

Jurisdiction	Preferred Sediment Controls II (Contd.)									
	Compost	Floating	Roc k Filter	Sediment	Sediment	Straw Bale	Vegetate	Treatment/	Perimeter	InletSoxx for

	Socks and Berms	Turbidity Barrier	Dam	Barrier	Basin/Trap	Sediment Trap	d Buffer Strips	Coagulation Unit	Drain	Inlet Protection
City of Casper, WY (http://www.casperwy.gov/PublicWorks/StormWaterManagement/ErosionandSediment/tabid/531/Default.aspx)					Yes					

Sediment Controls II (Non-U.S. Manuals)

Jurisdiction	Preferred Sediment Controls II									
	Compost Socks and Berms	Floating Turbidity Barrier	Roc k Filter Dam	Sediment Barrier	Sediment Basin/Trap	Straw Bale Sediment Trap	Vegetated Buffer Strips	Treatment/ Coagulation Unit	Perimeter Drain	InletSoxx for Inlet Protection
Singapore (http://www.pub.gov.sg/ecm/download/Pages/default.aspx)		Yes			Yes			Yes	Yes	
Malaysia (http://www.water.gov.my/urban-stormwater-mainmenu-564/188), (http://msmam.com/msma-chapters/)			Yes	Yes	Yes		Yes			
Scotland and Northern Ireland (http://www.ciria.org/service/AM/ContentManagerNet/Default.aspx?template=/TaggedPage/TaggedPageDisplay.cfm&TPLID=66&ContentID=16011&TPPID=5891&AspNetFlag=1&Section=free_publications&ThisPage=2)				Yes	Yes					
City of Calgary, Canada (http://www.calgary.ca/UEP/Water/Pages/Watersheds-and-rivers/Erosion-and-sediment-control/Erosion-and-Sediment-Control.aspx?redirect=/wqs)	Yes				Yes		Yes			
City of Edmonton, Canada (http://www.edmonton.ca/city_government/utilities/erosion-and-sedimentation-control.aspx)			Yes	Yes	Yes		Yes			
City of Moncton, Canada (http://www.moncton.ca/Government/Departments/Engineering_and_Environmental_Services.htm)			Yes	Yes	Yes		Yes			
City of Winnipeg, Canada (for Activities around Waterways and Watercourses) (http://www.winnipeg.ca/ppd/riverbank.stm)		Yes			Yes					
Credit Valley Conservation, Mississauga, Canada (http://www.creditvalleyca.ca/planning-permits/planning-services/engineering-plan-review/erosion-and-sediment-control-during-construction/)			Yes		Yes					Yes
Nova Scotia, Canada (http://www.gov.ns.ca/nse/surface.water/guidelines.asp#guidelines)			Yes	Yes	Yes		Yes			

Jurisdiction	Preferred Sediment Controls II (cont.)									
	Compost Socks and Berms	Floating Turbidity Barrier	Roc k Filter Dam	Sediment Barrier	Sediment Basin/Tra p	Straw Bale Sediment Trap	Vegetate d Buffer Strips	Treatment/ Coagulation Unit	Perimeter Drain	InletSoxx for Inlet Protection
Darling Range, Perth, Australia (http://www.agric.wa.gov.au/PC_92445.html)					Yes					
New South Wales, Australia (http://www.landcom.nsw.gov.au/news/publications-and-programs/the-blue-book.aspx), (http://www.environment.nsw.gov.au/resources/stormwater/erosionsediment0642.pdf)	Yes	Yes		Yes	Yes					
South west of Western Australia, Australia (http://www.amrshire.wa.gov.au/environment/links/)	Yes			Yes						
Sunshine Coast Council, Queensland, Australia (http://www.sunshinecoast.qld.gov.au/sitePage.cfm?code=erosion-sediment-control)		Yes			Yes					
IECA- Australia- Principles of Construction Site Erosion and Sediment Control (http://www.austieca.com.au/publications/best-practice-erosion-and-sediment-control-bpesc-document)	Yes		Yes	Yes	Yes					
Auckland Council, New Zealand (http://www.aucklandcouncil.govt.nz/EN/planspoliciesprojects/reports/technicalpublications/Pages/technicalpublications51-100.aspx)					Yes	Yes				

Appendix C. Selected Erosion and Sediment Control Design Attributes

Summary of state construction and development requirements (summarized from: *EPA Development Document for Final Effluent Guidelines and Standards for Construction & Development Category*, November 2009)

State Requirements - Summary					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Alabama	1,800 (EPA 2007)	(1) 8-hour detention time for sites > 5 acres (EPA 2007) (2) 67 cy/acre (1,809 ft^3) - (Alabama Handbook for Erosion Control, Sediment Control and Stormwater Management on Construction Sites and Urban Areas June 2003, Revised 1-06)	The 2004 TDD Section 7 notes: a sediment basin storage volume of 3,600 ft^3/acre drained, and sediment basin requirements for drainage areas ≥ 10 acres.	Statewide standard varies with background, < 50 Nephelometric Turbidity Units (NTUs) above background. The EPA literature noted “None.” The 2002 TDD Appendix A notes: Turbidity <50 NTU. Turbidity limits as set forth by the Alabama Department of Environmental Management are 50 NTUs above background for any Alabama waterbody with a Fish and Wildlife classification (Alabama Department of Environmental Management 2001). PG Environmental (PG) determined that the Alabama Department of Environmental Management-Water Division Water Quality Program (2006) states in its specific water quality criteria Section 335-6-10-.09 that there shall be no turbidity other than natural origin and that in no case shall turbidity exceed 50 NTUs above background.	13 days (EPA 2007)

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Alaska	3,600 (2004 TDD Section 7)	The EPA 2007 literature referenced the CGP and noted a sediment basin volume of 1,800 ft^3/acre plus 1.5 ft for sediment accumulation - generally designed to remove medium silt (62 microns) particles	The 2004 TDD Section 7 notes sediment basin requirements for drainage areas ≥ 10 acres. 2002 water quality standards specify that all stormwater treatment devices shall be designed based on the 2-year, 6-hour rain event (assume runoff), and the Best Management Practice (BMP) must also be capable of removing particles greater than 20-microns during such an event.	The 2002 TDD Appendix A notes total suspended solids (TSS) > 20 microns. The EPA 2007 literature notes "None."	14 days. Reference to the CGP (EPA 2007)
Arizona	3,600 (EPA 2007; 2004 TDD Section 7)	Sizing based on a 2-year, 24-hour event (EPA 2007)	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥ 10 acres.	None (EPA 2007)	14 days (EPA 2007)
Arkansas	3,600 (EPA 2007; 2004 TDD Section 7)	Temporary or permanent sediment basins shall be based on either the smaller of 3,600 ft^3/acre, or a size based on the runoff volume of a 10-year, 24-hour storm event (EPA 2007)	The 2004 TDD Section 7 notes sediment basin requirements for drainage areas ≥ 10 acres.	PG estimated post-construction standard only. A goal of 80 percent removal of TSS from these flows (e.g., stormwater detention structures-including wet ponds), which exceed predevelopment levels should be used in designing and installing, where practicable (EPA 2007; state literature)	14 days (EPA 2007)

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
California	3,600 (EPA 2007; 2004 TDD Section 7)	Other design standards include a settling velocity approach, where the precipitation intensity for a 10-year, 6-hour rain event is used (EPA 2007)	The 2004 TDD Section 7 notes sediment basin requirements for drainage areas ≥ 10 acres.	California's draft CGP includes turbidity effluent levels of 1,000 NTU. If Active Treatment Systems are used, the daily flow-weighted average is 10 NTU and the maximum for any single sample is 20 NTU.	Not specified (EPA 2007 and 2002 TDD Appendix A). 2004 TDD confirmed that CA has no stabilization standard within 14 days.
Colorado	1,800 general/3,600 transportation	N/A	The 2004 TDD Section 7 notes sediment basin requirements of 1,800 ft^3/acre drained. The EPA 2007 literature notes sediment basin sizing of 3,600 ft^3/acre for Colorado Department of Transportation (CDOT).	None (EPA 2007)	14 days. PERMIT NO. COR10*##F (http://www.epa.gov/region8/water/stormwater/downloads/Cof_con.pdf states 14 days. There is no stabilization standard within 14 days per 2004 TDD. Douglas County requires that disturbed areas be drill seeded and crimp mulched, or permanently landscaped, within 30 days from the start of land disturbance activities or within 7 days of the substantial completion of grading and topsoiling operations, whichever duration is shorter (EPA 2007)

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft³/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Connecticut	3,600 (EPA 2007)	The EPA 2007 literature notes basin sizing of 3,600 ft³/acre.	The 2004 TDD Section 7 notes a sediment basin storage volume of 1,800 ft³/acre drained. The EPA, 2007 literature noted that sediment basins required for sites greater than 2 acres.	PG estimated no numeric standard for active construction sites based on review of state literature. The EPA 2007 literature notes 80% TSS. The 2004 Connecticut Stormwater Quality Manual, Chapter 6 states, The State of Connecticut has adopted the 80 percent TSS removal goal based on EPA guidance and its widespread use as a target water quality performance standard. The 2004 Connecticut Construction General Permit for Stormwater discharges noted that the 80 percent TSS removal was for post-construction. The 2002 TDD Appendix A notes an 80 percent TSS reduction.	3 days. Where construction activities have permanently ceased or have temporarily been suspended for more than 7 days, or when final grades are reached in any portion of the site, stabilization practices shall be implemented within 3 days. Areas that will remain disturbed but inactive for at least 30 days shall receive temporary seeding. Areas that will remain disturbed beyond the planting season, shall receive long-term, nonvegetative stabilization sufficient to protect the site through the winter (EPA 2007)

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Delaware	3,600 (EPA 2007; 2004 TDD Section 7)	N/A	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥ 10 acres.	PG estimated no numeric standard. The EPA 2007 literature states “None.” The 2002 TDD Appendix A notes an 80 percent TSS reduction; however, PG determined from state literature that this was a post-construction standard.	14 days (EPA 2007)
Florida	3,600 (EPA 2007; 2004 TDD Section 7)	N/A	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥ 10 acres.	PG estimated no statewide numeric standard. The EPA 2007 literature states “None.” The 2002 TDD Appendix A notes some standards for specific regions, but no statewide requirements.	7 days (EPA 2007)
Florida, DEP, Northern District (only applies in NW Florida)				The 2002 TDD Appendix A notes an 80 percent TSS reduction.	
Florida, South Florida Water Management District General, Standard General, Noticed General and Individual Permits)					

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Florida, Southwest Florida Water Management District					
Florida, St. Johns River Water Management District				The 2002 TDD Appendix A notes a turbidity less than 29 NTU.	
Florida, Suwannee River Water Management District				The 2002 TDD Appendix A notes an 80 percent TSS reduction.	
Georgia	1,800 (EPA 2007; 2004 TDD Section 7)		The 2002 TDD Appendix A notes water runoff from 25-year, 24-hour storm event shall be treated for water quality management. PG assumed the 25-year storm event is for the emergency spillway per the 2004 TDD ("Typical return periods vary between 25 and 100 years, with 25 years recommended by the USDOT")	Statewide standard varies with background. Cannot increase turbidity by more than 25 NTU in warm waters and 10 NTU in cold water trout streams. Allowable turbidity in effluent varies based on site size and receiving stream drainage area (EPA 2007). The 2002 TDD Appendix A notes turbidity < 10 to 25 NTUs.	14 days (EPA 2007)

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Hawaii	3,600 (EPA 2007)	Basin sizing for a 2-year, 24-hour storm event for drainage areas ≥ 10 acres (EPA 2007)		No numeric requirements for stormwater pollutant removal have been established at the state level, but regional and municipal regulations are in place (EPA 2007)	30 days (EPA 2007)
Idaho	3,600 (EPA 2007; 2004 TDD Section 7)	Basin sizing for a 2-year, 24-hour storm event for drainage areas ≥ 10 acres (EPA 2007)	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥ 10 acres.	None. None listed in EPA 2007 or 2002 TDD Appendix A.	14 days (EPA 2007)
Illinois	3,600 (2002 TDD Appendix A)	No sizing criteria in permit (EPA 2007). The 2002 TDD Appendix A notes 3,600 ft^3/acre.	The 2002 Illinois Urban Manual states that the basin requirements shall be based on a 2-year, 24-hour storm or 134 cubic yards/acre (i.e., 3,600 ft^3/acre)—whichever is greater (EPA 2007). General NPDES Permit No. ILR10 5/30/2003 notes that "The management practices, controls and other provisions contained in the stormwater pollution prevention plan must be at least as protective as the requirements contained in Illinois Environmental Protection Agency's Illinois Urban Manual, 2002."	None (EPA 2007)	14 days (unless covered with snow or construction will resume within 21 days) (EPA 2007)

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Indiana	1,800 (2004 TDD Section 7)	No sizing criteria in permit (EPA 2007). The 2004 TDD Section 7 states that for a state program that did not note a sediment basin size, EPA assumed based on best professional judgment (BPJ) that the baseline size was 1,800 ft^3/acre.	Sediment basin requirements exist for some areas in State (EPA 2007)	Only in certain parts of Indiana (e.g., 80 percent of TSS removal in Marion County). (EPA 2007)	15 days (EPA 2007)
Iowa	3,600 (EPA 2007; 2004 TDD Section 7)	The 2002 permit states that a sediment basin shall be installed for drainage area more than 10 acres disturbed. (Flows from upland areas that are undisturbed may be diverted around the basin) (EPA 2007)	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥ 10 acres. The EPA 2007 literature notes: The 2006 Iowa Construction Site Erosion Control Manual states that the size of the sediment basin, is as measured from the bottom of the basin to the principal spillway and should provide at least 3,600 ft^3 of storage per acre of drainage. This provides storage equal to 1 inch of runoff per acre. Likewise, 1,800 ft^3 amounts to 1/2 inch of sediment storage per acre. The basin should be cleaned when the volume of sediment reaches 900 ft^3/acre. At this time, the cleanout shall be performed to restore the original design capacity of the basin. At no time should the sediment level be permitted to build higher than 1 foot below the principal outlet.	PG estimated no numeric standard. The EPA 2007 literature states "None." The 2002 TDD Appendix A notes an 80 percent TSS reduction; however, PG could not confirm that this standard was for active construction sites.	14 days (unless covered with snow or construction will resume within 21 days) (EPA 2007)

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Kansas	3,600 (EPA 2007; 2004 TDD Section 7)	Kansas 1/30/07 CGP definitions and Acronyms pages states, "Sediment Basin Design Criteria requires sedimentation structures that receive runoff from 10 acres or more of disturbed area to provide at least 3,600 ft^3 of storage per acre of area drained into the sediment basin. KDHE may approve alternate storage volumes if significant portions of undisturbed area drain to the sediment basin."	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥ 10 acres. The EPA 2007 literature notes that the 2007 permit requires a storage capacity of 3,600 ft^3/acre and the Sediment Basin Design Criteria in the permit states, "rational method or other equivalent runoff calculations based on storage of a 2.6 inch rainfall event with a minimum runoff coefficient of 0.77 for disturbed acreage and appropriate runoff coefficients for undisturbed acreage must be provided to determine the revised storage volume requirement." The field guide for Missouri and Kansas says that for drainage areas of 20 acres or less, the sediment storage shall be 1,800 ft^3/acre with a detention time of at least 24 hours (EPA 2007)	None (EPA 2007)	Not specified; however, it states, "time should be minimized" (EPA 2007)

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Kentucky	3,600 (EPA 2007; 2004 TDD Section 7)	The 2002 permit requires a basin sizing of 3,600 ft^3/acre for drainage locations >10 acres (EPA 2007). The EPA 2007 literature notes in the 2007 Draft Kentucky BMP Manual requires basin sizing of 3,600 ft^3/acre, not to exceed 10 acre-feet for areas 5 to 120 acres with the goal to provide a detention time of 24 to 48 hours and 80 percent TSS reduction for the 10-year, 24-hour storm.	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥ 10 acres.	PG noted that there was only numeric standard requirements for Jefferson County and no statewide standard. 80% TSS removal only for Jefferson (EPA 2007). The 2002 Appendix A notes a goal of 80 % TSS reduction (compared to preconstruction levels). A goal of 80% removal of TSS from flows that exceed predevelopment levels (2002 General KPDES Permit for Stormwater Point Source Discharges, construction Activity, page IV-2)	14 days (unless covered with snow or construction will resume within 21 days) (EPA 2007)
Louisiana	3,600 (EPA 2007; 2004 TDD Section 7)	For 10 or more disturbed acres, either the smaller of 3,600 ft^3/acre or a 2-year, 24-hour storm. This does not apply to flows from off-site areas and flows from on-site areas that are either undisturbed of have undergone final stabilization where such flows are diverted around the sediment basin (EPA 2007).	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥10 acres. For drainage locations serving less than 10 acres, smaller sediment basins and/or sediment traps should be used. At a minimum, silt fences, vegetative buffer strips, or equivalent sediment controls are required for all downslope boundaries of the construction area unless a sediment basin providing storage for a calculated volume of runoff from a 2-year, 24-hour storm or	Not directly applicable. There are standards for permitted support activities related to a construction site (cement and concrete facilities, hot mix asphalt/asphaltic concrete facilities, stockpiles of sand and gravel, and non-process area stormwater from cement, concrete, and asphalt facilities). They establish monthly monitoring requirements and discharge limitations for flow (parameters - TSS, TOC, Oil & Grease, and allowable ranges of pH) (EPA	14 days (EPA 2007)

			3,600 ft^3 of storage per acre drained is provided (EPA 2007)	2007)	

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Maine	3,600 (2004 TDD Section 7)	No sizing criteria in permit (EPA 2007)	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥10 acres. The EPA 2007 literature states in the 2003 Erosion and Sediment Control BMPs Manual that the capacity of the sediment basin shall be equal to the stormwater volume to be detained plus the volume of sediment expected to be trapped. Periodic removal of sediment will be necessary to maintain basin's capacity. Temporary basins having drainage areas of 5 acres or less and a total embankment height of 5 feet or less may be designed with less conservative criteria. Any excavated pond with a drainage area in excess of 5 acres or spring flow in excess of 100 gallons per minute must be designed in accordance with embankment pond criteria. Excavated ponds must be designed to be drained within a 10-day period.	None (EPA 2007). The 2002 TDD Appendix A states: 40 to 80 percent TSS reduction. PG could not verify 2002 TDD Appendix A, and assumed no numeric standard.	14 days. Operators must stabilize with mulch, or other non-erodible cover, any exposed soils that will not be worked for more than 7 days. Must stabilize areas within 75 feet of a wetland or waterbody within 48 hours of the initial disturbance of the soil or before any storm event, whichever comes first (EPA 2007)

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Maryland	3,600 (EPA 2007)	N/A	EPA 2007 (minimum of 3,600 ft^3/acre)	PG estimated no numeric standard. None (EPA 2007). The 2002 TDD Appendix A states an 80 percent TSS reduction based on the average annual TSS loading from all storm events less than or equal to the 2-year/24-hour storm; however, PG could not confirm for active construction sites.	14 days (7 days for steep slopes) (EPA 2007)
Massachusetts	3,600 (2004 TDD Section 7)	Basin size based on the runoff volume of a 2-year, 24-hour storm event (2002 TDD Appendix A)	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥10 acres. In the EPA 2007 literature, it is noted that EPA issues permit.	PG estimated no numeric standard. None (EPA 2007). The 2002 TDD Appendix A notes an 80 percent TSS reduction; however, PG could not confirm for active construction sites.	14 days. In the EPA 2007 literature it is noted as 14 days with a CGP reference.

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Michigan	3,600 (2004 TDD Section 7; 2002 TDD Appendix A)	N/A	The 2002 TDD Appendix A notes sites > 10 acres require an on-site temporary sediment basin. The 2004 TDD Section 7 also notes sediment basin drainage requirements for drainage areas ≥10 acres. The EPA 2007 literature notes that the 1998 Guidebook for Best Management Practices for Michigan Watersheds provides sediment basin design recommendations (see longer write-up for details) (EPA 2007). The 1998 Guidebook for Best Management Practices for Michigan Watersheds provides sediment basin design recommendations. A straightforward method requires a storage volume that is equal to 1/2 inch of runoff from the contributing watershed. (For residential areas, 1/2 inch of runoff would be about a 1-year rainfall event in Michigan). For the high percentage of particulate pollutant removal, the detention basin should be designed so that it will take at least 24 hours to drain the entire volume stored. (For more information, see chapter 3 of the guidebook)	None (EPA 2007)	15 calendar days after final grading or the final earth change has been completed (EPA 2007)

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Minnesota	3,600 (EPA 2007; 2004 TDD Section 7)	For 10 or more disturbed acres; (1) The basins must provide storage below the outlet pipe for a calculated volume of runoff from a 2-year, 24-hour storm from each acre drained to the basin, except that in no case shall the basin provide less than 1,800 ft^3 of storage below the outlet pipe from each acre drained to the basin, (2) Where no such calculation has been performed, a temporary (or permanent) sediment basin providing 3,600 ft^3 of storage below the outlet pipe per acre drained to the basin shall be provided where attainable until final stabilization of the site (EPA 2007)	The 2004 TDD Section 7 also noted sediment basin drainage requirements for drainage areas ≥ 10 acres.	None; however, where an alternative, innovative treatment system is proposed and demonstrated by calculation, design or other independent methods to achieve 80 percent TSS removal a 2-year monitoring plan to sample runoff from the proposed method must be submitted (EPA 2007)	Steeper than 3:1, 7 days, 10:1 to 3:1, 14 days, flatter than 10:1, 21 days (EPA 2007)

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Mississippi	3,600 (EPA 2007; 2004 TDD Section 7)	The Planning and Design Manual states that the maximum allowable drainage area into the basin shall be 25 acres. The design capacity of the basin must be at least 67 yd^3/acre (1809 ft^3/acre). The capacity of the basin may be estimated by 40% x Height x Surface Area. The basin spillway shall be designed to handle peak flow from a 10-year, 24-hour storm event. If a principal spillway is used in conjunction with an emergency spillway, the principal spillway shall have a minimum capacity of 0.2 cfs per acre of drainage area when the water surface is at the crest of the emergency spillway. The embankment of the sediment basin shall be temporarily seeded within 15 days after its completion. The basin should be designed according the following data sheet (see more detailed summaries in the manual) (EPA 2007)	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥10 acres.	None (EPA 2007)	7 days. Within 7 days when a disturbed area will be left undisturbed for 30 days or more (EPA 2007)

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Missouri	3,600 (EPA 2007)	The 2007 permit states that basins are needed for 10 acres or more, with a basin sizing at least 3,600 ft^3/acre. In valuable water resource areas, the sediment basin needs to contain 1/2 inch of sediment from the drainage and withstand the 2-year, 24-hour storm (EPA 2007). PG noted that the 2007 permit 2-year, 24-hour storm event was not a statewide requirement (applies to valuable water resource areas)	The 2004 TDD Section 7 notes a sediment basin storage volume of 1,800 ft^3/acre drained. The EPA 2007 literature notes that in the 1995 Erosion and Sediment Manual the contributing area is recommended to be 20 acres or less and sized to store a minimum of 1,800 ft3 per disturbed acre with a detention of at least 24 hours. The site should be vegetated and stabilized immediately after construction.	The 2002 TDD Appendix A notes that settleable solids less than 2.5 ml/L per hour for normal land disturbance, and 0.5 ml/L per hour for land disturbance within sensitive areas. The EPA 2007 literature notes that per the Missouri State Operating Permit General Permit MO-R109000 3/8/2002: Construction site discharges shall not violate Missouri Code of State Regulations General Water Quality Standards 10 CSR 20 7.031(3) or exceed a maximum settleable solids concentration of 2.5 ml/L per hour for each stormwater outfall. If the disturbed area is near a Valuable Resources Water settleable solids may not exceed 0.5 ml/L per hour.	14 days; however, if the slope of the area is greater than 3:1 (3 feet horizontal to 1 foot vertical) or if the slope is greater than 3 percent and greater than 150 feet in length, then interim stabilization within 7 days of ceasing operations on that part of the site is required (EPA 2007)

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Montana	1,800 (2004 TDD Section 7)	No sizing criteria in permit (EPA 2007). The 2004 TDD Section 7 states that for a state program that did not note a sediment basin size, EPA assumed based on BPJ that the baseline size was 1,800 ft^3/acre. The 2002 TDD Appendix A notes a basin size based on the runoff volume of a 2-year, 24-hour storm event. PG could not verify the 2-year, 24-hour storm event.	In the EPA literature, it notes in the Erosion and Sediment Control Manual stating that desilting basins are appropriate for areas of disturbed soil between 5 acres and 10 acres in size. Desilting basins shall be designed to have a capacity equivalent to 100 m3 (1500 ft^3) of storage (as measured from the top of the basin to the principal outlet,) per hectare (acre) of contributory area. This design is less than that required to capture 0.01 mm (0.0004 in) particle size, but larger than that required to capture particles 0.02 mm (0.0008 in) or larger. The depth must be no less than 1 m (3 ft) nor greater than 1.5 m (5 ft). Basins shall be designed to drain within 72 hours following storm events.	The EPA 2007 literature notes that BMPs must minimize or prevent “significant sediment” (as defined in Part VI of the General Permit p. 28) from leaving the construction site. Significant sediment means sediment, solids, or other wastes discharged from construction site, or a facility or activity regulated under the General Permit which exceeds 1.0 cubic foot in volume in any area of 100 square feet that may enter state surface water or a drainage that leads directly to state surface water.	Not specified (EPA 2007). 2002 TDD Appendix A confirmed no stabilization within 14 days.

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Nebraska	1,800 (2004 TDD Section 7)	No sizing criteria in permit (EPA 2007). The EPA 2007 literature also noted that sediment basins required for 5 acres or more in size. Where slopes are equal to or steeper than 3:1, sediment basins may be required for smaller drainage areas. The 2004 TDD Section 7 states that for a state program that did not note a sediment basin size, EPA assumed based on BPJ that the baseline size was 1,800 ft^3/acre.		None (EPA 2007)	14 days (Permit NER110000)
Nevada	3,600 (EPA 2007; 2004 TDD Section 7)	The EPA 2007 literature notes in the 2002 permit states that basin requirements for drainage areas > 10 acres shall provided storage of 3,600 ft^3/acre or for a 2-year, 24-hour storm event for each disturbed acre. For a drainage location that serves 10 or more acres disturbed at one time and where a temporary sediment basin or equivalent controls is not attainable, smaller sediment basins and/or sediment traps should be used.	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥ 10 acres. The EPA 2007 literature notes to see design specifications from the Department of Conservation and Natural Resources (DCNR) and 1994 BMP manual.	None (EPA 2007).	14 days (EPA 2007)

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
New Hampshire	3,600 (EPA 2007; 2004 TDD Section 7)	The EPA 2007 literature references the CGP which specifies 3,600 ft^3/acre or 2-year, 24-hour runoff event.	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥ 10 acres. The EPA 2007 literature notes that EPA's CGP applies, and to see the design specifications from the 1992 Erosion and Sediment Control Handbook.	PG estimated no numeric standard. The standard referenced is not relevant to stormwater, only for excavation dewatering. The EPA 2007 literature states, must treat any uncontaminated excavation dewatering discharges to remove TSS and turbidity. TSS must meet monthly average and maximum daily TSS limitations of 50 mg/L and 100 mg/L, respectively.	14 days (EPA 2007)
New Jersey	1,800 (2004 TDD Section 7)	The 2004 TDD Section 7 states that for a state program that did not note a sediment basin size, EPA assumed based on BPJ that the baseline size was 1,800 ft^3/acre.	New Jersey Erosion and Sediment Control and Stormwater Management Requirements state that Sediment Control Tanks shall be sized accordingly: 1 ft^3 of storage for each gallon per minute of pump discharge capacity. Tanks may be connected in series to increase effectiveness (EPA 2007)	None, standards are for post-construction (EPA 2007)	Not specified (EPA 2007). 2002 TDD Appendix A confirmed no stabilization within 14 days.

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
New Mexico	3,600 (EPA 2007; 2004 TDD Section 7)	EPA Region 6 issues permit—the 2003 general permit states that for 10 or more disturbed acres at one time, a temporary (or permanent) sediment basin providing at least 3,600 ft^3/acre drained shall be provided until final stabilization of the site. For drainage locations which serve 10 or more disturbed acres at one time and where a temporary sediment basin or equivalent controls is not attainable, smaller sediment basins and/or sediment traps should be used. For drainage locations serving less than 10 acres, smaller sediment basins and/or sediment traps should be used. At a minimum, silt fences, vegetative buffer strips, or equivalent sediment controls are required for all down slope boundaries (and for those side slope boundaries deemed appropriate as dictated by individual site conditions) of the construction area unless a sediment basin providing storage for a calculated volume of runoff from a 2-year, 24-hour storm or 3,600 ft^3 of storage per acre drained is provided.	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥ 10 acres. The EPA 2007 literature notes that EPA Region 6 issues permit.	None (EPA 2007)	14 days (EPA 2007)

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
New York	3,600 (2004 TDD Section 7). For alternate size standards, see New York's Standards and Specifications for Erosion and Sediment Control (August 2005).	The New York August 2005 Standards and Specification for Sediment and Erosion Control states that the minimum sediment storage volume of the basin, as measured from the bottom of the basin to the elevation of the crest of the principal spillway shall be at least 3,600 ft^3/acre draining to the basin. This 3,600 ft^3 is equivalent to one inch of sediment per acre of drainage area. The entire drainage area is used for this computation, rather than the disturbed area above, to maximize trapping efficiency. The length to width ratio shall be greater than 2:1, where length is the distance between the inlet and outlet. A wedge shape shall be used with the inlet at the narrow end.	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥ 10 acres. The EPA 2007 literature notes to see details in New York's Standards and Specifications for Erosion and Sediment Control (August 2005)	None (EPA 2007)	7 days (Permit No. GP-0-08-001)

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
North Carolina	1,800 (EPA 2007; 2004 TDD Section 7)	The 2006 Erosion and Sediment Control Planning and Design Manual states that the sediment storage volume of the basin, as measured to the elevation of the crest of the principal spillway, is at least 1,800 ft^3/acre for the disturbed area draining into the basin (1,800 ft^3 is equivalent to a 1/2 inch of sediment per acre of basin drainage area) for a maximum of 100 acres. See more details on basin design provided in manual (EPA 2007)	The EPA 2007 literature notes a sediment basin storage volume of 1,800 ft^3/acre drained.	None. None listed in EPA 2007 or 2002 TDD Appendix A.	None specified. 2002 TDD Appendix A confirms no stabilization within 14 days. 20 acres of total disturbance at any given time for areas discharging to high quality waters (2002 TDD Appendix A).
North Dakota	3,600 (EPA 2007)	The 2004 permit states that (for 10 or more acres) the basins shall be sized to provide 3,600 ft^3 of storage below the outlet pipe per acre drained to the basin. Alterative designs may be used which provide storage below the outlet for a calculated volume of runoff from a 2-year, 24-hour storm and provides not less than 1,800 ft^3 of storage below the outlet pipe from each acre drained to the basin. (EPA 2007)	The 2004 TDD Section 7 notes a sediment basin storage volume of 1,800 ft^3/acre drained.	None (EPA 2007)	Not specified (EPA 2007). 2002 TDD Appendix A confirmed no stabilization within 14 days.

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Ohio	1,800 (EPA 2007; 2004 TDD Section 7)	N/A	The 2006 Rainwater and Land Development Manual states that for areas less than 100 acres, the volume of the dewatering zone shall be a minimum of 1,800 ft^3/acre of drainage (66.7 yd^3/acre) (EPA 2007)	None (EPA 2007)	7 days, or 2 days if near stream (EPA 2007)
Oklahoma	3,600 (EPA 2007; 2004 TDD Section 7)	The EPA 2007 literature notes that the 2002 general permit states that for 10 or more acres drained the basin shall provide storage for a 2-year, 24-hour storm event or 3,600 ft^3 of storage per acre. The 2002 TDD Appendix A notes 3,600 ft^3/acre.	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥ 10 acres.	None (EPA 2007).	14 days (EPA 2007)
Oregon	3,600 (EPA 2007)	N/A	Per the Oregon Erosion and Sediment Control Manual (April 2005), basin size shall be 3,600 ft^3/acre and be designed by a professional engineer. The 2004 TDD Section 7 notes a sediment basin storage volume of 1,800 ft^3/acre drained.	If discharging to a 303(d) listed waterbody or a waterbody with a TMDL for sediment and turbidity, sampling for turbidity is required to meet a 160 NTU benchmark. If unable to meet benchmark, an Action Plan using a BMP such as water treatment using electro-coagulation, chemical flocculation or filtration shall be implemented. (OR CGP)	1 day (PG assumed). The EPA 2007 literature notes apply temporary or permanent soil stabilization measures immediately on all disturbed areas as grading progresses.

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Pennsylvania	5,000 (EPA 2007)	The EPA 2007 literature notes that the 2005 permit states that (1) A sediment storage zone of 1,000 ft^3 per disturbed acre within the watershed of the basin is required; (2) A dewatering zone of 5,000 ft^3 for each acre tributary to the basin is to be provided. Reductions in the dewatering zone are allowed unless the basins is in a HQ or EV watershed, however the minimum required dewatering zone is at least 3,600 ft^3/acre. (3,600 to 6,000 ft^3/acre + 1,800 ft^3/acre = 4,800 to 6,000 ft^3/acre, assumed 5,000 ft^3/acre). The 2002 TDD Appendix A notes a 5-year runoff event for water quality treatment.	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥ 10 acres. The 2002 TDD Appendix A states that basins volumes should drain no quicker than 4 days and no longer than 7 days.	None (EPA 2007)	Not specified (EPA 2007). 2002 TDD Appendix A confirmed no stabilization within 14 days.

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Rhode Island	1,800 (2004 TDD Section 7)	The 2004 TDD Section 7 states that for a state program that did not note a sediment basin size, EPA assumed based on BPJ that the baseline size was 1,800 ft^3/acre. The EPA 2007 literature notes no sizing criteria in permit. The 2002 TDD Appendix A notes a 10-year runoff event for water quality treatment.	The Stormwater Design and Installation Standards Manual and the Soil Erosion and Sediment Control Handbook were not reviewed.	PG estimated no numeric standard. None (EPA 2007). The 2002 TDD Appendix A notes 80 to 90 percent TSS reduction; however, PG could not confirm for active construction runoff.	14 days (EPA 2007)
South Carolina	3,600 (EPA 2007; 2004 TDD Section 7)	The EPA 2007 literature notes basin sizing requirements for 10 or more acres provide storage for a 10-year, 24-hour storm event or at least 3,600 ft^3/acre. (10–year, 24-hour Soil Conservation Service (SCS) Type II, or Type III (coastal zone) storm event). The 2002 TDD Appendix A notes 3,600 ft^3/acre.	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥ 10 acres.	PG estimated no numeric standard. The EPA 2007 literature notes 80 percent of TSS removal for drainage areas > 5 acres. The 2002 TDD Appendix A notes 80 percent TSS reduction; however, PG could not confirm for active construction runoff.	14 days. As soon as possible (ASAP), but no later than 14 days (EPA 2007)
South Dakota	3,600 (EPA 2007; 2004 TDD Section 7)	The 2002 TDD Appendix A notes a 5-year runoff event for water quality treatment. (PG could not find reference for this)	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥ 10 acres.	None (EPA 2007).	14 days (EPA 2007)

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Tennessee	3,600 (EPA 2007; 2004 TDD Section 7)	The EPA 2007 literature notes that the 2005 permit states to design for a 2-year, 24-hour storm for 10 or more acres. Also, the 2002 Erosion and Sediment Control Handbook states that the total storage volume of the basin at the spillway should be at least 134 cubic yards (3,618 ft^3) per acre of drainage area. The volume of the permanent pool must be at least 67 cubic yards (1,809 ft^3) per acre of drainage area and the volume of dry storage must be at least an additional 67 cubic yards (1,809 ft^3) per acre of drainage area. The emergency spillway should be able to handle a 2-year or 5-year, 24-hour storm event. The outlets for the basin should pass the peak runoff expected from the contributing drainage area for a 25-year, 24-hour storm.	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥ 10 acres.	None (EPA 2007)	15 days, Pre-construction vegetative ground cover shall not be destroyed, removed or disturbed more than 10 days before grading or earth moving unless the area is seeded and/or mulched or other temporary cover is installed. Construction must be phased for projects in which over 50 acres of soil will be disturbed. No more than 50 acres of active soil disturbance is allowed at any time during the construction project (EPA 2007)

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Texas	3,600 (EPA 2007; 2004 TDD Section 7)	The EPA 2007 literature notes that the 2003 Permit states that sediment basins are required where feasible for common drainage locations that serve an area with 10 or more acres disturbed at one time. The temporary (or permanent) sediment basin should provide storage for a calculated volume of runoff from a 2-year, 24-hour storm from each disturbed acre drained. Where rainfall data is not available or a calculation cannot be performed, a sediment basin providing 3,600 $ft^3$of storage per acre drained is required where attainable until final stabilization of the site. The 2002 TDD Appendix A notes 3,600 ft^3/acre.	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥ 10 acres.	None, except for concrete batch plants (EPA 2007)	14 days (EPA 2007)

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Utah	3,600 (EPA 2007; 2004 TDD Section 7)	The EPA 2007 literature notes that the 2002 permit says for 10 or more acres basin storage shall provide for a 10-year, 24-hour storm event, or 3,600 ft^3/acre. Permit No.: UTRI00000 (10/31/200) states "...sediment basin that provides storage for a 10-year, 24-hour storm event, a calculated volume of runoff for disturbed acres drained, or equivalent control measures, until final stabilization of the site. Where calculations are not performed, a sediment basin providing 3,600 ft^3 of storage per acre drained (a 1 inch storm event)"	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥ 10 acres.	None (EPA 2007)	14 days (EPA 2007)
Vermont	1,800 (2004 TDD Section 7)	The EPA 2007 literature notes basin sizing of 3,600 ft^3/acre for moderate risk only, and no sizing criteria in permit. The 2004 TDD Section 7 states that for a state program that did not note a sediment basin size, EPA assumed based on BPJ that the baseline size was 1,800 ft^3/acre.	EPA 2007 literature found no sizing criteria and found 3,600 ft^3/acre for moderate risk only; therefore, assumed 1,800 per BPJ from 2004 TDD Section 7.	Vermont's CGP issued February, 2008 contains a numeric action level of 25 NTU for moderate-risk sites.	21 days, for low or moderate risk activities only (EPA 2007)

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Virginia	3,600 (EPA 2007; 2004 TDD Section 7)	The EPA 2007 literature notes that the Virginia Erosion and Sediment Control regulations state that sediment traps and sediment basins shall be designed and constructed based on the total drainage area to be served by the trap or basin. Surface runoff from disturbed areas that is comprised of flow from drainage areas greater than or equal to three acres shall be controlled by a sediment basin. The minimum storage capacity of a sediment basin shall be 134 cubic yards per acre (3,618 ft^3) of drainage area. The outfall system shall, at a minimum, maintain the structural integrity of the basin during a 25-year, 24-hour duration storm event. Runoff coefficients used in runoff calculations shall correspond to a bare earth condition or those conditions expected to exist while the sediment basin is used. The 2002 TDD Appendix A notes that sediment basins required for sites of 10 acres or more (except those with final stabilization); for sites less than 10 acres, same units required but only for side slope and downslope boundaries of construction sites.	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥ 10 acres.	None (EPA 2007)	7 days (EPA 2007)

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Washington	3,600 (eastern WA only). For alternate size standards, see WA BMP C241.	The 2002 TDD Appendix A notes a 24-hour/6-month storm for water quality treatment. 2-year (or 10-year peak if warranted) OR Rational Method See Eastern Washington BMP C241 (http://www.ecy.wa.gov/pubs/0410076/7.pdf). Western Washington has the same storm events but does not specifically mention 3,600 ft^3/acre.	The EPA 2007 literature notes basin requirements are different for western and eastern parts of State—see manuals. The 2004 TDD Section 7 notes a sediment basin storage volume of 1,800 ft^3/acre drained.	Statewide standard varies with background. PG noted that the WAC 173-201A-030 has been replaced with the WAC 173-201A-200 Freshwater designated uses and criteria (updated 2006). Table 200 (1) (e) contains updated aquatic life turbidity criteria. The EPA 2007 literature states that the Water Quality Standards for Surface Waters of the State of Washington WAC 173-201A-030 (1) (vi) states that turbidity shall not exceed 5 NTU over background turbidity when the background turbidity is 50 NTU or less, or has more than a 10 percent increase in turbidity when the background turbidity is more than 50 NTU.	Both the EPA literature and the 2002 TDD Appendix A note that stabilization varies by time of year and location in State. West of the Cascade Mountains Crest: During the dry season (May 1–Sept. 30): 7 days; during the wet season (October 1–April 30): 2 days.

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft³/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Washington, Small Parcel		The 2002 TDD Appendix A notes a 24-hour/6-month storm for water quality treatment.			
West Virginia	3,600 (EPA 2007; 2004 TDD Section 7)	The EPA 2007 literature notes that the 2002 permit states sediment basins and traps will be installed with 3,600 ft^3 of storage, measured from the bottom elevation of the structure to the top of the riser or weir, per acre of drainage and will have draw down times of 48 to 72 hours. The 2002 TDD Appendix A notes runoff from a 2-year storm required for water quality treatment (PG could not confirm with state literature)	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥ 10 acres.	None (EPA 2007).	7 days (EPA 2007)
Wisconsin	1,800 (2004 TDD Section 7). For alternate size standards, see WI DNR Conservation Practice Standard 1064.	The EPA 2007 literature notes in the Technical Standards document that basins shall be used for greater than 5 to 100 acres. The sizing criteria for determining treatment surface area of a sediment basin are based on the soil texture and peak outflow during the 1-year, 24-hour design storm. The overflow spillway should be designed to carry the peak rate of runoff expected from a 10-year, 24-hour design storm. The 2004 TDD Section 7 states that for a state program that did not note a sediment basin size, EPA assumed based on BPJ that the baseline size was 1,800 ft^3/acre.		The EPA 2007 literature notes that the current standard in Wisconsin (NR 151.11 pg 409) requires construction sites to implement erosion and sediment controls to reduce to the maximum extent practicable 80 percent of the sediment load carried in runoff on an annual basis, compared to a baseline of no sediment or erosion controls.	Not specified (EPA 2007). 2002 TDD Appendix A confirmed no stabilization within 14 days.

State Requirements – Summary (cont.)					
State	**Sediment basin storage volume (ft^3/acre drained)**	**Sediment basin (design parameters)**	**Sediment basin – notes/references**	**Numeric standard**	**Soil stabilization**
Wyoming	1,800 (2004 TDD Section 7)	The EPA 2007 literature notes No sizing criteria in the permit, and the 1999 Urban Best Management Practice (BMP) manual says use basins for 5 to 100 acres. The 2004 TDD Section 7 states that for a state program that did not note a sediment basin size, EPA assumed based on BPJ that the baseline size was 1,800 ft^3/acre.	1,800 ft^3/acre based on 2004 TDD Section 7.	Standard varies with background. The EPA 2007 literature notes that for cold water fisheries and drinking water supplies turbidity level increases must be less than 10 NTUs; for warm water /nongame fisheries turbidity level increases must be less than 15 NTUs. However, an exception shall apply to the North Platte River from Guernsey Dam to the Nebraska line during the annual "silt run" from Guernsey Dam. The 2002 TDD Appendix A notes turbidity levels must be less than 10 to 15 NTUs.	28 days, temporary stabilization (such as cover crop plantings, mulching or erosion controls blankets, surface roughening, etc.) for exposed soil areas where activities have permanently or temporarily ceased should be installed whenever practicable in areas where further work is not expected for 28 days or more (EPA 2007).
Puerto Rico					
District of Columbia	3,600 (EPA 2007; 2004 TDD Section 7)	Basin sizing for 2-year, 24-hour storm (EPA 2007)	The 2004 TDD Section 7 notes sediment basin drainage requirements for drainage areas ≥ 10 acres.	None (EPA 2007)	14 days (EPA 2007)