Costs of Urban Stormwater Control Practices

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Abstract

This research presents a method to determine the costs of several types of stormwater control practices including the costs of conventional drainage system. Several published literature sources were reviewed that contained costs of control practices. Standard unit cost data used in developing the conventional conveyance drainage system costs were obtained from RS Means. The cost data were transformed into equations and utilized to develop the cost module for the Source Loading and Management Model (WinSLAMM). An Excel spreadsheet model was also developed to estimate the costs of conventional stormwater drainage systems based on the published unit cost data. In an example, the costs estimated by the spreadsheet model were compared to the costs associated with the stormwater control practices as estimated by WinSLAMM for a 250-acre industrial site in Huntsville, AL. The costs of site biofiltration, large-scale grass swales, and a wet detention pond were compared to the costs for the conventional drainage system.

The cost information available from published literature sources and other references were in the form of tables and equations. The cost information gathered provided regional cost estimates for the control practices for a specific year. Cost indices published by the *Engineering News Record* were used to estimate the present costs from historical cost information and at locations where cost information is unavailable. These cost indices, from 1978 to 2005, were incorporated into WinSLAMM and the spreadsheet model.

Based on the cost data obtained form Southeastern Wisconsin Regional Planning Commission (1991), the component(s) that affected the control practice cost the most were also analyzed.

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Chapter I

Introduction

1.1 Background

Cost estimation plays a major role in all project management activities. Forecasting the total life-cycle project cost for different alternatives is a vital step in any decision-making activity. The life-cycle project costs include the initial construction costs, in addition to long-term maintenance costs, and eventual replacement costs. When considering replacements and alternatives for historical infrastructure components, costs of the historically "standard" approach and the new alternatives need to calculated in similar ways and include similar cost components. In urban stormwater management, there are costs for the stormwater control practices, plus costs for stormwater conveyance components, and the associated operation and maintenance costs. Developers, city planners, engineers, funding agencies, government and private agencies are interested in determining these costs for a project before its start. Cost also plays a major role in decision analysis when choosing the most cost-effective program when multiple objectives need to be considered and when more than one program can deliver the desired benefits.

1.2 Project Objectives

This research provides a consolidated and summary of information obtained from the a number of sources that reported on costs of stormwater controls, plus additional specialized references. The costs of the following stormwater control practices have been examined during this research: outfall stormwater controls (wet detention ponds, dry detention ponds, wet lands, infiltration ponds, and chemical treatment), critical source area controls (hydrodynamic separators, oil-water separators, storm drain inlet inserts, stormwater filters, and the multi-chambered treatment train), conservation design controls (grass filter strips, grass swales, permeable pavement, infiltration trenches, rain gardens, biofilters, bioretention devices, green roofs, and cisterns for water storage), public work practices (street cleaning and catchbasin cleaning), combined sewage overflow controls that can be applied to stormwater (surface storage, deep tunnels, swirl concentrators, screens, sedimentation basins, and disinfection), gross solids controls, and the costs associated with educational programs. The costs of these control practices reported in various sources were compiled, summarizes, and evaluated as a part of this thesis. This information is presented in the form given in the reports (tables, equations, and figures), and describes the information sources (locations and dates) of the information (if available), for each reference. Section 4.7 also has a comparison of the different costs for a typical application. This research also includes a review of *Engineering News Record* (ENR) cost indices that can be used to adjust the costs for different years and locations to current conditions for many US locations.

The cost data for the following control practices were used to develop the cost module for WinSLAMM (the Source Loading and Management Model for Windows): wet detention ponds, permeable pavement, street cleaning, catchbasin cleaning, biofiltration devices, and grass swales. WinSLAMM estimates the runoff volume and associated pollutants in urban runoff from specified land uses. WinSLAMM also enables the designing of control practices for the area under consideration and estimates their corresponding effect on runoff and pollutant loadings. The new cost module enables the user to estimate the cost of implementing and maintaining the selected control practices for the land use.

An Excel spreadsheet model was also developed to supplement the cost estimates made by WinSLAMM. This spreadsheet calculates the capital cost, present value of all costs, and annualized value of all initial construction and maintenance costs for a conventional stormwater conveyance system using *2006 RS Means Building Construction Cost Data* (64th Annual Edition). This spreadsheet model was used during this research to compare the costs of grass swales (computed using WinSLAMM) with the costs of a conventional stormwater conveyance system comprised of curbs and gutters with underground pipes at a new 250-acre industrial park in Huntsville, Alabama.

1.3 Cost Analysis Elements

1.3.1 Total Costs

The total cost includes capital (construction and land) and annual operation and maintenance costs. Capital costs occur when the stormwater control component is installed, unless retrofits or up-sizing occurs at a later time. Capital costs also include added financing costs that are amortized over the life of the project. The operation and maintenance costs occur periodically throughout the life of the stormwater control device or practice.

1.3.2 Capital Costs

Capital cost consists primarily of land cost, construction cost, and related site work. Capital costs include all land, labor, equipment and materials costs, excavation and grading, control structure, erosion control, landscaping, and appurtenances. It also includes expenditures for professional/technical services that are necessary to support the construction of the stormwater control device. Capital costs depend on site conditions, size of drainage area and land costs that vary greatly from site to site.

Land costs are site specific and also depend on the surrounding land use. The land requirements vary depending on type of stormwater control, as shown in Table 1. These values are the approximate areas needed for each of the listed controls, in relation to the impervious area in the watershed. As an example, wet detention ponds (retention ponds) should be sized to be about 2 to 3% of the total impervious area in the watershed, while grass filter strips need to be about the same size as the total impervious areas draining towards them.

Table 1. Relative Land Consumption of Stormwater Controls (US EPA, 1999)

Stormwater Control Type	Land Consumption (% of Impervious Area of the Watershed)
Retention Basin	2 to 3%
Constructed Wetland	3 to 5%
Infiltration Trench	2 to 3%
Infiltration Basin	2 to 3%
Permeable Pavement	0%
Sand Filters	0 to 3%

Bioretention	5%
Swales	10 to 20%
Filter Strips	100%

1.3.3 Design, Permitting and Contingency Costs

Design and permitting costs include costs for site investigations, surveys, design, and planning for the stormwater controls. Contingency costs are the unexpected costs incurred during the development and construction of a stormwater control practice. They are expressed as a fraction of the base capital cost and have been considered uniform for all stormwater controls. During the calculation of capital costs, 25% of the calculated base capital cost should be added that includes design, permitting, and contingency fees (Wiegand, et al. 1986; CWP 1998; and U.S. EPA 1999) and 5% to 7% of the calculated base capital cost that includes cost of erosion and sediment control (Brown and Schueler 1997; U.S.EPA 1999; and CWP 1998).

1.3.4 Operation and Maintenance (O&M) Costs

Operation and maintenance are post construction activities and ensure the effectiveness of an installed stormwater control practice. They include labor; materials; labor, energy and equipment for landscape maintenance; structural maintenance; sediment removal from sediment control devices and associated disposal; and litter removal. Similar to the design, permitting and contingency costs, the operations and maintenance costs are usually expressed as an annual percentage of capital costs, or the actual costs can be determined. Total annual O&M costs for both routine activities (periodic site inspections, grass mowing, litter and debris removal, bank stabilization, and maintenance of site vegetation for erosion control) and sediment removal was estimated to range from 3 to 5% of base construction costs for pond stormwater controls (Wiegand, et al, 1986).

1.3.5 Life Cycle Costs

Life cycle costs are all the costs that occur during the life time of the stormwater control device. It includes design, construction, O&M, and closeout activities. Life cycle costs can be used to help select the most cost-effective stormwater control option. Life cycle costs include the initial capital cost and the present worth of annual O&M costs that are incurred over time, less the present worth of the salvage value at the end of the service life (Sample, *et al*. 2003).

1.4 Research Outline

A stormwater conveyance system is a facility that is generally owned and maintained by the municipality to collect stormwater in the form of runoff and convey them to the nearest storage location for treatment or discharge into a nearest waterbody. During the conveyance of the stormwater through the facility, the stormwater may or may not undergo treatment depending on the type of the conveyance system. Grass swales, grass filter strips, porous pavement, infiltration trenches, rain gardens, biofilters, and green roofs are common stormwater conveyance systems that may treat the stormwater during conveyance. Stormwater can also be conveyed above ground through unlined ditches not created specifically for the purpose of conveying the stormwater. However, the traditional stormwater conveyance system in which the stormwater is collected or the stormwater is channeled through a grated opening that goes to a pipe and connects to the underground stormwater sewer system, offers few treatment opportunities.

The stormwater can also be treated through controls such as wet detention ponds and wetlands, chemical treatment by using alum or ferric chloride or infiltration ponds. The stormwater conveyance system network inlets can be fitted with catchbasin inserts, or replaced with hydrodynamic devices at critical source areas. These include hydrodynamic separators such as the Downstream Defender, Stormceptor, Vortechs, Multi Chambered Treatment Trains, stormwater filters such as Upflow Filters, and other inserts with specific functions such as oil-water separators, and gross solid removal devices. Public work practices such as street cleaning and catchbasin cleaning also aim at reducing the pollutants in the stormwater runoff before it enters the conveyance system. The costs involved in the construction, operation and maintenance of all the listed stormwater quality and quantity control practices have been discussed in Chapter II.

The cost data available in published literature was used in WinSLAMM and the spreadsheet model by transforming the data into equations. Chapter III discusses these regression equations that were developed and their implementation into the models.

The calculations and the processing of entered data by the Excel spreadsheet model is discussed in Chapter IV. The spreadsheet model was then applied to a 250 acre industrial site in Huntsville, Alabama. The site consists of 50 plots divided into four subareas based on the direction of natural drainage flows. The runoff from three of the subareas are drained through the stormwater pipe network into two different detention ponds located within the site and the forth subarea drains outside the site. The cost of this stormwater conveyance system being constructed at this site was estimated using the spreadsheet model. The site description, the hydrology calculations and the cost estimates for constructing the stormwater drainage conveyance system is discussed in Chapter V. Chapter VI presents the results and conclusions. Appendix A shows the cost adjustment factors for different locations based on ENR cost indices that have been incorporated into the spreadsheet model, the construction cost index values vs. time for different years for each city are given by ENR. Thiessen polygons are drawn for the US showing the areas that are best represented by each of the 20 cities where ENR cost indices are available.

Chapter II
Literature Review

2.1 Introduction

This chapter gives a brief introduction to the different cost estimation methodologies that can be used to calculate the costs of stormwater control practices. These methodologies are employed to estimate the costs of the stormwater control practices from available design information or unit cost information. Several equations developed using one or more of the methodologies are presented in this chapter. Also presented in the form of tables are the component and total costs of the following stormwater quality control practices:

- Conventional stormwater conveyance system components:
  - Pipelines
  - Trench excavation
  - Bedding
  - Backfill
  - Manhole
  - Inlets
  - Paving
  - Pump stations
- Combined sewage overflow controls that can be applied to stormwater systems:
  - Surface storage
  - Earthen and concrete basins
  - Deep tunnels
  - Swirl concentrators, screens, sedimentation basins, and disinfection
  - Gross solid controls
- Outfall stormwater controls:
  - Wet detention ponds and wetlands
  - Chemical treatment (alum and ferric chloride use)
  - Infiltration ponds
- Public work practices:
  - Street cleaning
  - Catchbasin cleaning
- Critical source area controls:
  - Hydrodynamic separators
  - Oil-water separator
  - Storm drain inlet inserts
  - Stormwater filters
  - Multi-chambered treatment train (MCTT)
- Conservation design controls:
  - Grass filter strips
  - Grass swales
  - Permeable pavement
  - Infiltration trenches, rain gardens, biofilters, and bioretention devices
  - Green roofs

- Cisterns and rain barrels for water storage for reuse
- Educational programs

2.2 Cost Estimation Methodologies

The five common methodologies of cost estimation are as follows (DOD, 1995):

- Bottom-Up Method
- Top-Down Method
- Analogy Method
- Expert Judgment
- Algorithm/Parametric Method

2.2.1 Bottom-Up Method

This method involves identifying and estimating the costs of individual components of a project and then combining these costs to estimate the cost of the entire project.

2.2.2 Top-Down Method

Costs of the entire project are estimated by partitioning the project into lower-level components and life cycle phases beginning at the highest level.

2.2.3 Analogy Method

In this technique, the cost data available from a previously completed project is extrapolated to estimate the cost of a proposed project.

2.2.4 Expert Judgment Method

This method involves consulting experts in the field to estimate the cost of a proposed project using their experience and their understanding of the proposed project.

2.2.4 Algorithmic or Parametric Method

In this method, equations to estimate costs are derived from research or historical cost data. Cost equations can use a single or multiple explanatory variables. The equation forms an efficient way to represent a database in the form of a single equation. Equations 2.1 and 2.2 represent single and multiple explanatory variable equations respectively.

(2.1) $$C = ax^b$$

where

C = Cost, $,
x = independent variable such as measure of component size, and
a,b = constants, depends on overall physical characteristics of component.

(2.2) $$C = f(x_1, x_2, ..., x_i, ..., x_n)$$

where

C = Cost, $, and
x_i = independent variable such as component size

Combinations of one or more of these methods were used to estimate the costs in this research. To estimate the costs of the conventional stormwater conveyance network, the bottom-up method was followed by breaking down the system into separate components such as trench excavation, bedding, pipe installation, backfill, manholes, inlets and curbs and gutters and then combining these costs to estimate the cost of the entire project. For estimating the cost of the control practices, the algorithmic method was followed by fitting equations to available regional cost data. These equations were representative of costs with one or more of the design components. These costs were then adjusted to present costs at a desired location using ENR building construction cost indices (analogy method).

2.3 Cost Estimates for Stormwater/Wastewater Conveyance Systems

2.3.1 Pipeline costs

Wastewater collection network costs developed by Dajani, *et al*. (1971) were used by fitting regression models to data from actual construction bids by the following multiple regression equation:

(2.3) $$C = a + bD^2 + cX^2$$

where

C = construction cost, \$,

D = pipe diameter, ft, and

X = average depth of excavation, ft

Rawls *et al*. (1972) presented a nonlinear relationship for predicting costs of urban drainage systems using land-use parameters by examining data from 126 small urban drainage systems received from agencies in Florida, Virginia, Washington D.C., Maryland, Tennessee, Illinois, Wisconsin, Ohio, New York, Texas, Colorado, Michigan, Nebraska, California, Arkansas, Oregon, and Missouri. The 1963 national average cost for each project was chosen because the reported costs from these agencies were for that year.

(2.4) $$C = 58{,}273 + 8.73\left(T^{0.04} S^{-0.89} {C_R}^{0.64} {D_B}^{0.23} Q^{0.73} {A_D}^{0.71}\right)$$

where

T = design return period, years,

S = ground slope, ft/1,000 ft.,

C_R = runoff coefficient,

D_B = smallest pipe size, in.,

Q = total capacity, cfs, and

A_D = total developed area, ac.

Pipe construction costs as a function of diameter and invert depth was developed by Merritt and Bogan (1973) using graphical relationships.

Grigg and O'Hearn (1976) presented storm drainage pipe costs as a function of pipe diameter, return period and urbanization factor:

(2.5) $$C = (1 + E)\, C_1(D)\, U$$

where

C = total drainage cost, \$,

E = other costs such as design, construction, and incidental costs that approximate the direct installation cost, %,

C_1(D)= cost of pipe (\$) as a function of diameter, D (in.) using published unit cost data, and

U = utilization factor, a function of return period and percentage imperviousness

Based on the rainfall data for Englewood, Colorado, it was illustrated that cost increased rapidly between 1-year and 10-year designs with considerable leveling after that.

Tyteca (1976) presented the costs of wastewater conveyance systems as a function of diameter and length of pipe of the following form

(2.6) $$C = \frac{K}{L} + \alpha D^{\beta}$$

where

C = total capital cost, \$,
L = length of pipe, m,
K = fixed cost, \$,
D = diameter, m, and
α, β = parameters

K and α range are difficult to specify and relate to ground conditions and obstacles. It is possible to estimate these three parameters by regression analysis. For the Belgium case study where extreme conditions were encountered Tyteca (1976) developed different cost functions for three different terrains:

For meadows,

(2.7) $$\frac{C}{L} = 20 + 93D^{1.681}$$

For river banks,

(2.8) $$\frac{C}{L} = 40 + 144D^{1.197}$$

For rivers and in urban areas,

(2.9) $$\frac{C}{L} = 126 + 180D$$

However, these regression equations had little transferability in space and time.

For small urban drainage systems Knapp (1967) presented prediction models (2.10 and 2.11) that can be used to calculate investment costs for conventional storm drainage facilities based on several sets of information on typical urban drainage systems collected from municipal agencies around the country and using 1963 national average costs.

(2.10) $$C = 42Q^{0.53}L^{0.56}S^{-0.14}I^{0.27}R^{0.53}$$

where

C = cost, \$,
Q = capacity, cfs,
S = slope, %,
I = number of inlets, and
R = runoff factor

(2.11) $$\frac{C}{A} = -74.3 + 6.1\left(\frac{L}{A}\right) + 214\left(\frac{Q}{A}\right) + 689\left(\frac{I}{A}\right) + 0.031\left(\frac{L}{S^{0.5}}\right)$$

where

$\frac{C}{A}$ = cost per acre, \$/ac,

$\frac{L}{A}$ = drainage density, ft/ac,

$\frac{Q}{A}$ = runoff intensity, cfs/ac,

$\frac{I}{A}$ = number of inlets per acre, and

$\frac{L}{S^{0.5}}$ = length-slope factor, with S in percentage

Storm sewer pipe cost was estimated by Han, *et al*. (1980) as a part of an optimization model. They used the following equations:

For H ≤ 20 feet, D ≤ 36 inches

(2.12) $$C = 1.93 + 1.688H - 12.6$$

For H > 20 feet, D ≤ 36 inches,

(2.13) $$C = 0.692D + 2.14H + 0.559DH - 13.56$$

For D > 36 inches,

(2.14) $$C = 3.638D + 5.17H - 111.72$$

where

C = installation cost of the pipe, \$/ft,

D = diameter, in. and

H = invert depth, ft.

The total cost of the drainage network was then estimated as the sum of pipe material cost, laying cost and the manhole cost expressed in the form:

(2.15) $$C_t = (L * C_p) + (L * C) + C_m$$

where

C_t = total cost of drainage network, \$,

L = length of pipe, ft,

C_p = unit cost of pipe material, \$/LF,

C = installation cost of pipe, \$/ft given by equations 2.12, 2.13 and 2.14, and

C_m = manhole cost, \$

Meredith (1972) presented installed sewer pipe costs (\$/linear foot of pipe) as a function of pipe diameter and mean invert depth below the ground surface H:

For d < 36 inches and H < 10 feet,

(2.16) $$C = 13.0 + 0.8(H - 10) + 0.915(d - 12)$$

For d < 36 inches and H > 10 feet,

(2.17) $$C = 13.0 + [1.67 + 0.042(d - 12)](H - 10) + 0.915(d - 12)$$

For d > 36 inches,

(2.18) $$C = 128.0 + 4.9(H - 11) + 2.5(d - 72)$$

where

C = cost of installed sewer pipe, \$

H = mean invert depth, ft, and

d = pipe diameter, in.

To estimate the costs of water resources infrastructure, the U.S. Army Corps of Engineers (1979) developed MAPS software. The software used a process engineering oriented approach for estimating costs. For calculating the costs for gravity pipes, the following data were required:

- Flow (maximum and minimum), MGD
- Length, ft
- Initial elevation, ft

- Final elevation, ft
- Terrain multipliers
- Design life (default = 50 years)
- Manning's n (default = 0.015)
- Number and depth of drop manholes
- Rock excavation, % of total excavation
- Depth of cover, ft (default = 5 ft)
- Dry or wet soil conditions
- Cost overrides

The average annual cost is calculated as:

(2.19) $$AAC = AMR + TOTOM$$

where

AAC = average annual cost, \$/yr
AMR = amortized capital cost, \$/yr
TOTOM = annual O&M cost, \$/yr

The amortized capital cost is:

(2.20) $$AMR = CRF * PW$$

where

CRF = capital recovery cost, and
PW = capital cost, \$

The capital costs are estimated as:

(2.21) $$PW = CC + OVH + PLAND$$

where

CC = construction cost, \$,
OVH = overhead costs, \$, and
PLAND = land costs, \$

Overhead costs are estimated as:

(2.22) $$OVH = 0.25*CC$$

(2.23) $$CC = AVC * WETFAC * DEPFAC * XLEN * SECI * CITY * CULT * \frac{(1 + Rock * 2)}{255.6}$$

where

AVC = unit cost of pipe for average conditions, \$/ft,
WETFAC = wetness factor
= 1.2 for wet soil
= 1.0 for average soil
= 0.8 for dry soil
DEPFAC = depth of cover factor
= 0.725 + (0.048 * DEPTH)
DEPTH = depth of cover, ft,
XLEN = length of pipe, ft,
SECI = ENR Construction Cost Index,
CITY = city multiplier,
CULT = terrain multiplier, and
Rock = rock excavation percent of total excavation, in decimal form

The terrain multiplier was calculated as:

$$(2.24)\quad CULT = \frac{(C1*0.8131 + C2*0.6033 + C3*0.6985 + C4*0.7169 + C5*0.7911 + C6*1.3127)}{100}$$

where

C1 = % open country,
C2 = % new residential,
C3 = % sparse residential,
C4 = % dense residential,
C5 = % commercial, and
C6 = % central city

The MAPS formulation is a blend of regression equations and other cost factors. However, the database did not consider all possible costs.

Moss and Jankiewicz (1982) presented the use of life cycle costing for different pipe materials based on bids from contractors. They considered three types of sewer materials in their case study in Winchester, Virginia: reinforced concrete (service life = 75 years), aluminum coated steel (service life = 25 years), and asphalt-coated galvanized steel (service life = 20 years). The service life depends on various factors such as material durability, in-place structural durability, abrasive characteristics of the pipe and soil, and corrosive characteristics of both groundwater and drainage. The service life was estimated based on discussions with manufacturers, literature searches, and experience. The least common multiple of service life, 300 years in this case, is used for comparison. The present worth is calculated by comparing the cost of the original installation and three replacement cycles for reinforced concrete, eleven replacement cycles for aluminum coated steel, and fourteen replacement cycles for asphalt-coated galvanized steel. The salvage cost for each replacement was also included.

RS Means, Building Construction Cost Data, 2006, 64^{th} Annual Edition provides unit cost data for building components including drainage and containment (stormwater conveyance pipes, catchbasins, manholes), curb and gutter, earthwork (excavation, backfill, bedding, and compaction). Cost information provided by RS Means includes materials costs, labor costs, and equipment costs. Labor costs provided by RS Means include time spent during the normal work day for tasks other than actual installation, such as material receiving and handling, mobilization at site, site movement, breaks and cleanup. For materials costs, RS Means provides the national average materials costs across U.S.

Tables 2 and 3 show the 2006 unit length cost data for corrugated metal pipe (CMP), galvanized and bituminous coated pipe with paved invert, 16 gauge thickness, and 20 foot lengths and reinforced concrete pipe (RCP) of class 3 and no gaskets. The cost includes material, labor, equipment and a 10% overhead and profit. The excavation and backfill costs are not included in this cost.

Table 2. Lookup Table for Corrugated Metal Pipe (RS Means, 2006)

Diameter (in.)	Cost ($/LF)
8	17.55
10	21.5
12	26
15	30
18	35.5
24	43
30	64.5
36	82
48	116
60	155
72	241

Table 3. Lookup Table for Reinforced Concrete Pipe (RS Means, 2006)

Diameter (in.)	Cost ($/LF)
12	29.5
15	33
18	36
21	43.5
24	50.5
27	69.5
30	74
36	97.5
42	121
48	144
60	216
72	289
84	450
96	550

In case of multipurpose facilities, the cost is affected by the other objectives that the stormwater system serves. For example, a combined sewer system transports both wastewater and stormwater. Stormwater detention systems can serve as both quantity and quality controls. Streets serve as traffic conduits and transport stormwater along their edges. One method used to divide the costs of multipurpose facilities for individual purposes is to design systems for each purpose independently, and then design the multipurpose system. The individual costs and the costs for the combined multipurpose facility are prorated to determine the costs for each purpose (USEPA, 2002).

The average non-pipe cost associated with sanitary sewer as a percent of total in-place pipe costs is shown in Table 4.

Table 4. Average Non-pipe Costs Associated with Sanitary Sewers (Dames and Moore, 1978)

Category	Pipe Cost (%)
Sanitary sewer miscellaneous appurtenances	7
Manholes	32
Drop manholes	2
Throughfare crossings	13
Stream crossings	1
Rock excavation	2
Pavement removal and replacement	13
Special bedding	1
Miscellaneous costs not categorized	28
Utility reconnection and removal	1
Total	100

2.3.2 Trench Excavation Costs

Trench excavation cost depends on fixed costs like labor and equipment and materials costs, but vary with depth and backhoe bucket size (cubic yards). The excavation costs not including blasting and backfilling are shown in Table 5. This cost includes 10% overhead and profit.

Table 5. Trench Excavation Costs (RS Means, 2006)

Depth (ft.)	Backhoe Size (CY)	Cost ($/CY)
1 - 4	3/8 CY tractor loader/backhoe	6.30
	1/2 CY tractor loader/backhoe	4.85
4 - 6	1/2 CY tractor loader/backhoe	4.85
	5/8 CY hydraulic backhoe	4.94
	3/4 CY hydraulic backhoe	4.27
6 - 10	3/4 CY hydraulic backhoe	5.70
	1 CY hydraulic backhoe	3.32
	1 1/2 CY hydraulic backhoe	2.59
10 - 14	3/4 CY hydraulic backhoe	6.40
	1 CY hydraulic backhoe	3.69
	1 1/2 CY hydraulic backhoe	2.87
14 - 20	1 CY hydraulic backhoe	4.15
	1 1/2 CY hydraulic backhoe	3.23
	2 1/2 CY hydraulic backhoe	2.67

2.3.3 Bedding Costs

Bedding provides sufficient compacted material necessary to protect the pipe from external loading forces. Pipe bedding costs vary with pipe diameter, side slope of trench, and the type of bedding used. Table 6 gives the cost of bedding in dollars per linear cubic yard (not including compaction) for three different bedding materials.

Table 6. Bedding Costs, (RS Means, 2006)

Bedding Material	Cost ($/LCY)
Crushed or screened bank run gravel	31.5
Crushed stone ¾ in. to ½ in.	39.5
Sand, dead or bank	13.7

2.3.4 Backfill Costs

Backfill costs depend on backhoe size, hauling distance of backfill material (ft.) and backfill depth (in.). Table 7 shows the cost in $/LCY for backfilling a trench using a FE Loader. The cost includes labor, equipment and a 10% overhead and profit.

Table 7. Backfill Costs w.r.t Backhoe Size (RS Means, 2006)

Backfill trench, F.E.Loader	Haul distance (ft.)	Cost ($/LCY)
1 CY bucket	minimum haul	1.47
1 CY bucket	100' haul	2.93
2-1/4 CY bucket	minimum haul	1.18
2-1/4 CY bucket	100' haul	2.36

2.3.5 Manhole Costs

For individual manhole costs, the following single variable equation developed by Han, *et al*. (1980) can be used:

(2.25) $$C_m = 259.6 + 56.4h$$

where

C_m = manhole cost, $, and

h = depth of manhole, ft

Meredith (1972) in his work gives the cost of manholes in terms of manhole depths:

(2.26) $$C_m = 250 + h^2$$

where

C_m = installed manhole cost, $, and

h = manhole depth, ft

Dames and Moore (1978) estimate manhole costs indirectly as 36 to 38% of the total in-place pipe cost.

Manhole costs are related to the diameter of the manhole and its depth (i.e. the maximum difference between the ground elevation and the invert elevations of the storm sewers entering the manhole, plus the extra depth for a sump). The costs of precast concrete manholes, (not including excavation, footing, backfill, and covers) are shown in Table 8. The costs include fixed operations cost and profit, labor, equipment and materials cost for installation of precast concrete manholes.

Table 8. Manhole Costs (RS Means, 2006)

Type	Depth, ft.	Cost, $/unit
Brick, 4 ft. I.D.	4	1175
	6	1675
	8	2275
	10	3065
	12	3855
Concrete Blocks, 4 ft. I.D.	4	850
	6	1225
	8	1675
	10	2073
	12	2471
Concrete, Cast-in-place 4 ft. × 4 ft., 8 in. Thick	4	1825
	6	2525
	8	3725
	10	4635
	12	5545

Table 9 presents the cost for manhole grates. These costs provided by RS Means include material, labor, equipment, and a 10% overhead and profit cost.

Table 9. Manhole Grate Costs (RS Means, 2006)

Manhole Type		Cost ($/Ea.)
Light Traffic	18 in. diameter, 100 lb.	300
	24 in. diameter, 300 lb.	410
	36 in. diameter, 900 lb.	745
Heavy Traffic	24 in. diameter, 400 lb.	420
	36 in. diameter, 1,150 lb.	1,275
Mass. State Standard	26 in. diameter, 475 lb.	810
	30 in. diameter, 620 lb.	585
Watertight	24 in. diameter, 350 lb.	595
	26 in. diameter, 500 lb.	590
	32 in. diameter, 575 lb.	1,100
24 in. square, 500 lb.		470
26 in. D shape, 600 lb.		700
3 piece cover & frame, 10 in. deep, 1200 lb.		1,700

Similar data on pumping station (fabricated steel, concrete, or fiberglass) costs and pavement costs (along with subbase costs) were obtained from R.S.Means and are shown in Tables 10 and 11 respectively. The costs include fixed operations cost and profit, and labor, equipment and materials costs.

Table 10. Capital Costs of Sewage Pump Stations (RS Means, 2006)

Description	Flow Rate (gpm)	Cost ($)
Sewage Pump Station	200	73,000
Sewage Pump Station	1000	135,000

Tyteca (1976) presented cost of pumping stations for stormwater pipelines as a function of power installations:

(2.27) $$C = K' + \gamma W^{\delta}$$

where

C = total capital cost, \$,
K' = fixed cost, \$,
W = power, hp, and
γ, δ = parameters reflecting local conditions such as economies of scale.

Table 11. Paving Costs (RS Means, 2006)

Activity	Material	Diameter (in.)	Unit	Depth (in.)	Cost ($)
Prepare and roll subbase < 2500 yd^3	Crushed Stone		yd^2		1.54
Prepare and roll subbase > 2500 yd^3	Crushed Stone		yd^2		0.92
Base Course	Crushed Stone	0.75	yd^2	3	3.91
Base Course	Crushed Stone		yd^2	6	6.90
Base Course	Crushed Stone		yd^2	9	9.95
Base Course	Crushed Stone		yd^2	12	13.05
Base Course	Crushed Stone	1.5	yd^2	4	5.75
Base Course	Crushed Stone		yd^2	6	8.20
Base Course	Crushed Stone		yd^2	8	10.80
Base Course	Crushed Stone		yd^2	12	15.75
Base Course	Bank Run Gravel		yd^2	6	4.46
Base Course	Bank Run Gravel		yd^2	9	6.55
Base Course	Bank Run Gravel		yd^2	12	8.60
Prime and seal	-		yd^2		1.82
Asphaltic Concrete Pavement	Binder Course	1.5	yd^2	1.5	4.01
Asphaltic Concrete Pavement	Binder Course		yd^2	2	5.25
Asphaltic Concrete Pavement	Binder Course		yd^2	3	7.60
Asphaltic Concrete Pavement	Binder Course		yd^2	4	9.95

Table.11 – Continued.

Activity	Material	Diameter (in.)	Unit	Depth (in.)	Cost ($)
Asphaltic Concrete Pavement	Wearing Course	1	yd^2	1	2.92
Asphaltic Concrete Pavement	Wearing Course		yd^2	1.5	4.34
Asphaltic Concrete Pavement	Wearing Course		yd^2	2	5.70
Asphaltic Concrete Pavement	Wearing Course		yd^2	2.5	6.95
Asphaltic Concrete Pavement	Wearing Course		yd^2	3	8.20

An example use of this data to calculate paving costs of a 30 feet wide subdivision street, with 12 inch bank run gravel base material, a primer, a wearing course of 2 inch of asphaltic concrete pavement, and curb and gutter (both sides):

Base course: 5.1 $\$/yd^3 * 30\ ft * yd^2/9\ ft^2 = 17\ \$/ft$

Primer: 1.82 $\$/yd^2 * 30\ ft * yd^2/9\ ft^2 = 6.07\ \$/\ ft$

Pavement: 4.52 $\$/\ yd^2 * 30\ ft * yd^2/9\ ft^2 = 15.07\ \$/ft$

Curb and gutter: 6.95 $/ft * 2 = 13.90 $/ft

Total cost per linear ft: $17 + $6.07 + $15.07 + $13.09 = $52.04

The cost per linear foot would increase with an increase in projected traffic that requires an increase in pavement thickness.

2.3.6 Inlet Costs

Stormwater enters the subsurface drainage system through inlets in roadway gutters, parking lots, depressions, ditches and other locations. The costs for unit precast catch basin inlets for different inside diameters and depths are provided in RS Means Building Construction Cost Data. Table 12 gives this data; the cost does not include the cost of footing, excavation, backfill, frame and cover.

Table 12. Cost of Inlets for Different Depths (RS Means, 2006)

Inside Diameter (ft.)	Depth (ft.)	Cost ($/unit)
4	4	1200
	6	1575
	8	2050
	10	2600
	12	3150
	14	3700
5	4	1275
	6	1800
	8	2300
	10	2894
	12	3488
	14	4082
6	4	2025
	6	2675
	8	3525
	10	4435
	12	5345
	14	6255

2.3.7 Curb and Gutter Costs

Curb and gutter costs are provided in RS Means for wood forms, steel forms, machine formed and precast 6 inches × 18 inches gutters for two different widths and straight and radial patterns for 6 inch high curbs and 6 inch thick gutters (Table 13).

Table 13. Curb and Gutter Costs (RS Means, 2006)

<table>
<tr><th>Type</th><th>Dimension</th><th>Cost ($/LF)</th></tr>
<tr><td rowspan="2">Wood Forms</td><td>24 in. wide</td><td>22.5</td></tr>
<tr><td>30 in. wide</td><td>24.5</td></tr>
<tr><td rowspan="6">Steel Forms</td><td colspan="2">24 in. wide</td></tr>
<tr><td>straight</td><td>10.45</td></tr>
<tr><td>radius</td><td>15.3</td></tr>
<tr><td colspan="2">30 in. wide</td></tr>
<tr><td>straight</td><td>11.85</td></tr>
<tr><td>radius</td><td>16.7</td></tr>
<tr><td rowspan="6">Machine Formed</td><td colspan="2">24 in. wide</td></tr>
<tr><td>straight</td><td>8.25</td></tr>
<tr><td>radius</td><td>10</td></tr>
<tr><td colspan="2">30 in. wide</td></tr>
<tr><td>straight</td><td>9.65</td></tr>
<tr><td>radius</td><td>11.4</td></tr>
<tr><td rowspan="2">Precast 6 in. * 18 in.</td><td>straight</td><td>13.75</td></tr>
<tr><td>radius</td><td>21</td></tr>
</table>

2.4 Combined Sewage Overflow Controls that can be Applied to Stormwater

There is substantial information concerning the costs of large-scale applications of combined sewer controls due to massive installations over the past few decades. Some of these controls may be suitable for the control of separate stormwater. A selection of these is discussed in the following subsections.

2.4.1 Surface Storage

Surface storage units are offline storage units at or near the surface and are generally made of concrete. The cost of construction of a surface storage, such as a large culvert, is given by the following equation (USEPA, 2002):

$$C = 4.546V^{0.826} \tag{2.28}$$

where

C = construction cost in millions, January 1999 costs, $, and

V = volume of storage system, Mgal

Storage costs depend heavily on land costs. Land costs range from zero if the land is assumed part of an easement or donated by the developer, to full costs, based on highly alternative use of land. Storage is used to detain or retain stormwater flows for later release at a slower rate. Storage can improve or degrade downstream water quality depending on how it is operated. Empirical cost on surface storage relating cost as a function of area or volume of the facility can be found in US EPA.

2.4.2 Earthen and Concrete Ponds

Costs of the following stormwater storage: earthen ponds, concrete basin covered, and concrete ponds uncovered, are presented in Tables 14, 15 and 16 respectively. Table 17 presents the capital costs as a function of volume for other stormwater storage devices. The costs are primarily associated with earthwork (moving and compaction) and liner if used. The costs depend on shape of the pond, borrow requirements, soil type, and groundwater problems. These costs presented by USEPA 1976 assume that the embankment soil is available on-site, there is no rock excavation and minimal groundwater problems.

The costs (1975 dollars) presented for these reservoirs by EPA were of the dimensions: 18 feet deep, length of twice its breadth, 2.5:1 internal slope, 3:1 external slope, 20 percent compaction loss, 16 foot top width of levee and a 2 percent bottom slope for to facilitate cleaning.

Table 14. Construction Costs for Earthen Ponds (US EPA, 1976)

Cost Component ($)	Volume (Mgal)							
	0.57	1.95	4.9	9.2	14.8	50.85	108.5	187.8
Earthwork	2,540	6,670	14,900	24,700	36,940	93,330	156,320	229,530
Liner	7,730	14,350	32,780	53,720	79,650	233,400	467,150	780,900
Paving	2,180	3,140	4,340	5,540	6,740	11,540	16,340	21,140
Seeding	870	1,750	3,150	4,960	6,540	13,800	20,600	28,000
Fencing	5,650	7,940	10,720	13,500	16,100	26,300	26,300	45,900
Miscellaneous Items	2,850	5,100	9,900	15,360	21,900	56,700	103,000	165,820
Contingency	3,270	5,790	11,350	17,650	25,210	65,150	118,290	190,430
Total Estimated Cost	25,090	44,740	87,140	135,430	193,080	500,220	908,000	1,461,720

Table 15. Construction Costs for Concrete Reservoir without Cover (US EPA, 1976)

Cost Component ($)	Volume (Mgal)								
	1	2	4	7.5	15	30	60	120	240
Concrete and Forms	80,370	109,030	166,360	230,390	358,450	513,270	822,940	1,239,770	2,073,370
Steel	110,400	149,600	277,200	313,600	486,400	692,000	1,104,000	1,648,800	2,739,200
Labor	99,140	135,850	208,610	294,060	465,840	686,800	1,129,260	1,771,140	3,055,330
Miscellaneous Items	43,490	59,170	97,830	125,710	196,600	283,810	458,430	698,960	1,180,190
Contingency	50,010	68,050	112,500	144,560	226,090	326,380	527,190	803,800	1,357,210
Total Estimated Cost	383,410	521,700	862,500	1,108,320	1,733,380	2,502,260	4,041,820	6,162,470	10,405,300

Table 16. Construction Costs for Concrete Reservoir with Cover (US EPA, 1976)

Cost Component ($)	Volume (Mgal)								
	1	2	4	7.5	15	30	60	120	240
Concrete and Forms	5,150	15,450	30,900	72,100	144,200	309,000	618,000	1,277,200	2,544,400
Steel	2,650	7,950	15,900	37,100	74,200	159,000	318,000	657,200	1,314,000
Labor	10,150	23,450	46,900	100,100	200,200	413,000	826,000	1,677,200	3,354,400
Precast Concrete	20,000	40,000	160,000	320,000	540,000	1,280,000	256,000	5,120,000	10,240,000
Roofing Material	2,000	4,000	16,000	32,000	64,000	128,000	256,000	512,000	1,024,000
Miscellaneous Items	6,000	13,600	40,500	84,200	168,390	343,350	686,700	1,386,540	2,773,080
Contingency	6,890	15,660	46,460	96,690	193,390	394,310	788,630	1,592,350	3,184,680
Cost for Cover	52,840	120,110	356,660	742,190	1,384,380	3,026,660	3,749,330	12,222,490	24,434,560
Total Estimated Cost With Cover	436,250	641,810	1,219,160	1,850,510	3,217,760	5,528,920	10,095,150	18,384,960	34,840,260

Table 17. Estimated Capital Cost of Storage as a Function of Volume (US EPA, 2002)

Type	Equation	Cost, C Units ($)	Volume, V, Range	V, units	Year	Reference
Reservoir	$C = 160\ V^{0.4}$	1,000	104-106	Acre-ft	1980	U.S.Army Corps of Engineers (1981)
Covered concrete tank	$C = 614\ V^{0.81}$	1,000	1 - 10	Mgal	1976	Gummerman, *et al*. (1979)
Concrete tank	$C = 5320\ V^{0.61}$	1,000	1 - 10	Mgal	1976	Gummerman, *et al*. (1979)
Earthen basin	$C = 42\ V^{0.61}$	1,000	1 - 10	Mgal	1976	Gummerman, *et al*. (1979)
Clear well, below ground	$C = 495\ V^{0.61}$	1,000	1 - 10	Mgal	1980	Gummerman, *et al*. (1979)
Clear well, ground level	$C = 275\ V^{0.61}$	1,000	0.01 - 10	Mgal	1980	Gummerman, *et al*. (1979)
CSO storage basin	$C = 3637\ V^{0.83}$	1,000	0.15 - 30	Mgal	1993	Gummerman, *et al*. (1979)
CSO deep tunnel	$C = 4982\ V^{0.80}$	1,000	1.8 - 2,000	Mgal	1993	U.S.EPA (1993b)

From the costs associated with earthen basin presented in Table 14 (USEPA, 1978), the total estimated capital cost was plotted against volume of the basin and regression equations were fitted to this data. Figures 1, 2 and 3 represent these equations for earthen reservoirs for different volume ranges. Figure 1 represents this data for earthen reservoirs for volumes between 0.57 Mgal to 14.8 Mgal. In Figure 2, the x-axis represents the entire volume range, the regression equation obtained is a best fit only for the volume range between 14.8 Mgal and 50.85 Mgal. Figure 3 presents the construction costs of earthen storage reservoirs for volumes ranging from 50.85 Mgal to 187.8 Mgal. Although a single polynomial equation can be used to represent the entire volume range for these reservoirs, residual analyses show a considerable error in costs for smaller storage volumes.

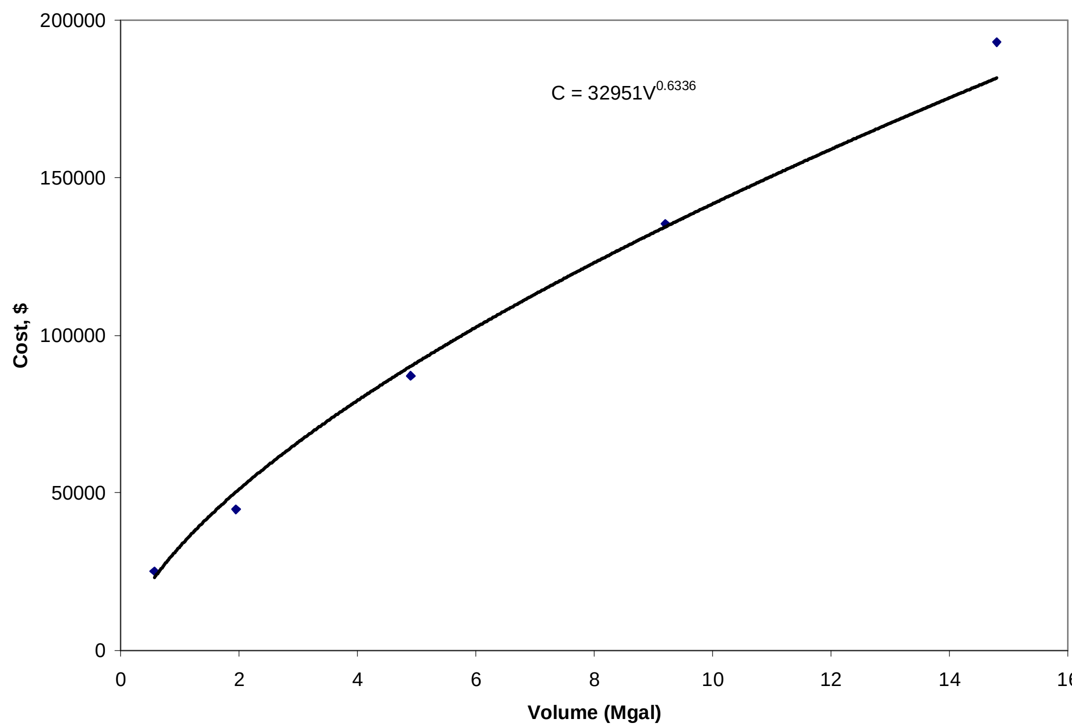


Figure 1. Construction Cost of Earthen Storage Reservoirs, 0.57 Mgal ≤ V ≤ 14.8 Mgal

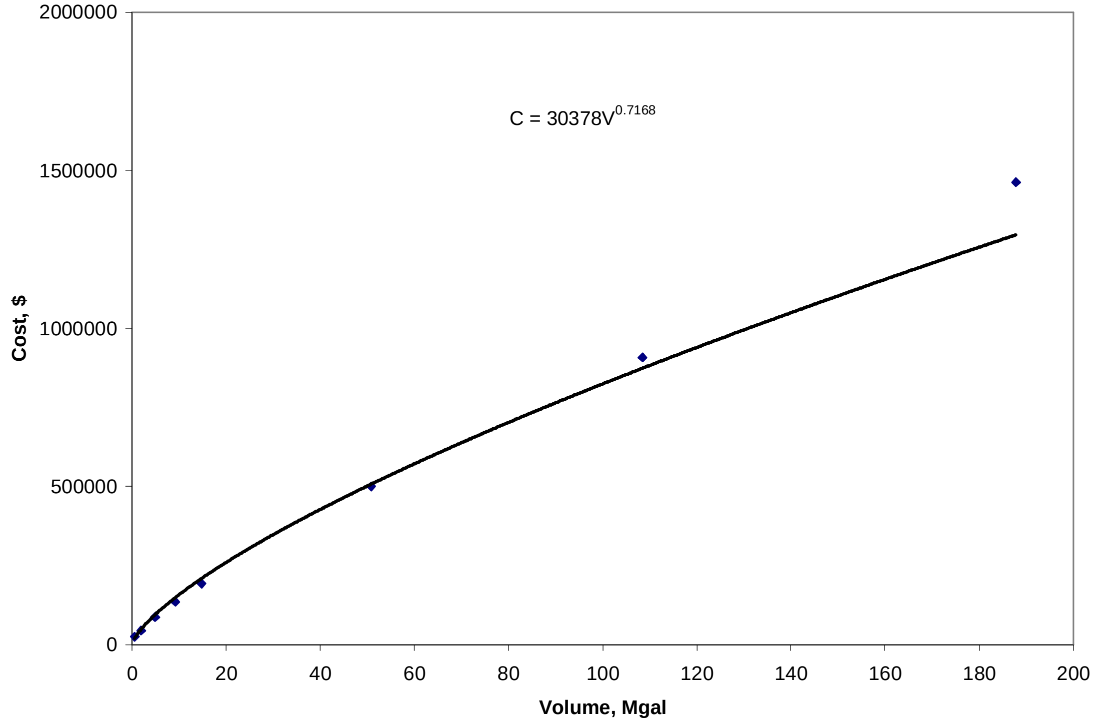


Figure 2. Construction Cost of Earthen Storage Reservoirs, 14.8 Mgal < V < 50.85 Mgal

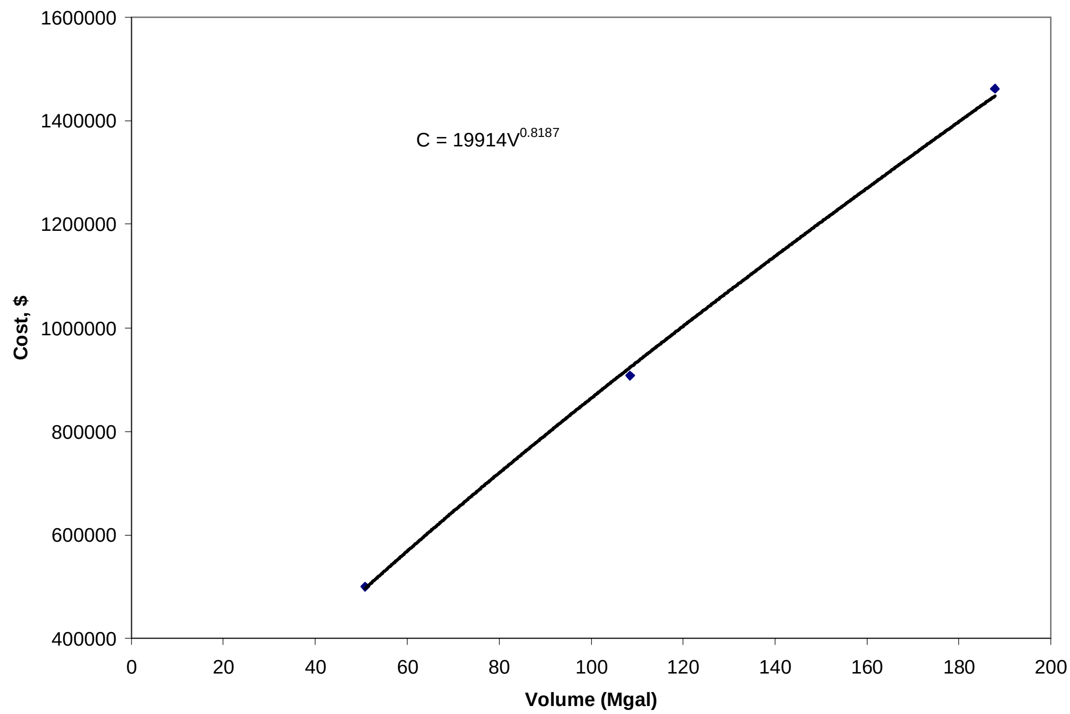


Figure 3. Construction Cost of Earthen Storage Reservoirs, 50.85 Mgal ≤ V ≤ 187.8 Mgal

A power function fitted to the data presented in Table 14 (USEPA, 1978) gives the equations 2.29, 2.30 and 2.31 for construction costs of earthen basins for three different volume ranges.

For $0.57 \le V \le 14.8$ Mgal

(2.29) $$C = 32951V^{0.6336}$$

For $14.8 < V < 50.85$ Mgal

(2.30) $$C = 30378V^{0.7168}$$

For $50.85 \le V \le 187.8$ Mgal

(2.31) $$C = 19914V^{0.8187}$$

where

C = construction cost, $, 1975 costs, and
V = volume, Mgal

Table 15 (USEPA, 1978) presents the total estimated cost and the component costs of concrete basins without cover. Figures 4, 5 and 6 represent the volume of this basin plotted against the estimated capital cost.

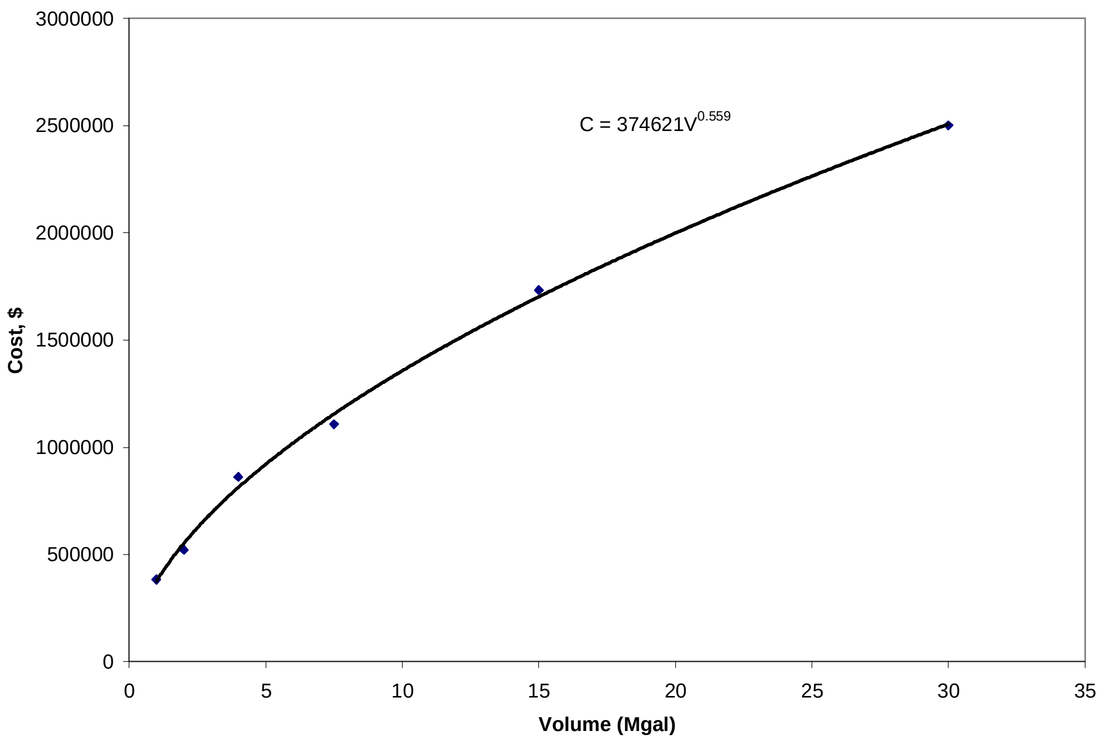


Figure 4. Construction Cost for Concrete Reservoir (without cover), 1 Mgal ≤ V ≤ 30 Mgal

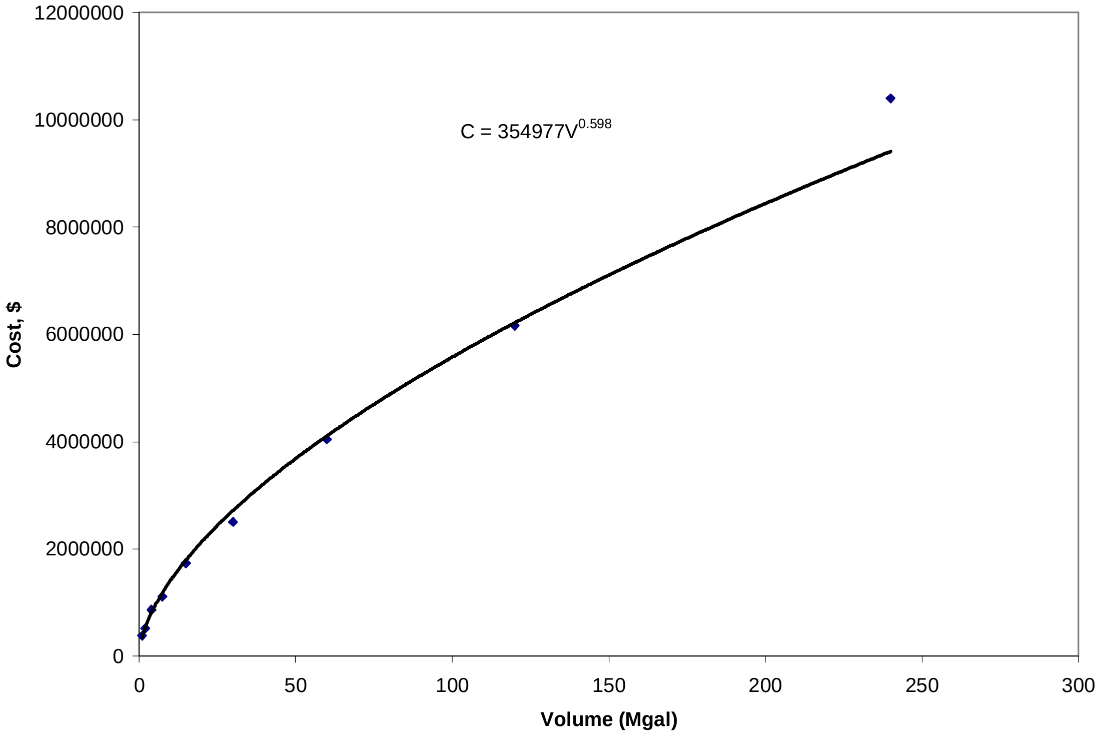


Figure 5. Construction Cost for Concrete Reservoir (without cover), 30 Mgal ≤ V ≤ 600 Mgal

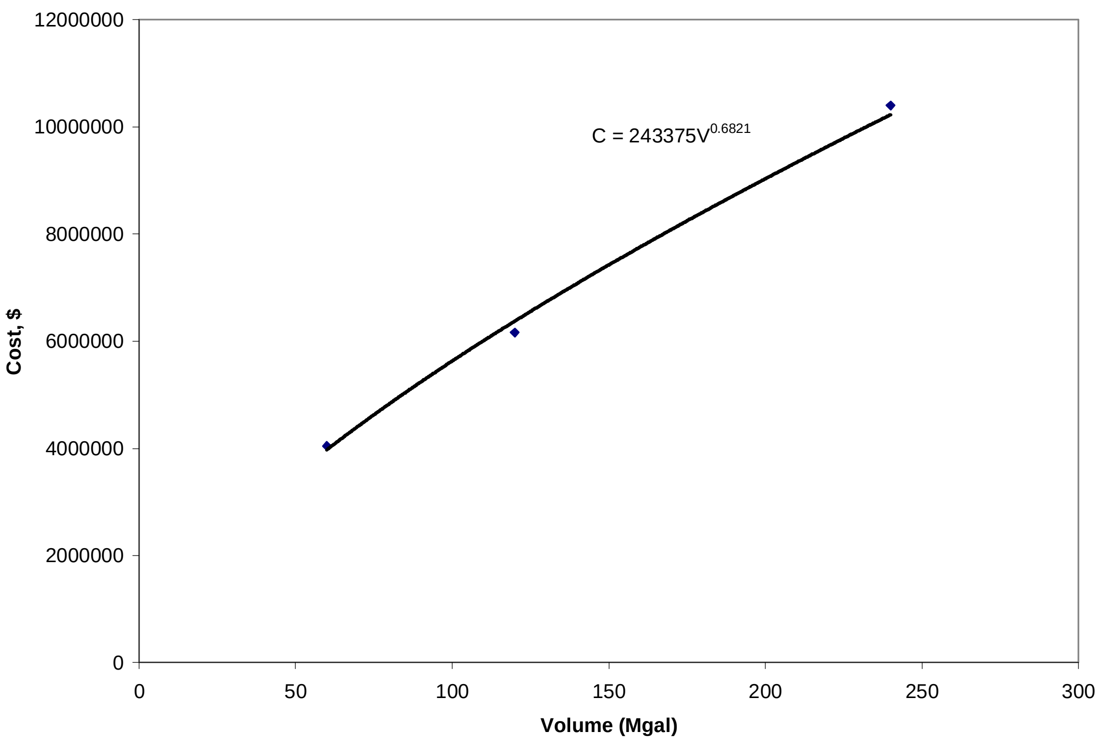


Figure 6. Construction Cost for Concrete Reservoir (without cover), 60 Mgal ≤ V ≤ 240 Mgal

A power function fitted to the data presented in Table 15 (USEPA, 1978) gives the equations as shown by equations 2.32, 2.33 and 2.34 for construction costs of concrete reservoirs without cover of different volume ranges.

For $1 \leq V \leq 30$ Mgal

(2.32) $$C = 374621V^{0.559}$$

For $30 < V < 60$ Mgal

(2.33) $$C = 354977V^{0.598}$$

For $60 \leq V \leq 240$ Mgal

(2.34) $$C = 243375V^{0.6821}$$

where

C = construction cost, $, 1975 costs, and V = volume, Mgal

Table 16 (USEPA, 1978) presents the costs of concrete basins with cover. Figures 7, 8 and 9 represent the volume of this basin plotted against estimated capital cost.

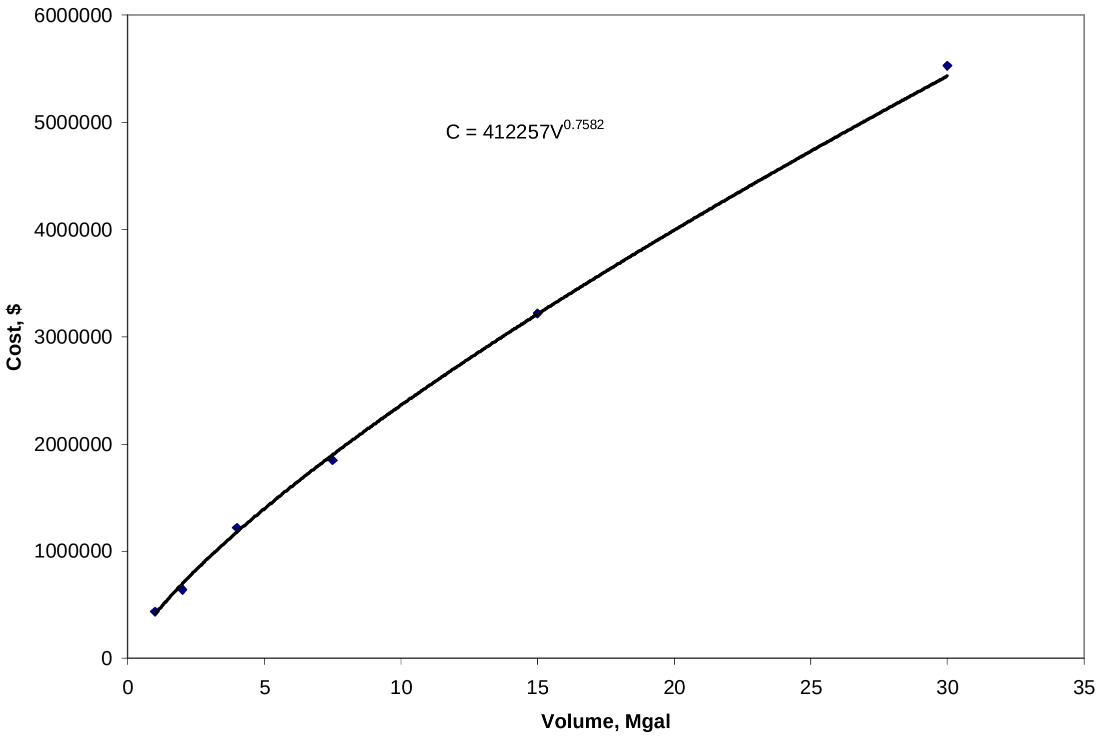


Figure 7. Construction Cost for Concrete Reservoir, 1 Mgal $\leq V \leq$ 30 Mgal

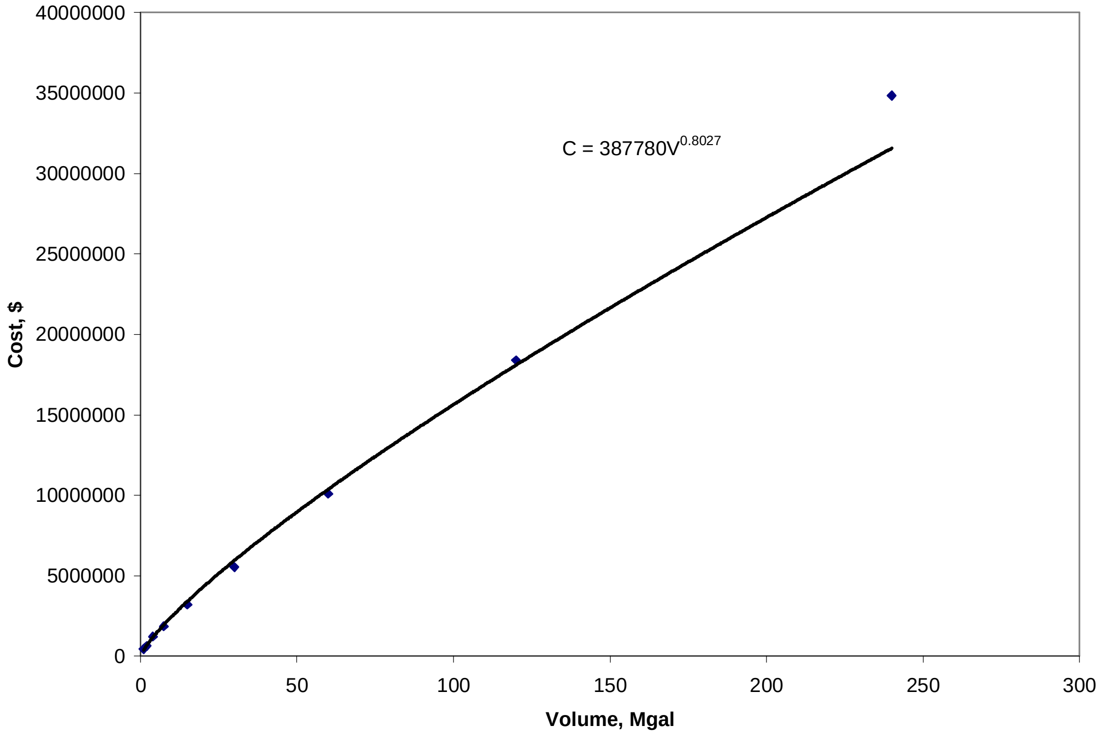


Figure 8. Construction Cost for Concrete Reservoir, 30 Mgal ≤ V ≤ 600 Mgal

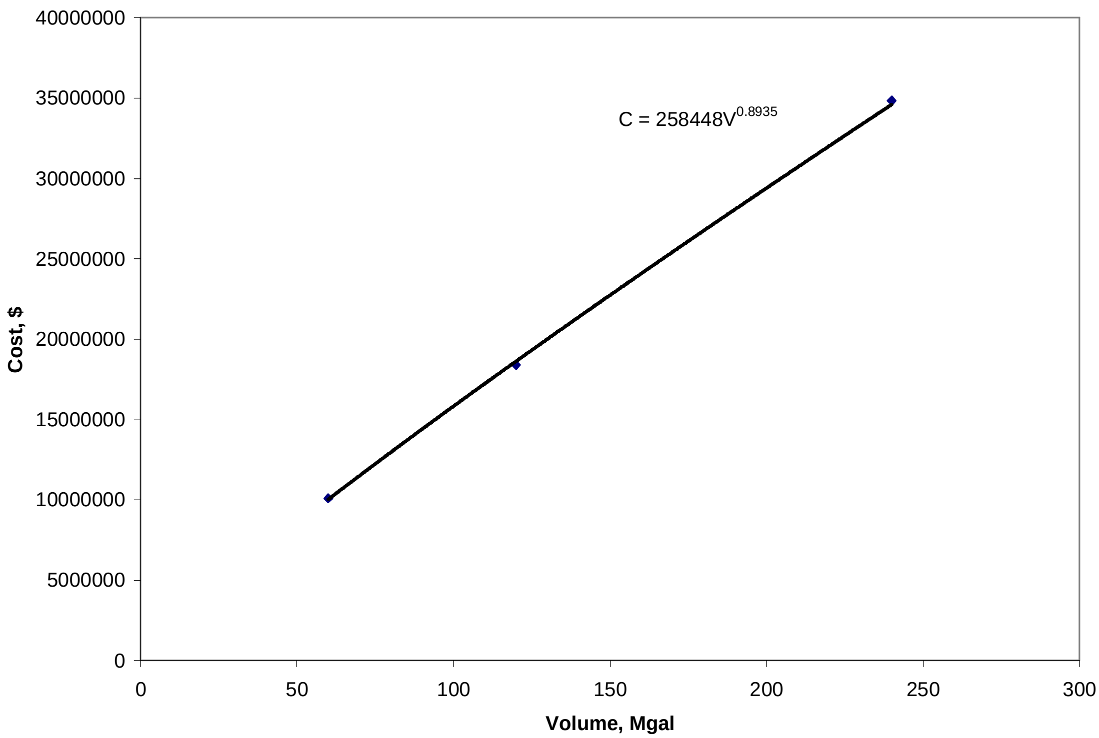


Figure 9. Construction Cost for Concrete Reservoir, 60 Mgal ≤ V ≤ 240 Mgal

A power function using the data presented in Table 16 (USEPA, 1978) data gives the equations 2.35, 2.36 and 2.37 for construction costs of concrete reservoirs without cover of different volume ranges.

For $1 \leq V \leq 30$ Mgal

(2.35) $$C = 412257V^{0.7582}$$

For $30 < V < 60$ Mgal

(2.36) $$C = 387780V^{0.8027}$$

For $60 \leq V \leq 240$ Mgal

(2.37) $$C = 258448V^{0.8935}$$

where

C = construction cost, $, 1975 costs, and
V = volume, Mgal

2.4.3 Deep Tunnels

Because of space limitations for near-surface storage in urban areas, deep tunnels can be bored into bedrock to store combined sewage waters before transport to a treatment plant. Although they function similarly to surface storage units, little additional treatment is suitable in these devices, beyond a component of a storage-treatment system in conjunction with a conventional wastewater treatment system, or for hydrograph modifications. Sedimentation is not desirable due to the difficulty and high cost of cleaning these units. They are therefore usually constructed with self-cleaning flushing devices, or other methods to remove any settled debris. Since these are associated with combined sewer systems, the flushed material is usually treated at the wastewater treatment plant after the runoff event has ended, and not discharged untreated. If used in a separate stormwater system, the flushed material would also have to be flushed to a treatment facility, and not discharged to the receiving water.

US EPA (2002) relates the construction cost to volume of storage as:

(2.38) $$C = 6.22V^{0.795}$$

where

C = construction cost, millions, January 1999 costs, $, and
V = volume of storage system, Mgal

Figure 10 shows a comparison of the construction costs of deep tunnel storage with surface storage.

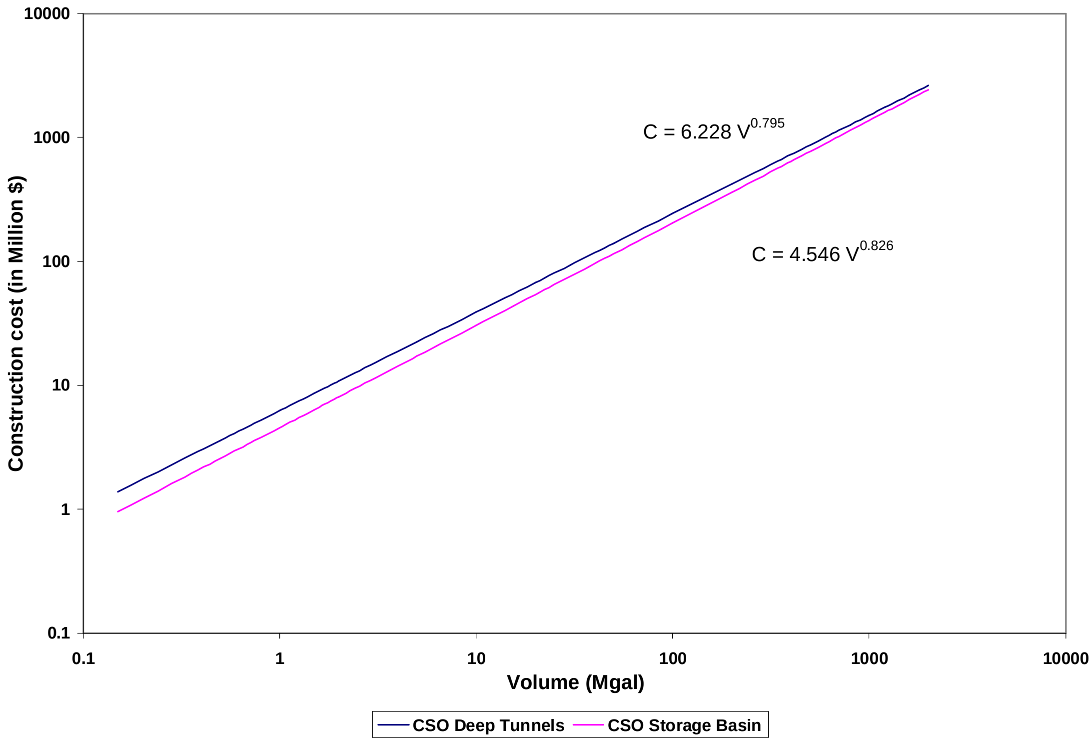


Figure 10. Comparison of Construction Costs of Deep Tunnel and Surface Storage

2.4.4 Swirl Concentrators, Screens, Sedimentation Basins and Disinfection

Swirl concentrators use centrifugal force and gravitational settling to remove heavier sediments and floatable material from combined sewer overflows. Similar devices have been used for the treatment of separate stormwater, although the settling and size characteristics of the pollutants of these two wastewaters can be vastly different. They are usually used in conjunction with storage facilities to treat relatively uniform flows. The best source of cost data for swirl concentrators, screens, sedimentation basins, and disinfection facilities is the US EPA (1976) which relates cost as a function of size or design flow.

For $3 \leq Q \leq 300$ MGD,

(2.39) $$C = 0.22Q^{0.611}$$

Coarse screens can also be used to remove large solids and floatables from wastewater discharges:

For $0.8 \leq Q \leq 200$ MGD,

(2.40) $$C = 0.09Q^{0.843}$$

Sedimentation basins allow physical settling prior to discharge. They can also have baffles to eliminate short circuiting of flows:

For $1 \leq Q \leq 500$ MGD,

(2.41) $$C = 0.218Q^{0.668}$$

Disinfection is used to kill pathogenic bacteria prior to CSO discharges:

For $1 \leq Q \leq 200$ MGD,

(2.42) $$C = 0.161Q^{0.464}$$

where

C = construction cost, millions, January 1999 cost, $, and

Q = design flow rate, MGD

These equations are plotted on Figure 11.

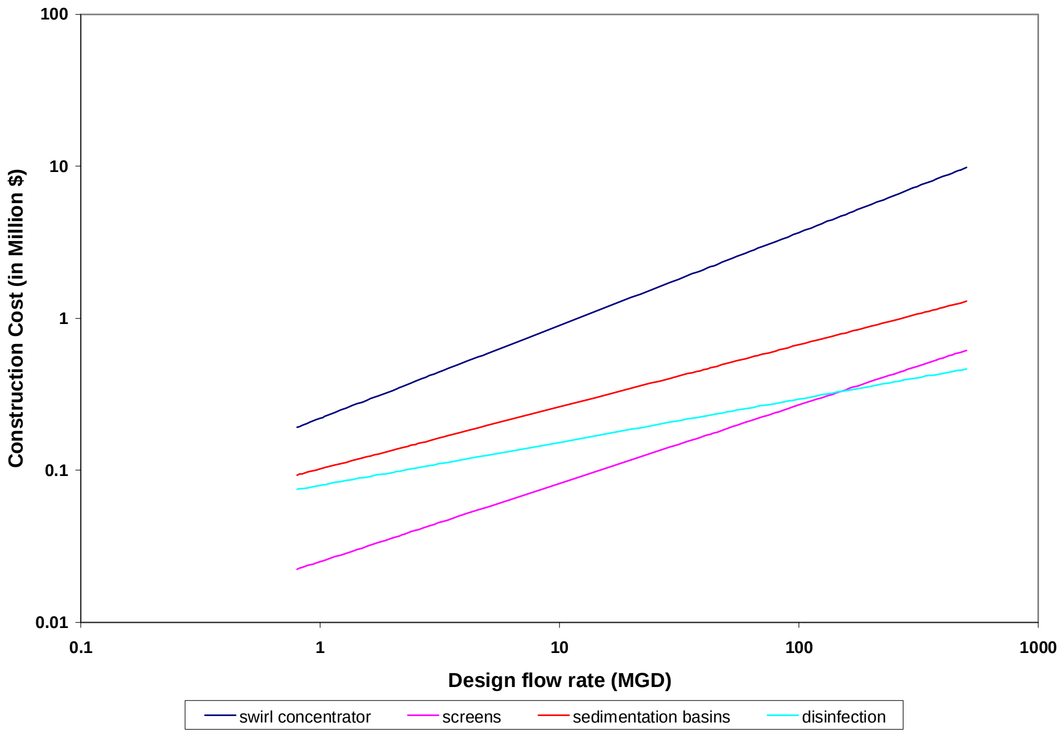


Figure 11. Construction Costs of Swirl Concentrators, Screens, Sedimentation Basins and Disinfection

2.5 Gross Solids Controls

The term “gross solids” include litter, vegetation, and other particles of relatively large size such as, manufactured items made from paper, plastic, cardboard, metal, glass, etc., that can be retained by a 5 mm mesh screen (Caltrans, 2003). The following costs are for initial purchase and installation only (operation and maintenance costs not included) of three types of gross solids removal devices (GSRD) designed for a pilot study done by CALTRANS (Phase I and Phase II), to evaluate their performance and implement them on highway drainage systems. Phase III – V consists of monitoring several variants of the existing GSRD designs, but the associated costs are unavailable.

The three design concepts developed in the Phase I pilot scale study were: Linear Radial, Inclined Screen and Baffle Box. There were two variants of the Linear Radial designs and three variants of the Inclined Screen. The Linear Radial - Configuration #1 uses a modular well casing with louvers to serve as a screen. The Linear Radial – Configuration #2 utilizes rigid mesh screen housing with nylon mesh bags that capture gross solids. The inclined screen – configuration #1 utilizes parabolic wedge-wire screens to separate gross solids. The Inclined Screen – Configuration #2 utilizes parabolic bars to screen out gross solids. The Baffle Box applies a two-chamber concept: the first chamber utilizes an underflow weir to trap floatable gross solids, while the second chamber uses a bar rack to capture solids that get past the underflow weir. The Phase II pilot project developed a modification of the Linear Radial – Configuration #1 by using a parabolic wedge wire screen to screen out gross solids. The device was designed so that it could be cleaned using front-end loader equipment.

Installation costs for these GSRDs are shown in the Table 18. They vary from site to site and also between GSRD types.

Table 18. GSRD Installation Costs (CALTRANS, 2003)

Design	Drainage Area (ac.)	Total Cost[a] ($)	Cost[b] ($)
Linear Radial #1	3.7	66,200	48,300
Linear Radial #2 (Site 1)	6.2	172,009	155,935
Linear Radial #2 (Site 2)	0.9	110,462	94,388
Inclined Screen #1	2.5	100,800	82,800
Inclined Screen #2 (Site 1)	3.4	150,425	134,351
Inclined Screen #2 (Site 2)	2.1	151,337	135,263
Baffle Box (Site 1)	3.0	129,422	113,348
Baffle Box (Site 2)	2.3	135,629	119,555
Inclined Screen #3	3.3	370,059	345,000

Note: a - Cost includes monitoring equipment, b - Cost not including monitoring equipment

Tables 19 and 20 give a brief description of some floatable and oil removal and solid removal stormwater controls, targeted pollutants for removal, and associated unit costs. This information was collected by the Water Resources Committee, American Public Works Association (APWA), Southern California Chapter, for the regional USEPA stormwater National Pollutant Discharge Elimination System permit program. The survey identified 50 stormwater controls that could be implemented for existing developed areas. To evaluate the costs, agencies throughout the nation were contacted to identify stormwater controls that have been implemented and to provide information concerning the evaluation process of the controls, implementation processes, siting issues, available pollutant removal effectiveness data, and construction and operation costs and issues.

Table 19. Cost of Floatable and Oil Removal Devices (APWA, 1992)

Type of Practice	Area of Benefit	Storm Protection Benefit	Targeted Pollutants	Construction Requirements	Capital Cost ($/ac)	O&M Cost ($/acre/yr)
Clarifiers and Oil and Water Separators on Parking Structures	Parking lot structure and receiving water	Collect debris before it can enter storm drain	Oil, grease, and anti-freeze from vehicles and foods and food wrappers	Install grit and oil separators	3000	2000 (Assumes 1 unit per 5 acres. Requires continuous maintenance to maintain effectiveness)
Oil and Grit Separators	Site dependent. For heavy traffic area or areas with high potential for oil spill	Remove pollutants	Sediments and hydrocarbons	Install grit and oil separators on storm drains	2000	2000
Sediment/Grease Trap	Installed on storm drain inlets	Intercept and trap sediment and grease from runoff	Sediment, oil, and grease	Install sediment and grease traps	3000	2000 (Assumes 1 unit per 5 acres. Requires continuous maintenance to maintain effectiveness)

Table 20. Costs of Solids Removal Practices (APWA, 1992)

Type of Practice	Area of Benefit	Storm Protection Benefit	Targeted Pollutants	Construction Requirements	Capital Cost ($/Mgal)	O&M Cost ($/Mgal/year)
Bar Screens	Site dependent	Restrict passage of objects which may obstruct pump station suction bays.	Large debris	Install bar screens before pump station suction bays.	4,000	1,000
Swirl Concentrators and Chlorination /Dechlorination	Site and need dependent	Treats stormwater flows prior to discharge.	Floatables, settleable solids, suspended solids, and coliform bacteria.	Install swirl concentrators.	12,000	1,000
Primary Clarifiers	Site and need dependent	Treats stormwater flows prior to discharge.	Floatables, settleable solids, suspended solids, and coliform bacteria.	Install primary classifiers	50,000	1,000
Primary Clarifiers and Filters	Site and need dependent	Treats stormwater flows prior to discharge.	Suspended solids, nutrients and coliform bacteria	Construct sedimentation basins and filters	350,000	2,000
Primary Clarifiers and Lime Precipitation	Site and need dependent	Treats stormwater flows prior to discharge.	Floatables, settleable solids, suspended solids, and coliform bacteria.	Install primary classifiers and lime precipitation facilities.	1,150,000	70,000

2.6 Outfall Stormwater Controls

Outfall stormwater controls are located at outfalls from developed areas and treat all flows coming from the area before discharge to the receiving water. They may have bypasses or overflows so excessive flows can be routed around the devices without damage, but with resulting reduced removal rates.

2.6.1 Wet Detention Ponds and Wetlands

Wet detention ponds are one of the most effective methods of removing pollutant loadings from stormwater. If designed properly and in conjunction with a hydrologic basin analysis, they are also suitable for attenuating peak runoff flows. When properly sized and maintained, they can achieve high rates of removal of sediment and particulate-bound pollutants.

Cost information on wet detention ponds is available from Young, *et al*. (1996) who presents cost as a function of storage volume:

(2.43) $$C = 61{,}000V^{0.75}$$

The cost of dry detention ponds is also a function of volume, according to Young, *et al.* (1996), and is represented as:

(2.44) $$C = 55{,}000V^{0.69}$$

where

C = construction cost, $, and

V = volume of pond, Mgal

The land cost is not included in these equations.

Wiegand, *et al*. (1985) also presented equations for the construction costs of wet ponds as,

(2.45) $$C = 33.99Vs^{0.644}\text{, Vs > 100,000 cf}$$

Wiegand, *et al*. (1985) presents construction costs for dry ponds as,

(2.46) $$C = 10.71Vs^{0.694}\text{, Vs > 10,000 cf}$$

where

C = construction cost, $, and

V_s = storage volume, cf

The storage volume for wet ponds is defined here as the volume of the pond to the top of the emergency spillway, plus the permanent pool volume. However, for flow analyses, the storage volume would not include the permanent pool volume. For dry ponds, the storage volume is the total volume below the emergency spillway. The components for these construction costs are earth-work (cut and fill, clear and grub), inlet/outlet works, riprap, aggregate, plus sediment and erosion control.

The Metropolitan Washington Council of Governments (1996) developed an equation for determining the cost of a pond based on volume, in 1985 dollars. The land costs are also not included in this formula:

(2.47) $$C = 6.1\left(\frac{V}{0.02832}\right)^{0.75}$$

where

C = construction cost in 1985 $, and

V = volume of storage of the pond up to the crest of the emergency spillway, including the permanent pool, m^3

Wet detention ponds also provide waterfowl and wildlife habitat, provisions for non-contact recreational opportunities, landscape and aesthetic amenities. They also provide streambank erosion control benefits, if properly designed. In Figure 12, “retention” ponds are wet-detention ponds, while “detention” ponds are dry-detention ponds. Dry ponds, which empty between most rains, are not as effective in removing pollutants as wet ponds due to lack of scour protection. Basic wetland costs would be similar to wet-detention pond costs, but with substantial additional costs associated with acquiring and planting the wetland plants.

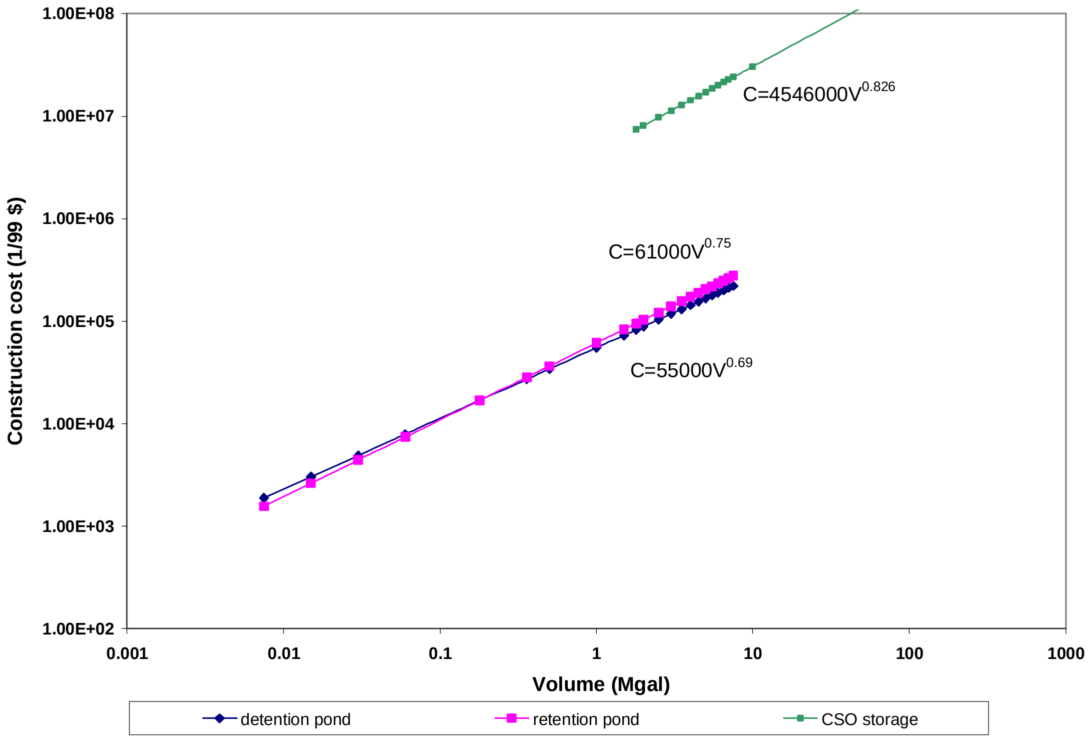


Figure 12. Comparison of Construction Costs of Detention, Retention and CSO Storage

Table 21 presents a summary of the reported costs of wet detention ponds. The estimated capital cost of a 0.25 acre wet detention pond is shown in Table 22, excluding land costs. This includes mobilization and demobilization costs of heavy equipment, site preparation, site development and contingencies. Tables 23, 24, 25 show the estimated capital costs of 1, 3 and 5 acre wet detention ponds, respectively.

Table 21. Summary of Reported Costs (January, 1989 $) of Wet Detention Ponds (SEWRPC, 1991)

Description	Capital Cost	Annual Operation and Maintenance Cost	Comments	Location	Reference
Pond with a 20-Acre Drainage Area	Construction Cost: 85 $V^{0.483}$ V = basin volume (cf)	$1870/pond	Excludes planning, design, administration and contingencies	Montgomery County, Maryland	Metropolitan Washington Council of Governments, March 1983
Pond Capacity: 1000 to 1.0 Million cf	Capital Cost: $107.4V^{0.51}$ V = pond volume (cf)	--	Includes planning, design, administration and contingencies	Washington, D.C., area	Metropolitan Washington Council of Governments, March 1983
Pond Size: a) 2700 gallons/acre b) 13600 gallons/acre c) 27200 gallons/acre d) 40700 gallons/acre e) 136000 gallons/acre	a) $311/acre served b) $1038/acre served c) $1470/acre served d) 2076/acre served e) $6228/acre served	a) $61/acre served b) $52/acre served c) $52/acre served d) $52/acre served e) $43/acre served	Valid for basins serving ≤ 50 acres	General	SEWRPC Technical Report No. 18, July 1977
Pond Size: a) 6 acres b) 8.5 acres c) 10 acres d) 11.5 acres	a) $1,231,163/pond b) $1,281,757- 2,151,978/pond c)$7207230/pond d) $1204538/pond	a) $5,521/pond b) $2,096- 3,064/pond c) $2,290/pond d) $10,288/pond	All drainage area ≤50 percent impervious. Ponds a), b), c) include discharge pump and canal. Design d) percolates discharge.	Fresno, California	Midwest Research Institute, March 1982

Table 21 – Continued.

Description	Capital Cost	Annual Operation and Maintenance Cost	Comments	Location	Reference
Pond Capacity of 6.5 acre-feet	$81,243/pond	$2,020/pond	--	Tri-County Michigan	Midwest Research Institute, March 1982
0.8-acre Pond Serving a 160-acre Drainage Area	$53,068/pond	$722/pond	Includes construction, materials, land, soil testing, and other indirect costs. Operation and maintenance cost includes labor, equipment and disposal costs.	Salt Lake County, Utah	Midwest Research Institute, March 1982
1000 to 1 Million cubic feet Pond Serving a Drainage Area of 20 to 1000 acres	Capital Cost: $108.36V^{0.51}$ V=pond volume (cf)	Operation and maintenance cost is 5 percent of capital cost	--	Washington, D.C., area	USEPA, Dec 1983
Pond Volumes V < 100000 cubic feet	Capital Cost: $6.1V^{0.75}$ V=pond volume (cf)	--	Excludes engineering, administration and contingencies.	Washington, D.C., area	T.R.Schueler, July 1987

Table 21 – Continued.

Description	Capital Cost	Annual Operation and Maintenance Cost	Comments	Location	Reference
Pond volumes $V \geq 100,000$ cf	Capital Cost: $34V^{0.64}$ V=pond volume (cf)	--	Capital cost excludes engineering, administration, land acquisition and contingencies	Washington, D.C., area	T.R.Schueler July 1987
Series of nine interconnected ponds	$51,900/pond	--	25 percent of capital cost includes grading, drainage and paving	Southern California	Robert Pitt, April 1987
Pond volume: a) 1 acre-foot b) 3 acre-foot c) 5 acre-foot d) 10 acre-foot e) 20 acre-foot	a) $19,504-45 580/pond b) $62,540-60,377/pond c) $94,022/pond d) $146,492/pond e) $227,900/pond	--	Capital cost excludes land acquisition, engineering, administration and contingencies	Southeastern Wisconsin	SEWRPC Community Assistance Planning Report No. 173, March 1989

Table 22. Estimated Capital Cost of a 0.25-acre Wet Detention Pond (SEWRPC, 1991)

Component	Unit	Extent	Unit Cost ($)			Total cost ($)		
			Low	Moderate	High	Low	Moderate	High
Mobilization-Demobilization-Heavy	Pond	1	390	1,000	1,610	390	1,000	1,610
Site preparation								
Clearing	Acre	0.50	2200	3,800	5,400	1,100	1,900	2,700
Grubbing	Acre	0.13	3800	5200	6600	494	676	858
General Excavation	Cubic yard	908	2.1	3.7	5.3	1,907	3,360	4,812
Place and Compact Fill	Cubic yard	608	0.6	1.1	1.6	365	669	973
Site development								
Salvaged topsoil, Seed and mulch	Square yard	1,089	0.4	1	1.6	436	1,089	1,742
Sod	Square yard	121	1.2	2.4	3.6	145	290	436
Riprap	Cubic yard	16	16.4	29.6	42.8	262	474	685
Pond inlet	Pond	1	2,620	5,740	8,860	2,620	5,740	8,860
Pond outlet	Pond	1	2,640	6,760	10,880	2,640	6,760	10,880
Landscape, fence, etc	Acre	0.25	1,000	2,000	3,000	250	500	750
Subtotal	--	--	--	--	--	10,609	22,459	34,306
Contingencies, Engineering, Legal Fees, and Administration	Pond	1	25 percent	25 percent	25 percent	2,652	5,610	8,577
Total	--	--	--	--	--	13,261	28,069	42,883

Table 23. Estimated Capital Cost of a 1-acre Wet Detention Pond (SEWRPC, 1991)

Component	Unit	Extent	Unit Cost ($)			Total Cost ($)		
			Low	Moderate	High	Low	Moderate	High
Mobilization-demobilization-heavy	Pond	1	390	1,000	1,610	390	1,000	1,610
Site preparation								
Clearing	Acre	2	2,200	3,800	5,400	4,400	7,600	10,800
Grubbing	Acre	0.5	3,726	5,175	8,901	1,863	2,588	3,300
General excavation	Cubic yard	5,771	2.1	3.7	5.3	11,699	20,613	29,526
Place and compact fill	Cubic yard	3,867	0.6	1.1	1.6	2,320	4,254	6,187
Site development								
Salvaged topsoil, Seed and mulch	Square yard	4,356	0.40	1.00	1.60	1,742	4,356	6,970
Sod	Square yard	424	1.20	2.40	3.60	581	1,162	1,742
Riprap	Cubic yard	48	16.40	29.60	42.80	787	1,421	2,054
Pond inlet	Pond	1	2,620	5,740	8,860	2,620	5,740	8,860
Pond outlet	Pond	1	2,640	6,760	10,880	2,640	6,760	10,880
Landscape, fence, etc	Acre	1	1,000	2,000	3,000	250	2,000	3,000
Subtotal	--	--	--	--	--	30,079	57,506	84,929
Contingencies, engineering, legal fees, and administration	Pond	1	25 percent	25 percent	25 percent	7,520	14,377	21,232
Total	--	--	--	--	--	37,599	71,883	106,161

Table 24. Estimated Capital Cost of a 3-acre Wet Detention Pond (SEWRPC, 1991)

Component	Unit	Extent	Unit Cost ($)			Total Cost ($)		
			Low	Moderate	High	Low	Moderate	High
Mobilization-demobilization-heavy	Pond	1	390	1,000	1,610	390	1,000	1,610
Site preparation								
Clearing	Acre	6	2,200	3,800	5,400	13,200	22,800	32,400
Grubbing	Acre	1.5	3,800	5,200	8,901	5,700	7,800	9,900
General excavation	Cubic yard	21,260	2.10	3.70	5.30	44,646	78,662	112,678
Place and compact fill	Cubic yard	14,244	0.60	1.10	1.60	8,546	15,668	22,790
Site development								
Salvaged topsoil, Seed and mulch	Square yard	13,068	0.40	1.00	1.60	5,227	13,068	20,909
Sod	Square yard	1,452	1.20	2.40	3.60	1,742	3,485	5,227
Riprap	Cubic yard	145	16.40	29.60	42.80	2,378	4,292	6,206
Pond inlet	Pond	1	2,620	5,740	8,860	2,620	5,740	8,860
Pond outlet	Pond	1	2,640	6,760	10,880	2,640	6,760	10,880
Landscape, fence, etc	Acre	3	1,000	2,000	3,000	3,000	6,000	9,000
Subtotal	--	--	--	--	--	90,089	165,275	240,460
Contingencies, engineering, legal fees, and administration	Pond	1	25 percent	25 percent	25 percent	22,522	41,319	60,115
Total	--	--	--	--	--	112,611	206,594	300,575

Table 25. Estimated Capital Cost of a 5-acre Wet Detention Pond (SEWRPC, 1991)

Component	Unit	Extent	Unit cost ($)			Total Cost ($)		
			Low	Moderate	High	Low	Moderate	High
Mobilization-demobilization-heavy	Pond	1	390	1,000	1,610	390	1,000	1,610
Site preparation								
Clearing	Acre	10	2,200	3,800	5400	22,000	38,000	54,000
Grubbing	Acre	2.5	3,800	5,200	6600	9,500	13,000	16,500
General excavation	Cubic yard	37,013	2.10	3.70	5.30	77,727	136,948	196,196
Place and compact fill	Cubic yard	24,799	0.60	1.10	1.60	14,879	27,279	39,678
Site development								
Salvaged topsoil, Seed and mulch	Square yard	21,780	0.40	1.00	1.60	8,712	21,780	34,848
Sod	Square yard	2,420	1.20	2.40	3.60	2,904	5,808	8,712
Riprap	Cubic yard	242	16.48	29.60	42.80	3,969	7,163	10,358
Pond inlet	Pond	1	2,620	5,740	8,860	2,620	5,740	8,860
Pond outlet	Pond	1	2,640	6,760	10,880	2,640	6,760	10,880
Landscape, fence, etc	Acre	5	1,000	2,000	3,000	5,000	10,000	15,000
Subtotal	--	--	--	--	--	150,341	273,478	396,642
Contingencies, Engineering, Legal fees, and Administration	Pond	1	25 percent	25 percent	25 percent	37,585	68,370	99,161
Total	--	--	--	--	--	187,926	341,848	495,803

The total capital costs (1989 dollars) and the total annual operation and maintenance costs are summarized in Table 26.

Table 26. Summary of Capital Costs for Wet Detention Pond (SEWRPC, 1991)

Water Surface Area (ac.)	Water Volume (cf.)	Capital Cost ($)			Annual Operation and Maintenance ($)
		Low	Moderate	High	
0.25	23,290.2	13,261	28,069	42,883	1,313
1.0	148,026.2	37,599	71,883	106,161	2,417
3.0	545,319.0	112,611	206,594	300,575	5,542
5.0	949,383.5	187,926	341,848	495,803	8,671

Figure 13 is a graphical representation of this data showing the total capital and total annual operation and maintenance cost (1989 dollars) for different pond water storage volumes in cubic feet.

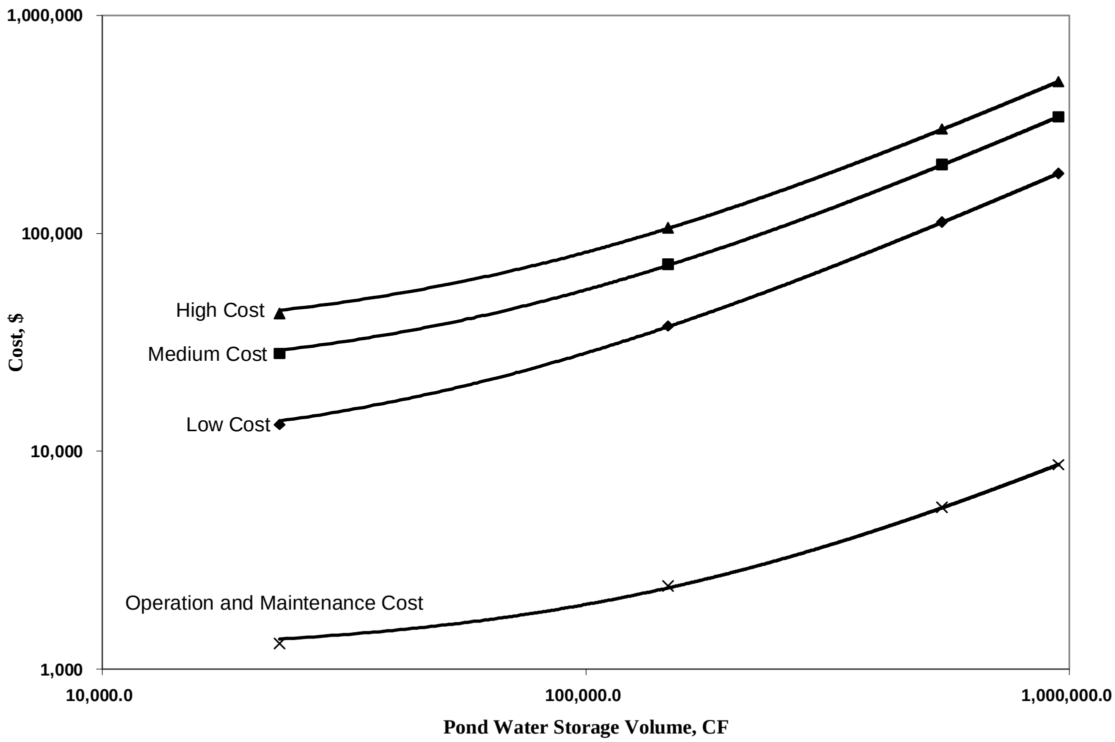


Figure 13. Cost of Wet Detention Pond for Different Water Storage Volumes

Linear-regression equations fitted to the data in Table 26 (SEWRPC, 1991) results in the total capital cost and the total annual operation and maintenance cost of wet detention ponds for different water storage volumes:

For low cost:

(2.48) $$C = 0.1884V + 9376.1$$

For moderate cost:

(2.49) $$C = 0.3384V + 21139$$

For high cost:

(2.50) $$C = 0.3384V + 32897$$

For total operation and maintenance cost:

(2.51) $$C = 0.0079V + 1192.2$$

where

C = Cost, $ and

V = Pond water storage volume, cf.

These equations were then included in the WinSLAMM model to enable it to automatically estimate the cost of wet detention ponds. This was achieved by adjusting the 1989 Wisconsin costs for wet detention ponds to 2005 costs using ENR construction cost indices. The average cost index of Chicago and Detroit was considered to adjust the Wisconsin (Milwaukee region) costs to the national average and also to adjust it for other cities listed by the ENR. Figure 14 shows the control practice cost selection screen for detention ponds in WinSLAMM.

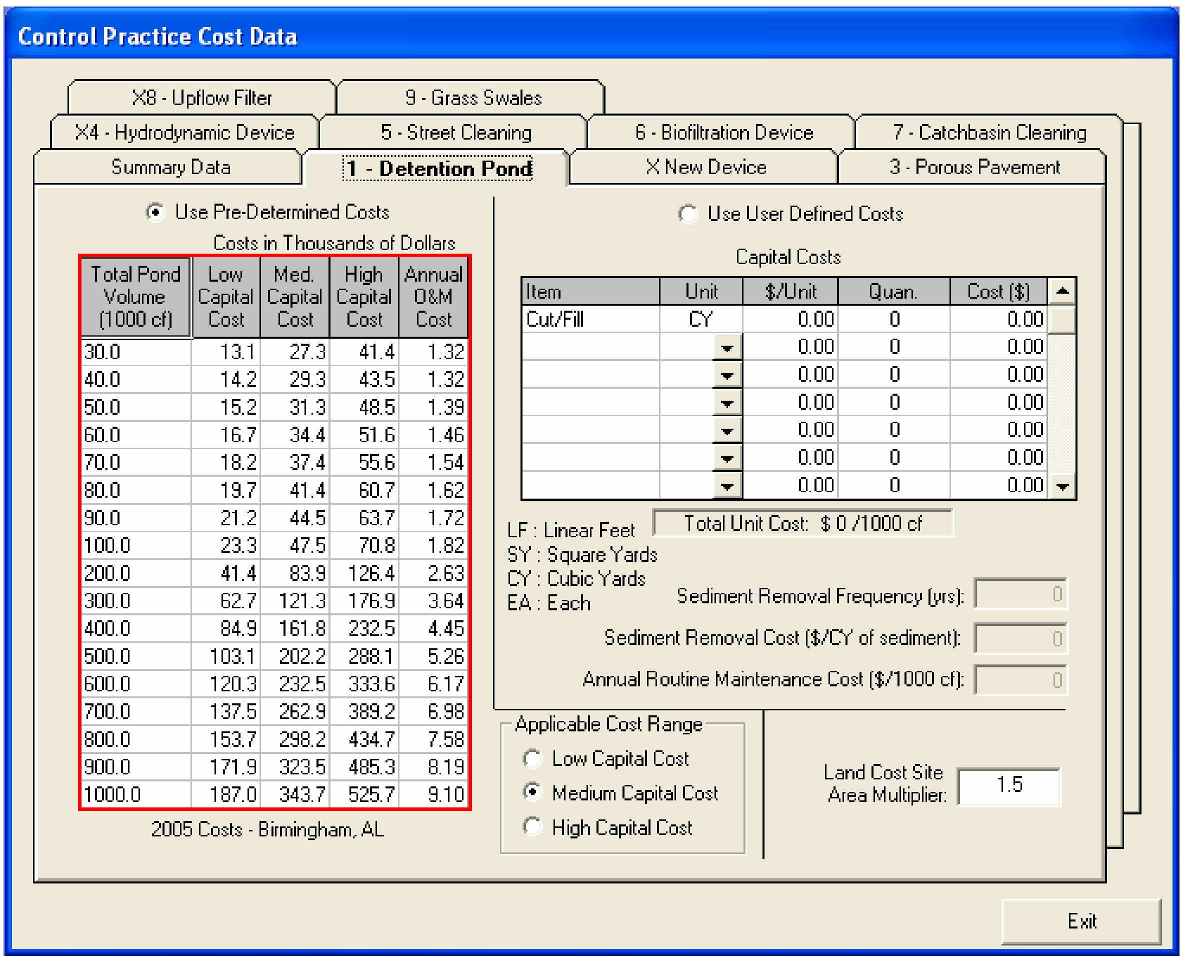


Figure 14. Detention Pond Cost Selection and Input Screen in WinSLAMM

CALTRANS retrofitted extended detention ponds at five locations (different watershed areas and pond design parameters) into existing highway locations and related infrastructure. All sites were located on the highway right-of-way and collected runoff from the highway. The summary of the contributing watersheds and the design characteristics of the detention ponds are given in Tables 27 and 28 and their construction costs in Table 29.

Table 27. Summary of Contributing Watershed Characteristics for CALTRANS Detention Ponds Retrofitted Locations (CALTRANS, 2001)

Site Location	Land Use	Watershed Area (hectare, acre)	Impervious Cover (%)
I-5/I-605	Highway	2.75 (6.8)	54
I-605/SR-91	Highway	0.40 (0.8)	100
I-5/SR-56	Highway	2.14 (5.3)	69
I-15/SR-78	Highway	5.42 (13.4)	21
I-5/Manchester	Highway	1.94 (4.8)	56

Table 28. Design Characteristics of CALTRANS Extended Detention Ponds (CALTRANS, 2001)

Site Location	Type	Water Quality Design Storm Depth (cm., in.)	Water Quality Volume (m^3)	Design Storm Water Depth in pond (m.)	Max. Water Depth Capacity of Pond (m.)	Pond Material	Length to Width ratio
I-5/I-605	Off-line	2.54 (1)	365	0.6	1.36	Concrete	4.5:1
I-605/SR-91	On-line	2.54 (1)	70	0.6	1.17	Earthen	9:1
I-5/SR-56	On-line	3.3 (1.3)	391	0.5	1.1	Earthen	6:1
I-15/SR-78	On-line	4.83 (1.89)	1123	1.15	2.5	Earthen	10:1
I-5/Manchester	Off-line	3.3 91.3)	253	0.83	1.22	Earthen	3:1

Table 29. Construction Costs of Wet Detention Ponds (CALTRANS, 2001)

Site Location	Actual Cost ($)	Actual Cost w/o monitoring ($)	Cost/WQV ($/cf)
I-5/I-605	169,732	127,202	9.88
I-605/SR-91	111,871	77,389	31.48
I-5/SR-56	161,853	143,555	10.41
I-15/SR-78	847,712	819,852	20.68
I-5/Manchester	370,408	329,833	36.95

Note: Water Quality Volume (WQV) = Water Quality Storm Depth * Tributary Area * Rv_{ave}

When the Water Quality Storm Depth already accounts for the Weighted Runoff Coefficient (Rv), the equation becomes WQV = (factored Water Quality Storm Depth) * Tributary Area.

where

Rv_{avg} = weighted runoff coefficient calculated using the following equation

$$Rv = \frac{\sum A_i Rv_i}{\sum A_i} \quad (2.52)$$

where

A_i = fraction of drainage area with runoff coefficient Rv_i, and

Rv_i = runoff vulume coefficient (runoff depth/rainfall depth) in area A_i (http://www.dot.ca.gov/hq/oppd/stormwtr/treatment/Handouts.doc)

The distribution of the component capital costs is largely a function of the pond area. The operation and maintenance costs of wet detention ponds range from $1300 for a 0.25 acre pond to nearly $8700 for a 5 acre pond. Routine and periodic maintenance of wet detention ponds include lawn and other landscape care, pond inspection, debris and litter removal, erosion control and nuisance control, inlet and outlet repairs and sediment removal. Table 30 presents the average annual operation and maintenance costs of wet detention ponds and Table 31 presents the costs involved for chemical treatment using alum or ferric chloride injection.

Table 30. Average Annual Operation and Maintenance Costs of Wet Detention Ponds (SEWRPC, 1991)

Component	Unit Cost	Pond Surface (ac.)				Comment
		0.25	1	3	5	
Lawn Mowing	0.85/1000 square feet	$74	$296	$889	$1,481	Maintenance area equals area cleared minus pond area. Mowed 8 times per year
General Lawn Care	$9/1000 square feet/year	$98	$392	$1,176	$1,960	Maintenance area equals area cleared minus pond area
Pond Inlet Maintenance	3 percent of capital cost in inlet	$172	$172	$172	$172	--
Pond Outlet Maintenance	5 percent of capital cost in outlet	$338	$338	$338	$338	--
Pond Sediment Removal	1 percent of capital cost	$281	$719	$2,067	$3,421	--
Debris and Litter Removal	$100/yr	$100	$100	$100	$100	--
Pond Nuisance Control	--	$50	$200	$600	$1,000	--
Program Administration and Inspection	$50/pond/yr, plus $25/inspection	$200	$200	$200	$200	Ponds inspected six times per year
Total Annual Operation and Maintenance	--	$1,313	$2,417	$5,542	$8,671	--

Table 31. Chemical Treatment, Alum or Ferric Chloride Injection (Peluso *et al*., 2002)

	Installation or Construction Cost	Operation, Inspection and Maintenance Costs	Maintenance Issues and Concerns
Chemical Treatment	For an alum treatment facility, with an average cost of $245,000 per system serving a drainage area of less than 310 acres, the average initial cost is $790 per acre treated	Annual operation and maintenance cost is $100 per acre of drainage area served.	• Maintenance is high as chemicals are continuously added and the waste precipitate is removed for disposal. • Accumulated floc must be pumped out of sump area on a periodic basis and disposed.

2.6.2 Infiltration Ponds

Infiltration ponds are similar to wet detention ponds. They perform similar to infiltration trenches in removing waterborne pollutants by capturing surface runoff and filtering it through the soil. An infiltration pond usually does not have an outlet other than an emergency spillway to pass excess runoff. Table 32 presents a summary of construction costs of infiltration ponds. Tables 33 and 34 present selected unit costs, the calculated component costs, and total capital costs for a 0.25 and 1.0 acre infiltration ponds, both 3 feet deep. The cost of underground drainage systems is not included because such systems are required only when the soil has marginal permeability. In such cases, it is preferable to use a wet pond.

Periodic maintenance includes annual inspections and periodic inspections after large storms, mowing pond side slopes and bottom areas, debris and liter removal, erosion control, odor control, and management of mosquitoes (Table 35). Deep tilling may be needed every 5 years to break up clogged layers. Tilling is then followed by grading, leveling and revegetating the surface.

Table 32. Equations for Estimating Costs of Infiltration Pond (SEWRPC, 1991)

Capital Cost ($)	Annual Operation and Maintenance Cost ($)	Location	Reference
Construction Cost = 4.16 $V^{0.75}$ V = pond volume (cubic feet)	5 to 20 percent of pond cost construction, 4-9 percent of pond capital cost	Washington D.C Metropolitan area	Wiegand, *et al.*, June 1986
Construction Cost = 73.52 $V^{0.51}$ V = pond volume (cubic feet)	3 to 5 percent of pond construction cost, 2-4 percent of pond capital cost	Washington D.C Metropolitan area	T.R.Schueler, *et al.*, April 1985
Construction Cost = 14.63 $V^{0.69}$ V = pond volume (cubic feet)	3-5 percent of pond construction cost, 2-4 percent of pond capital cost	Washington D.C Metropolitan area	T.R.Schueler, *et al.*, April 1987
Construction Cost = 1.18 V V = pond volume (cubic feet)	$0.15/cubic foot, or 13 percent of capital cost	City of Oconomowoc Wisconsin	Donohue & Associates, Inc, April 1989

Table 33. Estimated Capital Cost of a 0.25-acre Infiltration Pond (SEWRPC, 1991)

Component	Unit	Extent	Unit Cost ($)			Total Cost ($)		
			Low	Moderate	High	Low	Moderate	High
Mobilization-Demobilization-heavy	Pond	1	390	1,000	1,610	390	1,000	1,610
Site preparation								
Clearing	Acre	0.5	2,200	3,800	5,400	1,100	1,900	2,700
Grubbing	Acre	0.13	3,800	5,200	6,600	494	676	878
General Excavation	Cubic yard	834	2.10	3.70	5.30	1,751	3,086	4,420
Place and Compact Fill	Cubic yard	559	0.60	1.10	1.60	335	615	894
Level and Till	Square yard	1076	0.20	0.35	0.50	215	377	538
Site Development								
Salvaged Topsoil, Seed and Mulch	Square yard	1,210	0.40	1.00	1.60	484	1,210	1,936
Sod	Square yard	1,210	1.20	2.40	3.60	1,452	2,904	4,356
Riprap	Cubic yard	10	16.40	29.60	42.80	164	296	428
Pond Inlet	Each	1	2,620	5,740	8,860	2,620	5,740	8,860
Landscape, Fence, etc	Acre	0.5	1,000	2,000	3,000	500	1,000	1,500
Subtotal	--	--	--	--	--	9,505	18,804	28,100
Contingencies	Pond	1	25 percent	25 percent	25 percent	2,376	4,701	7,025
Total	--	--	--	--	--	11,881	23,505	35,125

Table 34. Estimated Capital Cost of a 1.0-acre Infiltration Pond (SEWRPC, 1991)

Component	Unit	Extent	Unit Cost ($)			Total Cost ($)		
			Low	Moderate	High	Low	Moderate	High
Mobilization-Demobilization-heavy	Pond	1	390	1,000	1,610	390	1,000	1,610
Site preparation								
Clearing	Acre	2.00	2,200	3,800	5,400	4,400	7,600	10,800
Grubbing	Acre	0.50	3,800	5,200	6,600	1,900	2,600	3,300
General Excavation	Cubic yard	4,240	2.10	3.70	5.30	8,904	15,688	22,472
Place and Compact Fill	Cubic yard	2,841	0.60	1.10	1.60	1,705	3,125	4,546
Level and Till	Square yard	4,570	0.20	0.35	0.50	917	1,600	2,285
Site Development								
Salvaged Topsoil, Seed and Mulch	Square yard	4,840	0.40	1.00	1.60	1,936	4,840	7,744
Sod	Square yard	4,840	1.20	2.40	3.60	5,808	11,616	17,424
Riprap	Cubic yard	10	16.40	29.60	42.80	164	296	428
Pond Inlet	Each	1	2,620	5,740	8,860	2,620	5,740	8,860
Landscape, Fence, etc	Acre	2.0	1,000	2,000	3,000	2,000	4,000	6,000
Subtotal	--	--	--	--	--	30,741	58,105	85,469
Contingencies	Pond	1	25 percent	25 percent	25 percent	7,685	14,526	21,367
Total	--	--	--	--	--	38,426	71,631	106,836

Table 35. Average Annual Operation and Maintenance Costs of Infiltration Ponds (SEWRPC, 1991)

Component	Unit Cost	Pond Top Surface Area (ac.)		Comment
		0.25	1	
Lawn Mowing	0.85/1000 square feet	$148	$592	Maintenance area equals two times pond area. Mow 8 times per year
General Lawn Care	$9/1000 square feet/year	$196	$784	Maintenance area equals two times pond area
Pond Inlet Maintenance	3 percent of capital cost in inlet	$172	$172	--
Soil Leveling and Tilling	$0.35/square yard	$38	$160	Pond bottom area leveled and tilled at 10-yr intervals following sediment removal
Pond Sediment Removal	$421.1/pond bottom acre/year	$84	$379	--
Debris and Litter Removal	$100/yr	$100	$100	Area revegetated equals pond bottom area at 10-yr intervals
Grass Reseeding with Mulch and Fertilizer	$0.3/square yard	$29	$131	--
Program Administration and Inspection	$50/pond/yr, plus $25/inspection	$150	$150	Ponds inspected four times per year
Total Annual Operation and Maintenance	--	$917	$2,468	--

2.7 Public Works Practices

2.7.1 Street Cleaning

Most street cleaning programs are intended to improve aesthetics and prevent clogging of inlets and storm drainage systems. Street cleaning is a relatively labor-intensive operation that uses expensive equipment that has high maintenance costs and also requires a large investment for disposal facilities, and maintenance facilities. The reported costs of street cleaners are presented in Table 36. The unit costs for street cleaning programs (including capital, operation, and maintenance costs) are summarized in Table 37.

Table 36. Reported Costs of Street Cleaners (SEWRPC, 1991)

Street Cleaner Type	Manufacturer and Model	Capital Cost ($)	Reference
Mechanical Street Sweeper	Elgin Pelican	65,000-75,000	Bruce Municipal Equipment, Inc Menomonee Falls, Wisconsin
	EMC Vangaurd 4000		Bark River Culvert & Equipment Company, Milwaukee, Wisconsin
	Single broom	89,225	
	Double broom	93,550	
Vacuum Street Cleaner	Elgin Whirlwind	120,000	Bruce Municipal Equipment, Inc Menomonee Falls, Wisconsin
	VAC/ALL Model E-10		Bark River Culvert & Equipment Company, Milwaukee, Wisconsin
	Single broom	61,467	
	Double broom	73,467	
Regenerative Air Street Cleaner	Elgin Crosswind	110,000	Bruce Municipal Equipment, Inc Menomonee Falls, Wisconsin
	FMC Vangaurd 3000SP		Bark River Culvert & Equipment Company, Milwaukee, Wisconsin
	Single broom	73,165	
	Double broom	77,700	
	TYMCO Model 600	87,000	Illinois Truck Equipment Appleton, Wisconsin

Table 37. Reported Unit Costs for Street Cleaning Programs (SEWRPC, 1991)

Cost Factor	Nationwide Urban Runoff Program Studies						
	Milwaukee, Wisconsin	Winston-Salem, Forsyth County, North Carolina	San Francisco Bay area, California	Champaign, Illinois	San Jose, California (Pitt, 1979)	City of Milwaukee (1988)	Mean of all studies
$/ pound of solids collected	NA	0.17-0.93	0.12-0.34	NA	0.05-0.32	NA	0.32
$/cubic yard of solids collected	NA	NA	NA	NA	40	13.4	26.7
$/curb-mile swept	25	17.9	12.9-19.4	14.3-18	27.2	25	21.2
$/hour of sweeping operation	36	21.8-46.6	NA	NA	29.7	NA	33.3

Note: NA – Not Available

2.7.2 Catchbasin Cleaning

A catchbasin is a stormwater runoff inlet equipped with a small sedimentation basin or grit chamber with a capacity ranging from 0.5 to 1.5 cubic yards. Stormwater enters the catchbasin through the surface inlet and drops to the bottom where the largest and heaviest of the sediment and other pollutants carried by runoff are deposited and accumulated. The water then enters the subsurface conveyance system.

Catchbasins must be periodically cleaned to remove sediment and debris accumulated in the grit chamber. The catchbasins are cleaned manually using shovels, a clamshell bucket, vacuum educators, or vacuum attachments to street cleaners. Cleaning frequency is based on available manpower and equipment, and by the level needed to prevent clogging of stormwater sewers. Cleaning frequencies typically range from twice a year to every several years. Materials removed from catchbasins are normally deposited in landfills. Catchbasins can be difficult to clean in areas having traffic and parking congestion and cleaning is difficult if snow or ice is present.

Capital costs for material and labor to install catchbasins generally range from $200 to $4000 per catchbasin. In Castro Valley Creek, California, catchbasins were cleaned once a year and approximately 60 pounds were removed each time. The cost (1982 dollars) of cleaning catchbasins at three different locations is shown in Table 38.

Table 38. CALTRANS Catchbasin Cleaning Costs
(USEPA, 1999)

Location	Cost of cleaning ($ per catchbasin)
Castro Valley, California	7.7
Salt Lake County, Utah	10.3
Weston-Salem, North Carolina	6.3

The resulting cleaning cost at Castro Valley, California was about $0.13 per pound of solids removed. In the city of Wisconsin, Milwaukee, where the catchbasins were cleaned using attachments to a vacuum street cleaner, catchment cleaning costs were about $0.09 per pound of solids removed. Generally, about $8 was estimated for each catchbasin cleaning in communities that use a vacuum attachment to a vacuum street cleaner, compared to $15 for manual cleaning.

2.8 Critical Source Area Controls

Critical source area controls are used at locations where unusually high concentrations of stormwater pollutants originate. It is usually more effective to reduce the concentrations and resultant pollutant discharges at these locations than to allow the water to mix with other stormwaters, possibly requiring the treatment of much larger flows. These areas are usually located in commercial and industrial areas and include loading docks, storage areas, vehicle maintenance areas, public works yards, scrap yards, etc.

2.8.1 Hydrodynamic Separators

Hydrodynamic separators are flow-through structures with a settling or separation unit to remove gross pollutants, grit, and bed load sediments, and possibly other pollutants. No additional outside energy is required for operation. Separation usually depends on gravitational settling, possibly assisted by lamella plates or swirl action, and may also include coarse screens. These devices are available in a wide range of sizes and can be used in conjunction with other controls in the watershed to produce treatment trains. Four commonly used commercial hydrodynamic separators are the Continuous Deflector Separator**™** (CDS), the Downstream Defender**™**, the Stormceptor**™**, and the Vortechs**™** units, described in the following paragraphs. Table 39 shows the costs per unit and the O&M costs of these hydrodynamic separators.

2.8.1.1 Continuous Deflective Separator™ (CDS)

The CDS hydrodynamic separator is suitable for floatables and gross pollutant removal. The system utilizes a rotational action of the water to enhance gravitational separation of solids, plus a screen. Separated debris is captured by a litter sump located in the center of the unit. Flow rate capacities of CDS units vary from 3 to 300 cfs depending on the application and size of the unit. Precast modules are available for flows up to 62 cfs, while higher flows require cast-in-place construction. Polypropylene or copolymer sorbents can be added to the CDS unit separation chamber to assist in the capture of free floating oils.

2.8.1.2 Downstream Defender™

The Downstream Defender™ (Hydro International, Ltd.) is also used to capture floatables and gross settleable solids. The hydrodynamic force of the swirl action increases the gravitational separation of floatables, gross pollutants and grit from the stormwater. It uses a sloping base, a dip plate and internal components to assist in pollutant removal. The Downstream Defender™ comes in standard manhole sizes ranging from 4 to 10 feet in diameter for flows from 0.75 to 13 cfs. For larger flows, units can be custom designed up to 40 feet in diameter.

2.8.1.3 Stormceptor™

The Stormceptor**™** uses a deep settling chamber with a high flow by-pass to capture floatable materials, gross pollutants and settleable solids. They are available in prefabricated sizes up to 12 feet in diameter by 6 to 8 feet deep. The cost of the Stormceptor**™** is based on costs of the two system elements, the treatment chamber and by-pass insert, and the access way and fittings.

2.8.1.4 Vortechs™

Vortechs**™** (Vortechnics) removes floatable materials and settleable solids with a swirl-concentrator and flow-control system. It is constructed in precast concrete and consists of the following main components: baffle wall and oil chamber, circular grid chamber, and flow control chamber. Vortechnics manufactures nine standard-sized units that range from 9 feet by 3 feet to 18 feet by 12 feet.

Table 39. Costs of Hydrodynamic Separators (US EPA, 1999; Stormceptor, 1997)

Separator Type	Cost per unit	O & M Cost	Comments
Continuous Deflective Separators™ (CDS)	$2,300 to $7,200 per cfs capacity (including installation)	NA	• Maintenance of CDS is site-specific and requires that the unit be checked after every runoff for first 30 days after installation. • The system is inspected for the amount of sediment deposition using a ”dip stick.” • Monthly inspections are also recommended during the wet season. • Yearly inspection to examine for damage of the screen and to determine if the unit needs to be cleaned out.
Downstream Defender™	$10,000 to $35,000 per pre-cast unit (including installation)	NA	• Inspection every month for a period of one year of operation to determine rate of sediment and floatables accumulation. • Use of sump vac to remove captured floatables and solids.

Table 39 – Continued.

Separator Type	Cost per unit	O & M Cost	Comments
Stormceptor™	$7,600 to $33,560 for units that range from 900 to 7200 gallons + cost of installation	Cleaning is required once a year and typical cleaning cost (equipment and personnel) is estimated to be $250 and disposal costs is estimated to be in the order of $300 to $500.	• Maintenance depends on site conditions and is indicated by sediment depth. Needs a vacuum truck. • Cleaning is required when the sediment reaches 1 foot of its capacity limit. • Visual inspection is performed through the manhole by dipping a dip stick and is especially recommended for units that may capture petroleum based pollutants.
Vortechs™	$10,000 to $40,000 per unit that can treat runoff flows from 1.6 cfs to 25 cfs (not including shipping and installation)	NA	• Inspections once a month is required during the first year of installation and after heavy contaminant loadings like winter sanding, fuel spills etc. • The unit requires cleaning when sediment reaches within one foot of the inlet pipe. • Cleaning involves removal of sediments and is generally done using a vacuum truck.

2.8.2 Oil-Water Separator

One example oil-water separator (OWS) for treating stormwater is the Aero-Power® 500 gallon STI-P3 unit which separates oil and water by allowing the oil droplets to collide and coalesce to become large globules that are then captured in the unit. This OWS unit consists of three compartments: forebay, oil separator, and afterbay. The forebay captures gross sediments, the oil separator contains a parallel corrugated coalescer and a removable oleophallic fiber coalescer to promote separation of oil, and the afterbay discharges treated stormwater with less than 10 mg/L of grease and oil concentration. Table 40 shows the summary of construction and annual operation and maintenance cost for one CALTRANS Oil-water separator.

Table 40. CALTRANS Oil-water Separator Costs (CALTRANS, 2001)

Construction Cost (1999 dollars)	Cost ($\$/m^3$) of water volume	Annual O&M Cost (1999 $)
128,305	1,970	790

The OWS needs to be inspected for accumulated sediments in the forebay and oil in the oil separator. Operation and maintenance efforts are based on: administration, inspection, maintenance, vector control, equipment use, and direct costs (Table 41).

Table 41. Expected Annual Maintenance Costs for Oil-Water Separator (CALTRANS, 2001)

Activity	Labor Hours	Equipment and Materials ($)	Cost ($)
Inspections	1	0	44
Maintenance	10	0	440
Vector Control	12	0	744
Administration	3	0	132
Direct Costs	-	180	180
Total	26	$180	$1,540

2.8.3 Storm Drain Inlet Inserts

Storm drain inlet inserts are typically bags or trays of filter media, filter fabrics, or screens, designed to trap contaminants and debris prior to discharge into storm drain systems. They are manufactured stormwater treatment controls and have low capital costs compared to other controls. They can usually be placed into traditional storm inlets without alteration of the inlets. However, they may have very high maintenance costs to prevent clogging if placed in areas of large debris loadings.

FossilFilter™ drain inlet inserts have a trough structure that is installed under the inlet of a storm drain inlet. The trough is made of fiberglass and consists of a large center opening for bypass of water when flow-through capacity of the filter is exceeded. The trough contains stainless steel filter cartridges filled with amorphous alumina silicate for removal of petroleum hydrocarbons and other contaminants.

StreamGaurd™ drain inlet inserts are a conical shaped porous bag made of polypropylene fabric and contains an oil absorbent polymer. As stormwater flows through the insert, the fabric absorbs oil and retains sediment. The overflow cutouts near the top of the cone allow bypass when the fabric's flow through capacity is exceeded.

Although the size of the inlets vary, the variation is not enough to significantly affect the cost of an inlet insert. In most cases, they are installed on a unit (per drain inlet) basis and not according to runoff volume or flow basis, although most are intended to treat up to about 20 gpm before bypassing excess flows. Table 42 shows the construction and annual maintenance cost for one CALTRANS storm drain inlet for a single test location.

Table 42. CALTRANS Storm Drain Inlet Costs (CALTRNS, 2001)

Construction Cost (1999 $)	Cost/WQV ($/m^3)	Annual O&M Cost (1999 $)
370	10	1,100

Maintenance involves frequent inspections for debris and trash during rainy seasons and monthly inspections during dry seasons. Also, the inlets need to be inspected for oil and grease at the end of each target storm. The operation and maintenance efforts are based on: administration, inspection, maintenance, vector control, equipment use, and direct costs (Table 43).

Table 43. Average Annual Maintenance Costs of Storm Drain Inlet Inserts (CALTRANS, 2001)

Activity	Labor Hours	Equipment and Materials (1999, $)
Inspections	11	-
Maintenance	9	0
Vector Control	17	-
Administration	84	-
Direct Costs	-	563
Total	121	563

2.9 Stormwater Filters

A typical sand filter consists of two or three chambers. The first chamber acts as a sedimentation chamber, where floatable and heavy sediments are removed. The second chamber has the sand bed which removes additional pollutants by filtration. The third is the discharge chamber, where treated filtrate is discharged through an underdrain system either into the storm drainage system or directly into surface waters. The following paragraphs present the costs associated with the Austin sand filter, the Delaware sand filter, the Washington, D.C., sand filter and the Storm-Filter™.

2.9.1 Austin and Delaware Sand-Filters

The Austin sand filter has a sedimentation chamber and an open air filter separated by a concrete wall. Runoff from the sedimentation chamber flows into the filter chamber through a perforated riser. The orifice riser is placed in such a position that the full sedimentation chamber would drain in 24 hours. The filter chamber has a level spreader to distribute runoff evenly over the 450 mm deep bed. Construction cost estimates by the U.S.EPA (EPA 832-F-99-007, Sept 1999) is $18,500 (1997 dollars) for a 1 acre drainage area. The cost per acre decreases with larger drainage areas.

The Delaware Sand-Filter consists of a separate sedimentation chamber and filter chamber. A permanent pool of runoff is maintained in the sedimentation chamber. As runoff enters the sedimentation chamber, standing water is forced into the filter chamber through a weir. The sand filter is 300 mm deep and the storage in the unit accommodates 5 mm runoff. The construction costs estimated by the U.S.EPA (EPA 832-F-99-007, Sept 1999) for a Delaware sand filter is similar to a precast Washington, D.C. sand filter system, with the exception of lower excavation costs because of the Delaware filters' shallower depth.

CALTRANS installed and monitored sand filters at six locations (Table 44). The sites selected were relatively small, highly impervious watersheds such as park-and-ride (P&R) lots and maintenance stations (MS). The Austin filter was installed at five locations: Eastern Regional MS, Foothill MS, Termination P&R, La Costa P&R and SR-78/I-5 P&R. The Delaware sand filter was installed at one location: Escondido MS. Excessive amounts of sediments caused premature clogging of the filter media. The design characteristics of the installed sand filter are shown in Table 45.

Table 44. Summary of Contributing Watershed Characteristics for Sand Filters (CALTRANS, 2001)

Site Location	Filter Type	Watershed Area (Hectare)	Impervious Cover (%)
Eastern Regional MS	Austin	0.6	90
Foothill MS	Austin	0.7	100
Termination P&R	Austin	1.1	90
La Costa P&R	Austin	1.1	56
SR-78/I-5 P&R	Austin	0.3	80
Escondido MS	Delaware	0.3	85

Table 45. Design Characteristics of the CALTRANS Sand Filters (CALTRANS, 2001)

Site Location	Design Storm (mm)	WQV (m^3)	Sedimentation Chamber Area (m^2)	Filter Chamber Area (m^2)
Eastern Regional MS	25	115	54	27
Foothill MS	25	217	102	40
Termination P&R	25	222	114	57
La Costa P&R	36	286	180	72
SR-78/I-5 P&R	38	106	56	32
Escondido MS	48	12.2 (120)[a]	27	27

Note: [a] The volume of water treated at Escondido MS is 120 m^3 during the design storm. The Delaware design specifications require the filter design volume to be 38 m^3/ha of tributary area. Therefore, the sedimentation basin at Escondido is designed to capture 12.2 m^3 of water; but during the design storm, 120 m^3 of water flows through the device.

Table 46 shows the actual construction costs for the sand filters. At the District 7 site, pumps were used to return treated runoff to the storm drain system. At the District 11 site, gravity flow was used. In addition, excavation was less at the District 11 site, further reducing the costs (1999 dollars).

Table 46. Actual Construction Costs for Sand Filters (CALTRANS, 2001)

District	Site	Actual Cost ($)	Actual Cost w/o Monitoring ($)	Cost w/o monitoring/WQV ($/m^3)
7 (Los Angeles)	Eastern Regional MS	353,702	342,660	2,979
	Foothill MS	485,946	476,106	2,194
	Termination P&R	471,637	463,461	2,088
11 (San Diego)	La Costa P&R	239,678	225,285	787
	SR-78/I-5 P&R	222,529	211,631	1,997
	Escondido MS	453,012	416,714	3,472

An adjusted cost for the Austin Sand Filter was obtained by excluding the cost of pumps and shoring costs from the District 7 costs and using the average clearing and grubbing costs for similar stormwater controls instead of using the original clearing and grubbing cost (Table 47). Also, the adjusted cost used an average facility reconstruction cost for similar stormwater controls, excluding a 3 percent add-on for miscellaneous costs for site-specific factors. In the case of the Delaware Sand Filter, the actual cost was adjusted because of the contractor's inexperience with extensive cast-in-place construction, and due to the device being subject to heavy traffic loads.

Table 47. Adjusted Construction Costs for Sand Filters (CALTRANS, 2001)

Sand filter	Adjusted Construction Cost ($)	Cost/WQV ($/m^3)
Austin Sand filter		
Mean (5)	242,799	1,447
High	314,346	2,118
Low	203,484	746
Delaware Sand Filter		
One Location	230,145	1,912

Maintenance involves removal of sediments from the sedimentation chamber when the accumulation exceeds 300 mm, and removal of the uppermost layer (50 mm) of the sand bed when the drain time exceeds 48 hours. Also, the removed sand must be immediately replaced by new sand to restore the original depth. The filters need to be inspected weekly for trash accumulation and monthly for damage to the inside or outside structure, emergence of woody vegetation and evidence of graffiti or vandalism. Table 48 shows the associated annual maintenance costs.

Table 48. Actual Average Annual Maintenance Effort for Sand Filters (CALTRANS, 2001)

Activity	Labor Hours	Equipment and Materials ($)
Inspections	12	0
Maintenance	40	40
Vector Control	41	0
Administration	65	0
Direct Cost	-	832
Total	158	872

The expected annual maintenance cost for the sand filter is shown in Table 49.

Table 49. Expected Annual Maintenance Costs for Final Version of Sand Filter (CALTRANS, 2001)

Activity	Labor Hours	Equipment and Materials (1999 $)	Cost (1999 $)
Inspections	4	0	176
Maintenance	36	125	1,709
Vector Control	0	0	0
Administration	3	0	132
Direct Costs	-	888	888
Total	43	$1,013	2,905

2.9.2 Washington, D.C. Sand Filter

The Washington, D.C sand filter consists of three underground chambers. The sand filter is designed to accept the first 0.5 inches of runoff. The sedimentation chamber removes floatables and coarse sediments from runoff. Runoff is discharged from the sedimentation chamber through a submerged weir into a filtration chamber that consists of sand and gravel layers totaling 1 meter in depth with underdrain piping wrapped in filter fabric. The underdrain system collects the filtered water and drains them into a third chamber where the water is collected and discharged.

The sand filters should be inspected after every storm event. The Washington D.C. sand filters experienced clogging about every 3 to 5 years. Accumulated trash, debris and paper should be removed from the sand filters every 6 months. Corrective maintenance of the filtration system involves removal and replacement of the top layers of the sand and gravel or filter fabric that has become clogged. Sand filter systems require periodic removal of vegetative growth. The cost for precast Washington, D.C. sand filters, with drainage areas less than 0.4 hectares (1 acre), ranges between $6,600 and $11,000 in 1997 dollars (USEPA, Sept. 1999). This is considerably less than the cost for the same size cast-in-place system. Also, the cost to replace the gravel layer, filter fabric and top portion of the sand for Washington, D.C. sand filter is approximately $1,700 in 1997 dollars (USEPA, Sept. 1999).

2.9.3 Storm-Filter™

The Contech Stormwater Solutions, Inc. Storm-Filter™ is a water quality treatment device that uses cartridges filled with different filter media. In this cost analysis, the filter media was perlite/zeolite and the following siting conditions were used:

- No construction activity up-gradient or no bare soil
- Tributary area of less than 8 ha.
- Hydraulic head of 1 m to operate by gravity flow

The Storm-Filter™ is designed based on the runoff flows. The maintenance site chosen for the cost analysis used by CALTRANS was Kearny Mesa, San Diego (0.6 ha.) for a design storm of 36 mm, design storm discharge of 76 L/s, water quality volume (WQV) of 194 m^3 containing 86 canisters and 3 chambers (Tables 50,51 and 52). The perlite/zeolite combination was chosen for this site as perlite is recommended for the removal of TSS and oil and grease, while zeolite is recommended for the removal of soluble metals, ammonium and some organics.

Table 50. Summary of Contributing Watershed Characteristics for CALTRANS Storm-Filter (CALTRANS, 2001)

Site	Land Use	Watershed Area (ha.)	Impervious Cover (%)
Kearny Mesa	Maintenance Station	0.6	100

Table 51. Design Characteristics of the CALTRANS Storm-Filter (CALTRANS, 2001)

Site	Design Storm (mm.)	Design Storm Discharge (L/s)	WQV (m^3)	Number of canisters	Number of Chambers
Kearny Mesa	36	76	194	86	3

Table 52. Actual Construction Cost for Storm-Filter (CALTRANS, 2001)

Site	Actual Cost (1999 $)	Actual Cost w/o monitoring (1999 $)	Cost/WQV ($/$m^3$)
Kearny Mesa	325,517	305,355	1,575

The adjustment of construction costs was associated with features associated with monitoring. Excluding this cost reduces the cost by 6 percent (Table 53).

Table 53. Adjusted Construction Costs for Storm-Filter, (CALTRANS, 2001)

Adjusted Construction Cost (1999 $)	Cost/WQV ($/$m^3$)	Annual O&M Cost ($)
305,356	1,572	7,620

Maintenance of the Storm-Filter™ includes inspection of sediment accumulation, and removal from the pretreatment chamber when accumulation exceeds 300 mm, weekly inspection during wet weather season, monthly inspection according to manufacturer's guidelines, including flushing of underdrains.

Table 54 presents the expected maintenance costs that would be incurred for a Storm-Filter™ serving about 2 ha of 100% paved area, and following these maintenance activities (CALTRANS, 2003):

- Perform inspections and maintenance as recommended, which includes checking for media clogging, replacement of filter media, and inspection for standing water.
- Schedule semiannual inspection for beginning and end of the wet season to identify potential problems.
- Remove accumulated trash and debris in the pretreatment chamber, stilling basin, and the filter chamber during routine inspections.
- Remove accumulated sediment in the pretreatment chamber every 5 years or when the sediment occupies 10 percent of the volume of the filter chamber, whichever occurs first.

Table 54. Expected Annual Maintenance Costs for Final Version of Storm-Filter (CALTRANS, 2001)

Activity	Labor Hours	Equipment and Materials ($)	Cost ($)
Inspections	1	0	44
Maintenance	39	131	1,847
Vector Control	12	0	744
Administration	3	0	132
Direct Costs	-	2,800	2,800
Total	55	2,931	5,567

2.9.4 Multi-Chambered Treatment Train

The multi-chambered treatment train (MCTT) is a device that can be installed underground in areas having little space for more conventional surface treatment. It was developed by Pitt, *et al*. (1997) to provide high levels of treatment of a variety of metallic and organic pollutants, along with conventional pollutants. It includes a combination of unit processes, including a grit chamber to capture large particulates, a main settling tank to capture particulates down to very small sizes, and a final sorption/ion-exchange chamber to capture filterable forms of pollutants. Several MCTTs have been constructed as part of demonstration projects, and some cost information was developed as part of these projects.

A Milwaukee, WI, MCTT installation is at a public works garage and yard and serves about 0.1 ha (0.25 acre) of pavement. This MCTT was designed to withstand very heavy vehicles driving over the unit. The estimated cost was $54,000 (including a $16,000 engineering cost), but the actual total capital cost was $72,000. The high cost was likely due to uncertainties associated with construction of an unknown device by the contractors and because it was a retro-fit installation. It therefore had to fit within very tight site layout constraints. As an example, installation problems occurred due to sanitary sewerage not being accurately located as mapped.

The Minocqua, WI, MCTT is located at a 1 ha (2.5 acre) newly paved parking area serving a state park and downtown commercial area. It is located in a grassed area and is also a retro-fit installation, designed to fit within an existing storm drainage system. The installed capital cost of this MCTT was about $95,000. Box culverts 3.0 m X 4.6 m (10 ft X 15 ft) were used for the main settling chamber (13 m, or 42 ft long) and the filtering chamber (7.3 m, or 24 ft long). The grit chamber (a 7.6 m^3, 2,000 gal. baffled septic tank) was also used to pre-treat water entering the MCTT.

It is anticipated that MCTT costs could be substantially reduced if designed to better integrate with a new drainage system and not installed as a retro-fitted stormwater control practice. Plastic tank manufactures have also expressed an interest in preparing pre-fabricated MCTT units that could be sized in a few standard sizes for small critical source areas. It is expected that these pre-fabricated units would be much less expensive and easier to install for small sites than the above custom built units.

CALTRANS, during its BMP retrofit pilot program, installed MCTTs at two locations: Via Verde Park and Rides and Lakewood Park and Rides. A third unit has since been installed at a maintenance yard. Table 55 shows the summary of the contributing watershed characteristics for the MCTT retrofit program conducted by CALTRANS.

Table 55. Summary of Contributing Watersheds Characteristics for CALTRANS MCTT Retrofit Program (CALTRANS, 2001)

Site	Land Use	Watershed Area (ha.)	Impervious Cover (%)	Design Storm (mm.)
Via Verde P&R	Park & Ride lot	0.44	100	25
Lakewood P&R	Park & Ride lot	0.76	100	25

MCTTs need a vertical distance from the pavement surface to the stormwater drainage pipe of at least 1.5 m for gravity flow. In most cases, this is provided by having the inlet at the surface of the paved area, dropping directly into the initial catchbasin/grit chamber. These two test sites lacked sufficient head and two pumps were therefore installed at each site, one to transfer runoff from the sedimentation chamber to the filter chamber and one to return treated discharge water to the pre-existing drainage system. These pumps were triggered manually on the day following a storm event to ensure runoff remained in the sedimentation chamber for 24 hours.

Standard three-chambered MCTTs were used at these sites. The first chamber consisted of a catchbasin with a sump and packed column aerators. This is followed by a main settling chamber with tube settlers to improve particulate removal and sorbent pillows to capture floating hydrocarbons. The sedimentation chamber was designed so that the water quality volume was held above the tube settlers, which are 0.6 m deep with 0.3 m of plenum space underneath. The dimension of the MCTT used in these sites is shown in Table 56. The final chamber consisted of 600 mm thick sorbent/ion-exchange (“filter”) media of 50/50 mixture of sand and peat moss (the Milwaukee MCTT also contained activated carbon in the last chamber, along with the peat and sand).

Table 56. Design Characteristics for CALTRANS MCTT Retrofit Program (CALTRANS, 2001)

Site	WQV (m^3)	Sedimentation Chamber Area (m^2)	Filter Chamber Area (m^2)
Via Verde P&R	123	35.5	17.4
Lakewood P&R	173	61.2	32.9

The following construction costs of the CALTRANS MCTTs included engineering design for the retrofit sites, excavation costs, grading, material, filter media, unknown field conditions (such as encountering boulders and unmapped utility lines), and labor (Table 57).

Table 57. Actual Construction Costs for MCTTs
(CALTRANS, 2001)

Site	Actual Construction Cost (1999 $)	Actual Cost w/o monitoring (1999 $)	Cost w/o monitoring/WQV ($/m^3)
Via Verde P&R	383,793	375,617	3,054
Lakewood P&R	464,743	456,567	2,639

Table 58 shows the adjusted costs for the MCTTs excluding the cost of pumps (site did not allow gravity drainage) and extensive shoring (due to space constraints at the site). The costs were reduced by 41 percent and 52 percent for both locations. Also, miscellaneous site factors that adjusted the cost by 1 percent were also excluded. The CALTRANS costs also reflect the mandated LA County design storm of 25 mm. The recommended design, based on continuous long-term simulations for the area, was much less than this volume (closer to 8 mm or runoff).

Table 58. Adjusted Construction Costs for MCTTs
(CALTRANS, 2001)

MCTT	Adjusted Construction Cost (1999 $)	Cost/WQV ($/m^3)
Mean	275,616	1,875
High	320,531	1,895
Low	230,701	1,856

Maintenance of the MCTTs included removal of sediments from the sedimentation chambers when accumulation exceeds 150 mm and removing and replacing the media every 3 years, and replacement of sorbent pillows if darkened by oily stains. Neither of these maintenance activities were needed during the CALTRANS study, since even after two wet seasons, the total accumulated sediments was less than 25 mm. Inspections for structural repairs and leaks, and repair or replacement of pumps, plus vector control are included in the following maintenance costs (Table 59).

Table 59. Expected Annual Maintenance Costs for Final
Version of MCTTs (CALTRANS, 2001)

Activity	Labor Hours	Equipment and Materials (1999 $)
Inspections	24	-
Maintenance	84	308
Vector Control	70	-
Administration	131	-
Direct Cost	-	2,504
Total	309	2,812

2.10 Conservation Design Controls

Conservation design stormwater controls include a wide range of practices, including better site layout and decreased use of directly connected paved and roof areas. These practices are almost exclusively part of initial developments, and are difficult to retrofit. The following discussions are for some of the more common conservation design elements.

2.10.1 Grass Filter Strips

Grass filter strips differ from grassed swales in that the strips are designed to accommodate overland sheetflow, rather than channelized flow. The advantages of grass filter strips are low cost and ease of maintenance. The disadvantages of filter strips include the land requirements and the tendency for stormwater runoff to concentrate and form a channel, which essentially “short circuits” the filter strip causing erosion and reduced pollutant reductions.

The costs for vegetated filter strips can be divided into mobilization and demobilization of equipment, site preparation, site development, and contingencies. Site construction activities include the placement of salvaged top soil, seeding and mulching, or sodding. Contingencies include planning, engineering, administration, and legal fees. Tables 60, 61 and 62 present the estimated capital cost (1987 dollars) of 25 feet, 50 feet and 100 feet wide grass swales respectively.

Maintenance of grassed filter strips include management of a dense vegetative cover; prevention of channel or gully formation, frequent spot repairs, fertilization (very minimal), and irrigation. Also, exposed areas should be quickly reseeded, or sodded. The strips should be examined annually for damage by foot or vehicular traffic, gully erosion, damage to vegetation and evidence of concentrated flows. Table 63 shows the average annual operation and maintenance cost for grassed filter strips.

Table 60. Estimated Capital Cost of a 25-foot Wide Grassed Filter Strip (SEWRPC, 1991)

Component	Unit	Extent	Unit Cost ($)			Total Cost ($)		
			Low	Moderate	High	Low	Moderate	High
Mobilization-Demobilization-Light	Strip	1	107	274	441	107	274	441
Site Preparation								
Clearing	Acre	0.70	2,200	3,800	5,400	1,540	2,600	3,780
Grubbing	Acre	0.70	3,800	5,200	6,600	2,660	3,640	4,620
Grading	Square yard	3,333	0.10	0.20	0.30	333	667	1,000
Site Development								
Salvaged Topsoil, Seed and Mulch	Square yard	1,667	0.40	1.00	1.60	667	1,667	2,667
Sod	Square yard	1,667	1.20	2.40	3.60	2,000	4,001	6,001
Subtotal	--	--	--	--	--	7,307	12,909	18,509
Contingencies	Strip	1	25 percent	25 percent	25 percent	1,827	3,227	4,627
Total	--	--	--	--	--	9,134	16,136	23,136

Table 61. Estimated Capital Cost of a 50-foot Wide Grassed Filter Strip (SEWRPC, 1991)

Component	Unit	Extent	Unit Cost ($)			Total Cost ($)		
			Low	Moderate	High	Low	Moderate	High
Mobilization-Demobilization-Light	Strip	1	107	274	441	107	274	441
Site Preparation								
Clearing	Acre	1.30	2,200	3,800	5,400	2,860	4,940	7,020
Grubbing	Acre	1.30	3,800	5,200	6,600	4,940	6,760	8,580
Grading	Square yard	6,292	0.10	0.20	0.30	629	1,258	1,888
Site Development								
Salvaged Topsoil, Seed and Mulch	Square yard	3,146	0.40	1.00	1.60	1,258	3,146	5,034
Sod	Square yard	3,146	1.20	2.40	3.60	3,775	7,550	11,326
Subtotal	--	--	--	--	--	13,569	23,928	34,289
Contingencies	Strip	1	25 percent	25 percent	25 percent	3,392	5,982	8,572
Total	--	--	--	--	--	16,961	29,910	42,861

Table 62. Estimation of Capital Cost of a 100-foot Wide Grassed Filter Strip (SEWRPC, 1991)

Component	Unit	Extent	Unit Cost ($)			Total Cost ($)		
			Low	Moderate	High	Low	Moderate	High
Mobilization-Demobilization-Light	Strip	1	107	274	441	107	274	441
Site Preparation								
Clearing	Acre	2.50	2,200	3,800	5,400	5,500	9,500	13,500
Grubbing	Acre	2.50	3,800	5,200	6,600	9,500	13,000	16,500
Grading	Square yard	12,100	0.10	0.20	0.30	1,210	2,420	3,630
Site Development								
Salvaged Topsoil, Seed and Mulch	Square Yard	6,050	0.40	1.00	1.60	2,420	6,050	9,680
Sod	Square Yard	6,050	1.20	2.40	3.60	7,260	14,520	21,780
Subtotal	--	--	--	--	--	25,997	45,764	65,531
Contingencies	Strip	1	25 percent	25 percent	25 percent	6,499	11,441	16,383
Total	--	--	--	--	--	32,496	57,205	81,914

Table 63. Average Annual Operation and Maintenance Costs for Grassed Filter Strips (SEWRPC, 1991)

Component	Unit Cost (1987 $)	Strip Width			Comment
		25 feet	50 feet	100 feet	
Lawn Mowing	$0.85/1000 square feet	$0.17/linear foot	$0.34/linear foot	$0.68/linear foot	Maintenance area equals width times strip length. Mow 8 times per year
General Lawn Care	$9/1000 square feet/year	$0.23/linear foot	$0.45/linear foot	$0.9/linear foot	Lawn maintenance area equals width times strip length
Grass Reseeding with Mulch and Fertilizer	$0.3/square yard	$0.01/linear foot	$0.02/linear foot	$0.03/linear foot	Area revegetated equals 1 percent of lawn maintenance area per year
Filter Strip Inspection	$25/inspection	$0.1/linear foot	$0.1/linear foot	$0.1/linear foot	Inspect four times per year
Total	--	$0.51/linear foot	$0.91/linear foot	$1.71/linear foot	--

2.10.2 Grass Swales

Grass swales are natural or man-made grass-lined channels, normally of parabolic or trapezoidal cross sections, used to carry stormwater in place of curb and gutters and underground pipes. Pollutants are removed by settling and infiltration into soil and by biological uptake of nutrients. Swales may reduce runoff from roadway and adjacent tributary land areas by allowing water to infiltrate. They also increase the time of concentration within the watershed, further reducing peak flow rates. Grassed swales therefore provide the benefits of reducing peak flows and increasing pollutant removal, at low capital cost. Swales are not practicable in areas with flat grades, steep grades, or in wet or poorly drained soils.

The cost data on grassed swales found in Young, *et al*. (1996) is as follows:

(2.53) $$C = KL$$

where

C = construction cost, January 1999 costs, $,
L = length of swale, ft, and
K = constant, 5 to 14 ($/ft)

The costs of grassed swales can be divided into a number of components: mobilization and demobilization of equipment, site preparation, site development, and contingencies. Tables 64 and 65 present unit costs, calculated component costs, and total capital costs (1987 dollars) for a 1.5 foot deep swale with a bottom foot of 1 foot and top width of 10 feet; and for a 3 foot deep swale that is 3 feet deep having a top width of 21 feet. They have a length of 1,000 feet, gradient of 2 percent, and side slopes of three horizontal to one vertical.

Table 64. Estimated Capital Cost of a 1.5-foot Deep, 10-feet Wide, 1,000-feet Long Grass Swale (SEWRPC, 1991)

Component	Unit	Extent	Unit Cost ($)			Total Cost ($)		
			Low	Moderate	High	Low	Moderate	High
Mobilization-Demobilization-Light	Swale	1	107	274	441	107	274	441
Site Preparation								
Clearing	Acre	0.50	2,200	3,800	5,400	1,100	1,900	2,700
Grubbing	Acre	0.25	3,800	5,200	6,600	950	1,300	1,650
General Excavation	Cubic yard	372	2.10	3.70	5.30	781	1,376	1,972
Level and Till	Square yard	1,210	0.20	0.35	0.50	242	424	605
Site Development								
Salvaged Topsoil, Seed and Mulch	Square yard	1,210	0.40	1.00	1.60	484	1,210	1,936
Sod	Square yard	1,210	1.20	2.40	3.60	1,452	2,904	4,356
Subtotal	--	--	--	--	--	5,116	9,388	13,660
Contingencies	Swale	1	25 percent	25 percent	25 percent	1,279	2,347	3,415
Total	--	--	--	--	--	6,395	11,735	17,075

Table 65. Estimated Capital Cost of a 3.0-feet Deep, 21-feet Wide, 1,000-feet Long Grass Swale (SEWRPC, 1991)

Component	Unit	Extent	Unit Cost ($)			Total Cost ($)		
			Low	Moderate	High	Low	Moderate	High
Mobilization-Demobilization-Light	Swale	1	107	274	441	107	274	441
Site Preparation								
Clearing	Acre	0.75	2,200	3,800	5,400	1,650	2,850	2,700
Grubbing	Acre	0.50	3,800	5,200	6,600	1,900	2,600	1,650
General Excavation	Cubic yard	1,563	2.10	3.70	5.30	3,283	5,783	1,972
Level and Till	Square yard	2,420	0.20	0.35	0.50	484	847	605
Site Development								
Salvaged Topsoil, Seed and Mulch	Square yard	1,815	0.40	1.00	1.60	726	1,815	1,936
Sod	Square yard	1,815	1.20	2.40	3.60	2,178	4,356	4,356
Subtotal	--	--	--	--	--	10,327	18,525	26,723
Contingencies	Swale	1	25 percent	25 percent	25 percent	2,582	4,631	6,681
Total	--	--	--	--	--	12,909	23,156	33,404

Table 66 shows the summary of the capital cost (1989) grass swales for different swale depths and bottom width.

Table 66. Summary of Capital Costs in Thousands of Dollars for Grass Swales (SEWRPC, 1991)

Swale Depth (ft.)	Bottom Width (ft.)				
	1	3	5	8	10
1	8.5	9.6	11	13	15
3	21	23	25	27.5	29
5	39	42	43.5	46	49.5

The capital cost of grass swales as a function of swale depths for different bottom widths is presented in Figure 15.

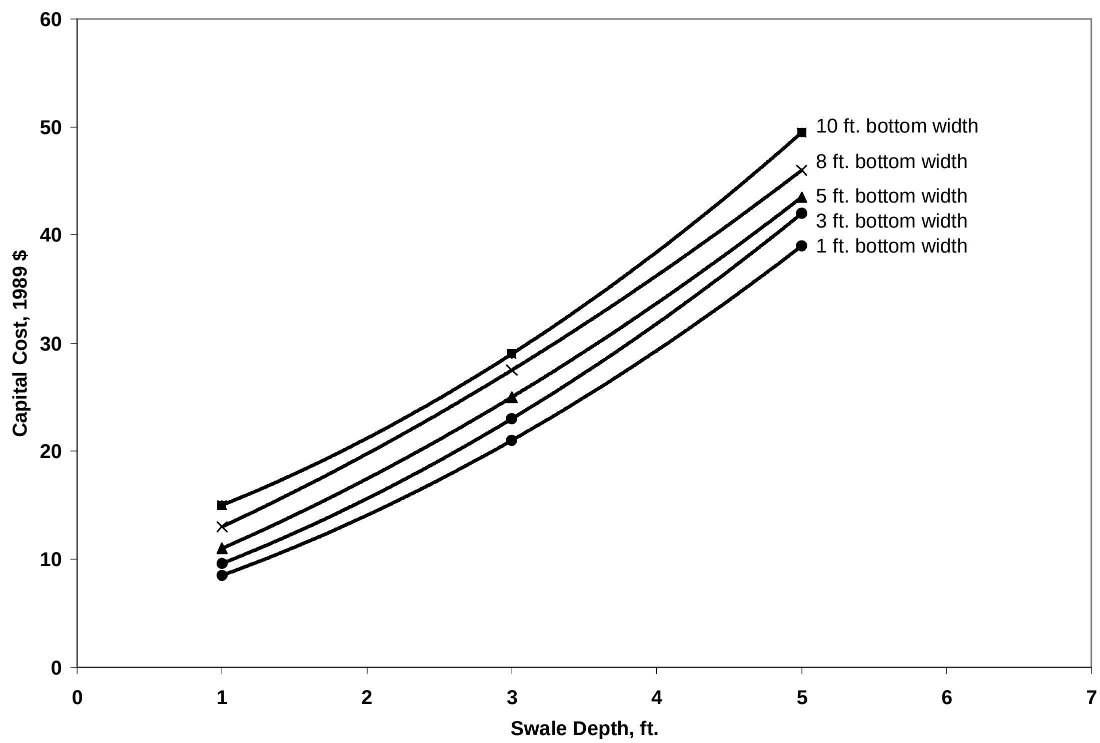


Figure 15. Capital Cost of Grass Swale for Different Swale Depths

A polynomial equation fitted to the data presented in Table 66 relates the capital cost of grass swales to different bottom widths.
For $1 \leq x \leq 5$ ft.

(2.54) $$C_C = Ax^2 + Bx + C$$

where

C_C = capital cost, in thousands of dollars, and
x = swale depth, ft.
A, B, C = constants, depends on swale bottom width

Table 67 gives the values of the constants A, B and C for different swale widths.

Table 67. Constants A, B, C Values in Capital Cost Equation for Different Swale Bottom Widths

Constant	Bottom Width (ft.)				
	1	3	5	8	10
A	0.69	0.70	0.56	0.50	0.81
B	3.50	3.90	4.75	5.25	3.75
C	4.31	5.00	5.69	7.25	10.44

Table 68 summarizes the operation and maintenance cost (1989 dollars) in thousands of dollars for grass swales for different swale depths and bottom widths.

Table 68. Summary of O&M Costs for Grass Swales (SEWRPC, 1991)

Swale Depth, (ft)	Bottom Width (ft.)				
	1	3	5	8	10
1	0.525	0.56	0.59	0.645	0.68
3	0.7175	0.75	0.785	0.8325	0.87
5	0.91	0.94	0.98	1.02	1.06

Swale maintenance costs (Table 69) include selected unit costs for debris removal, grass mowing, spot reseeding and sodding, weed control, swale inspection, and program administration.

Table 69. Average Annual Operation and Maintenance Costs for Grass Swales (SEWRPC, 1991)

Component	Unit Cost (1987 $)	Swale Size (depth and top width)		Comment
		1.5 feet deep, one foot bottom width, 10 foot top width	3 feet deep, three foot bottom width, 21 foot top width	
Lawn Mowing	$0.85/1,000 square feet	$0.14/linear foot	$0.21/linear foot	Maintenance area = (top width+10 feet) * length. Mow 8 times per year
General Lawn Care	$9/1,000 square feet/year	$0.18/linear foot	$0.28/linear foot	Maintenance area = (top width+10 feet)* length
Swale Debris and Litter Removal	$0.10/square yard	$0.10/linear foot	$0.10/linear foot	--
Grass Reseeding with Mulch and Fertilizer	$0.3/square yard	$0.01/linear foot	$0.01/linear foot	Area revegetated equals 1 percent of lawn maintenance area per year
Program Administration and Inspection	$0.15/linear foot/year, plus $25/inspection	$0.15/linear foot	$0.15/linear foot	Ponds inspected four times per year
Total	--	$0.58/linear foot	$0.75/linear foot	--

The operation and maintenance (O&M) cost (1989 dollars) of grass swales as a function of swale depths for different bottom widths is presented in Figure 16.

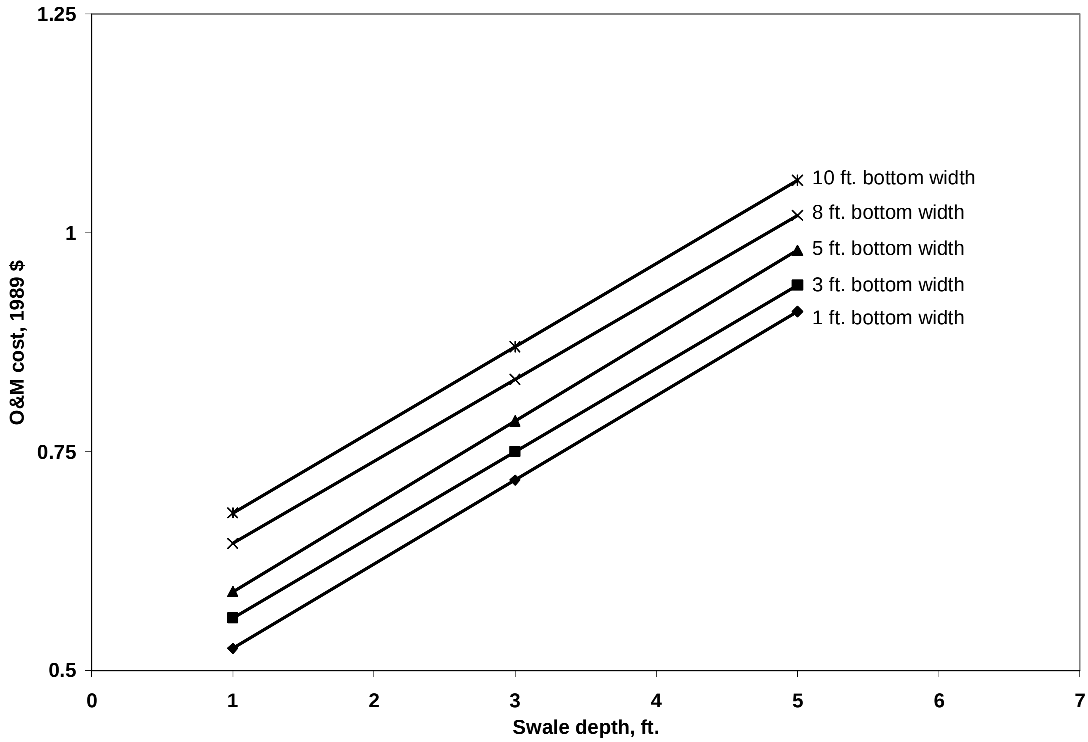


Figure 16. Operation and Maintenance Cost of Grass Swale for Different Swale Depths

A straight line (first order polynomial) is observed for the data presented in Table 66 as shown in Equation 2.60.

(2.55) $$C_{O\&M} = mx + B$$

where

$C_{O\&M}$ = operation and maintenance cost, in thousands of dollars,
x = swale depth, ft., and
m, B = constants, depends on swale bottom width

The values of these constants determined form the regression equation fitted to the data has been presented in Table 70.

Table 70. Constants m, B Values in O&M Cost Equation for Different Swale Bottom Widths

Constant	Bottom Width (ft.)				
	1	3	5	8	10
m	0.096	0.095	0.098	0.094	0.095
B	0.429	0.465	0.493	0.551	0.585

These equations were added to WinSLAMM to allow cost estimate for grass swales. The constants m, B values are adjusted according to the city selection based on cost index values in

WinSLAMM. Figure 17 shows the cost data input screen for grass swales in WinSLAMM adjusted to 2005 in Birmingham, AL, conditions.

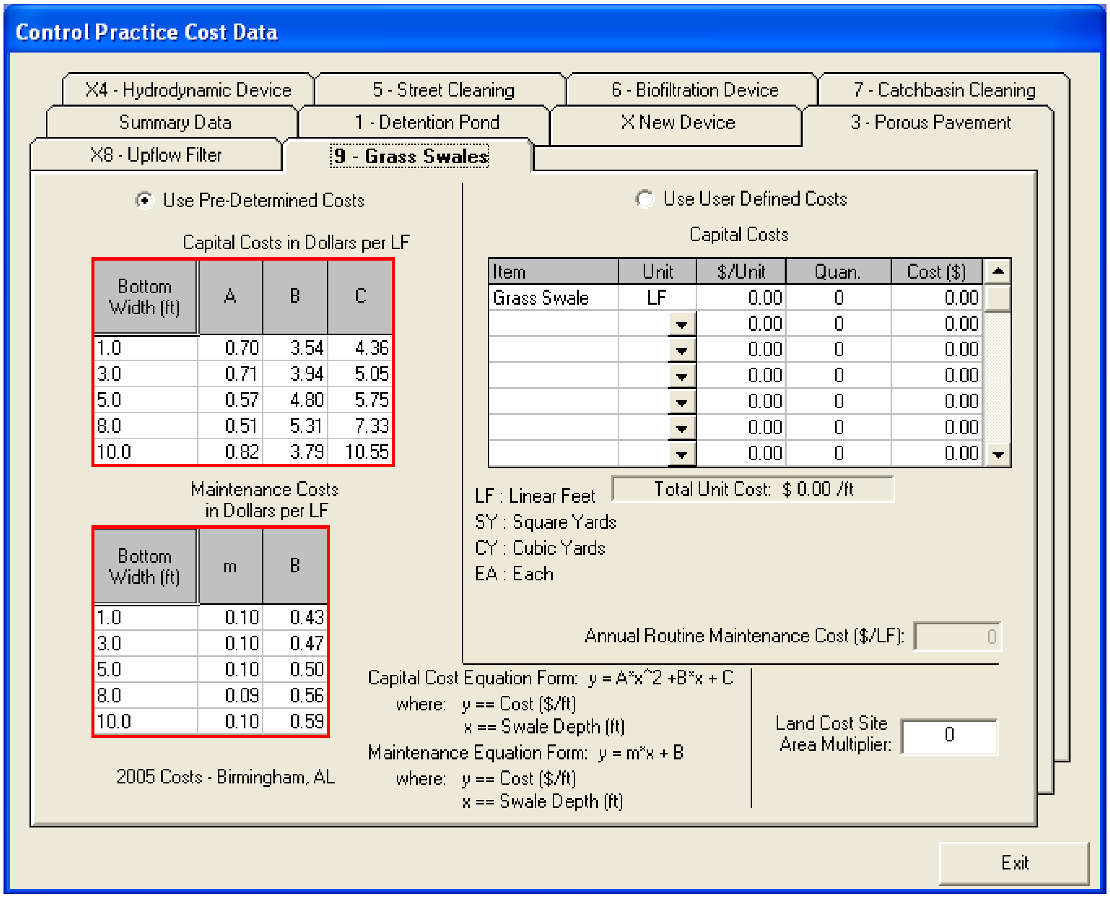


Figure 17. Cost Data Input Screen for Grass Swales in WinSLAMM

2.10.3 Permeable Pavement

Permeable pavement removes waterborne pollutants from stormwater runoff and allows it to filter through the underlying soil. Permeable pavements functions similar to other infiltration measures. The pavement traps some particulate bound pollutants, but most of the runoff and pollutants are discharged to the groundwater, as there is usually little organic-rich soil beneath permeable pavements that trap the pollutants as in most other infiltration devices.

A permeable pavement is constructed of a permeable asphalt or bituminous concrete surface with a 2.5 to 4 inch thickness that is placed over a highly permeable layer of crushed stone or gravel, 24 inches thick. A filter fabric can be placed beneath the gravel or stone layer to prevent movement of fines into the deeper layers, although many installations show clogging of the filter fabric, and most recent designs use rock filters and not filter fabrics. Runoff from the stone and gravel layers then infiltrates into the soil. If the infiltration rate is slow, perforated underdrain pipes can be placed in the stone layer to convey the water back to a surface waterway.

The primary advantage of permeable pavement is that it can be put to dual use reducing land use requirements. But, permeable pavements are not as durable as conventional pavements. Also, they are costlier than conventional pavements.

Construction costs involve site excavation, development and contingencies. Site development components can include construction of the permeable surface layer, placement of stone fill, filter layer, and supplemental underdrain system. Contingencies include planning, engineering, administration and legal fees. Estimated incremental costs (over conventional pavement) of a 1.0-acre permeable pavement parking lot (1989 dollars) are shown in Table 71.

Table 71. Estimated Incremental Cost of a 1.0-acre Permeable Pavement Parking Lot (SEWRPC, 1991)

Component	Unit	Extent	Unit Cost ($)			Total Cost ($)		
			Low	Moderate	High	Low	Moderate	High
Site Preparation								
General Excavation	Cubic yard	1,452	2.10	3.70	5.30	3,049	5,372	7,696
Site Development								
Geotextile Fabric	Square yard	5,082	1.00	2.00	3.00	5,082	10,164	15,246
Crushed Stone Fill	Cubic yard	1,452	14.80	19.40	24.00	21,490	28,169	34,848
Permeable Pavement	Square yard	4,840	0.50	0.50	1.00	2,420	3,630	4,840
Subtotal	--	--	--	--	--	32,041	47,335	82,630
Contingencies	Site	1	25 percent	25 percent	25 percent	8,010	11,834	15,658
Total	--	--	--	--	--	40,051	59,169	98,288

Maintenance involves the need for frequent cleaning as they are prone to easy clogging. Vacuum cleaning of the pavement may be required as much as four times a year, followed by jet hosing to open up asphalt pores. The pavement surface needs to be annually inspected, and after large storm events, for cracks and potholes. An observation well may be installed at the downslope end of the pavement to monitor water levels in the storage layers and to collect water samples. Incremental maintenance costs in 1989 dollars (Table 72) are estimated to be $200 per acre per year regardless of the depth of the stone reservoir.

Table 72. Incremental Average Annual Maintenance Costs (Over Conventional Pavement) of a Permeable Pavement Parking Lot (SEWRPC, 1991)

Component	Unit Cost	Permeable Pavement Parking Lot	Comment
Vacuum Cleaning and High-Pressure Jet Hosing	$17/acre vacuum cleaning, plus $8.00/acre jet hosing	$100/acre/year	Vacuum and hose area four times per year
Inspection	$25/inspection	$100/acre/year	Inspect four times per year
Total	--	$200/acre/year	--

The cost of individual components and the estimated incremental capital cost, above conventional pavement, for a 1 acre permeable pavement parking lot is presented in Table 65 (SEWRPC, 1991). Table 73 summarizes the capital costs and the O&M cost (1989 $) for permeable pavement for different stone reservoir thicknesses.

Table 73. Summary of Incremental Capital and O&M Costs for Permeable Pavement of Different Reservoir Thicknesses (SEWRPC, 1991)

Incremental Stone Reservoir Thickness (ft.)	Capital Cost (1000 $)			O&M Cost ($)
	Low Cost	Med. Cost	High Cost	
0.5	26	41	55	0.2
1	40	60	80	0.2
1.5	60	85	115	0.2
2	81	110	150	0.2

Figure 18 shows the capital and O&M cost, 1989 $ of permeable pavement for different reservoir depths.

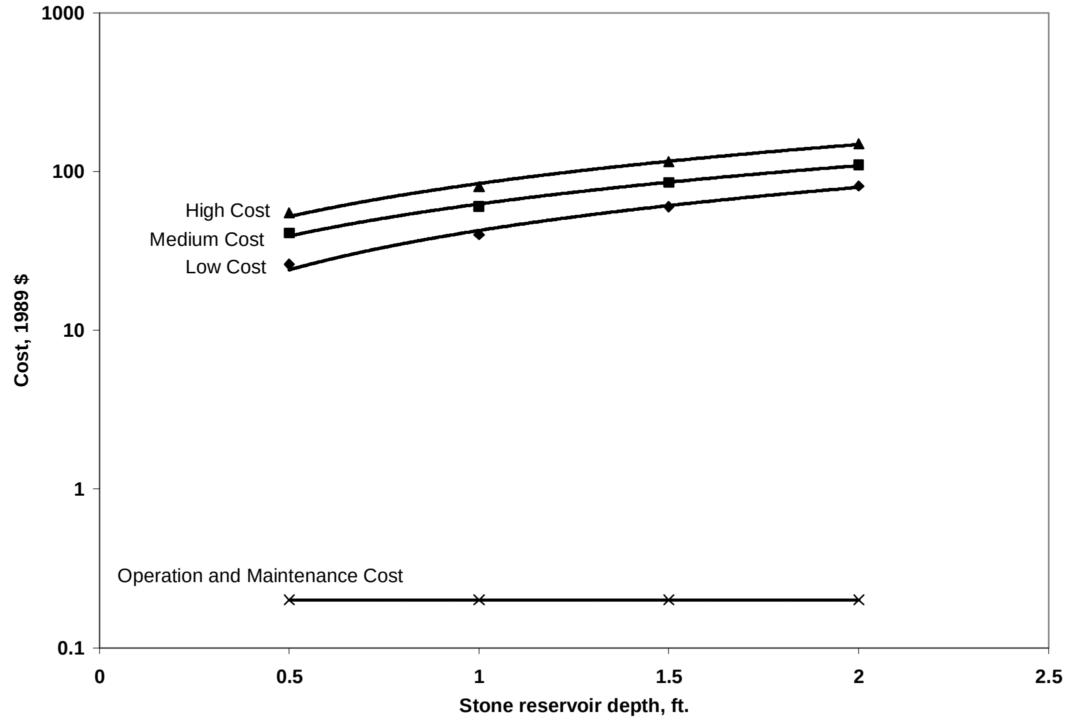


Figure 18. Cost of Permeable Pavement for Different Stone Reservoir Depths

Regression-equations fitted to the data presented in Table 73 results in first-order polynomials as shown in Equations 2.56, 2.57 and 2.58.

For low cost:

(2.56) $$C = 37D + 5.5$$

For medium cost:

(2.57) $$C = 46.4D + 16$$

For high cost:

(2.58) $$C = 64D + 20$$

where

C = capital cost, 1989 $ and

D = stone reservoir thickness, ft.

These equations were included in WinSLAMM to enable the capital, and annual operation and maintenance costs for permeable pavements to be calculated. Figure 19 shows the cost input/section screen for permeable pavement in WinSLAMM.

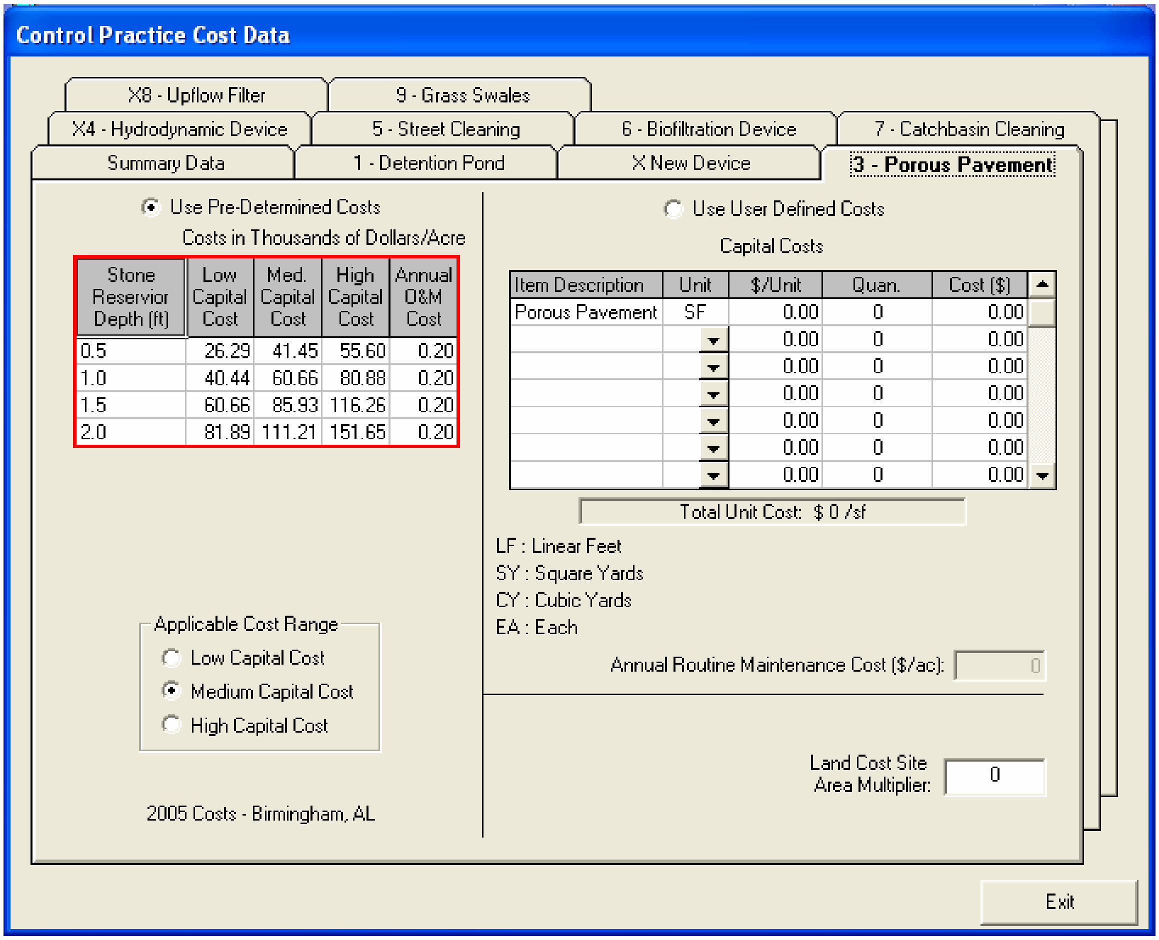


Figure 19. Cost Data Input Screen for Permeable Pavement in WinSLAMM

2.10.4 Infiltration Trenches

Infiltration devices remove stormwater pollutants by filtering the runoff through the underlying organic-rich soil. There are a number of different, but closely related devices that operate in a similar manner; rain gardens, biofilters, and bioretention devices. Infiltration trenches are used in places where space is a problem. They consist of excavating a void volume, lining it with a filter fabric (which may clog, so rock filters may be a better choice), and then installing underdrains (optional) and back-fill material. The media can range from crushed stone (infiltration trenches providing more storage, but with less treatment) to soils amended with compost (enhanced evapotranspiration and better treatment of infiltrating water).

Infiltration trenches are used to serve areas less than 10 acres. The surface of the trench consists of vegetation and with special inlets to distribute the water evenly. Infiltration trenches help recharge groundwater, reduce runoff and augment low stream flows. Rain gardens generally serve a much smaller area, generally just a portion of runoff from an adjacent roof.

Maintenance of infiltration trenches involve annual inspections and inspections after every storm event, mowing, vegetative buffer strip maintenance, and rehabilitation of trench when clogging begins to occur. Infiltration trenches have a history of failure due to clogging, while the smaller rain gardens have a better operational history.

The available cost data for construction of infiltration trenches by Young, *et al*. (1996) gives total cost as a function of the total volume of the trench:

(2.59) $$C = 157V^{0.63}$$

where

C = construction cost, January 1999 costs, \$, and

V = volume of trench, ft^3

Wiegand, *et al*. (1985) provides construction costs of infiltration trenches as a function of storage volume as:

(2.60) $$C = 26.55Vs^{0.634}, \ Vs < 10{,}000 \text{ cu ft}$$

where

C = construction cost, 1985 \$, and

V_s = storage volume defined as stormwater volume of void space for the maximum design event frequency

The SEWRPC data presented in Tables 74 and 75 gives the cost (1989 dollars) of mobilization and demobilization of equipment, site preparation, site development, and contingencies for infiltrations trenches of varying sizes.

Table 74. Estimated Capital Cost of a 3-feet Deep, 4-feet Wide, 100-feet Long Infiltration Trench (SEWRPC, 1991)

Component	Unit	Extent	Unit Costs ($)			Total Costs ($)		
			Low	Moderate	High	Low	Moderate	High
Mobilization-Demobilization-Light	Trench	1	107	274	441	107	274	441
Site Preparation								
Clearing	Acre	0.12	2,200	3,800	5,400	264	456	648
Grubbing	Acre	0.01	3,800	5,200	6,600	38	52	66
Trench Excavation	Cubic yard	43.3	2.10	5.60	9.10	91	242	394
Site Development								
Salvaged Topsoil, Seed and Mulch	Square yard	111	0.40	1.00	1.60	44	111	178
Sod	Square yard	444	1.20	2.40	3.60	533	1066	1,598
Crushed Stone fill	Cubic yard	43.3	14.80	19.40	24.00	641	840	1,039
Geotextile Fabric	Square yard	171	1.00	2.00	3.00	171	342	513
Shallow Observation Well	Vertical foot	4	66.00	160.00	254.00	264	640	1,016
Subtotal	--	--	--	--	--	2,153	4,023	5,893
Contingencies	Trench	1	25 percent	25 percent	25 percent	538	1,006	1,473
Total	--	--	--	--	--	2,691	5,029	7,367

Table 75. Estimated Capital Cost of a 6-feet Deep, 10-feet Wide, 100-feet Long Infiltration Trench (SEWRPC, 1991)

Component	Unit	Extent	Unit Costs ($)			Total Costs ($)		
			Low	Moderate	High	Low	Moderate	High
Mobilization-Demobilization-Light	Trench	1	107	274	441	107	274	441
Site Preparation								
Clearing	Acre	0.14	2,200	3,800	5,400	308	532	756
Grubbing	Acre	0.02	3,800	5,200	6,600	76	104	132
Trench Excavation	Cubic yard	222	2.10	5.60	9.10	466	1,243	2,020
Site Development								
Salvaged Topsoil, Seed and Mulch	Square yard	111	0.40	1.00	1.60	44	111	178
Sod	Square yard	444	1.20	2.40	3.60	533	1,066	1,598
Crushed Stone fill	Cubic yard	222	14.80	19.40	24.00	3,268	4,307	5,328
Geotextile Fabric	Square yard	388	1.00	2.00	3.00	171	776	1,164
Shallow Observation Well	Vertical foot	4	66.00	160.00	254.00	264	1,120	1,778
Subtotal	--	--	--	--	--	2,153	9,533	13,395
Contingencies	Trench	1	25 percent	25 percent	25 percent	1,418	2,383	3,349
Total	--	--	--	--	--	7,088	11,916	16,744

Maintenance costs include buffer strip maintenance and trench inspection and rehabilitation. The average annual operation and maintenance costs (1989 dollars) for infiltration trenches of two different sizes are listed in Table 76.

Table 76. Average Annual Operation and Maintenance Costs for Infiltration Trenches (SEWRPC, 1991)

Component	Unit Cost	Trench Size		Comment
		100 Feet Long by Three Feet Deep by Four Feet Wide	100 Feet Long by Six Feet Deep by 10 Feet Wide	
Buffer Strip Mowing	$0.85/1000 square feet/mowing	$10	$10	Maintenance area equals area cleared minus area grubbed. Mow twice per year
General Buffer Strip Lawn Care	$9/100 square feet/year	$45	$45	Maintenance area equals area cleared minus area grubbed
Program Administration and Trench Inspection	$25/inspection, plus $50/trench/year for administration	$100	$100	Inspect twice per year
Major Trench Rehabilitation	$0.4 to 19 per linear foot at 15 year intervals	$79	$334	-
Minor Trench Rehabilitation	$0.25 to $3.7 per linear foot at 5-year intervals	$51	$126	-

Infiltration trench costs are used to calculate biofilter costs in the Source Loading and Management Model (WinSLAMM). Table 77 presents capital costs in thousands of dollars for biofilters of different trench depths and trench bottom widths.

Table 77. Summary of Capital Cost of Biofilters for Different Trench Widths and Depths, in Thousands of Dollars (SEWRPC, 1991)

Trench Width (ft.)	Trench Depth (ft.)						
	3	4	5	6	8	10	12
2	40.5	46	52	57	64	74	86
5	54	63	70.5	80.5	95	110	135
10	75	90	103	120	145	170	204
15	98	120	140	155	198	230	270
20	120	145	160	200	240	300	345
25	140	175	205	230	300	365	415
30	170	205	235	280	340	410	500

The capital cost of biofiltration device plotted against trench widths for different trench depths is shown in Figure 20.

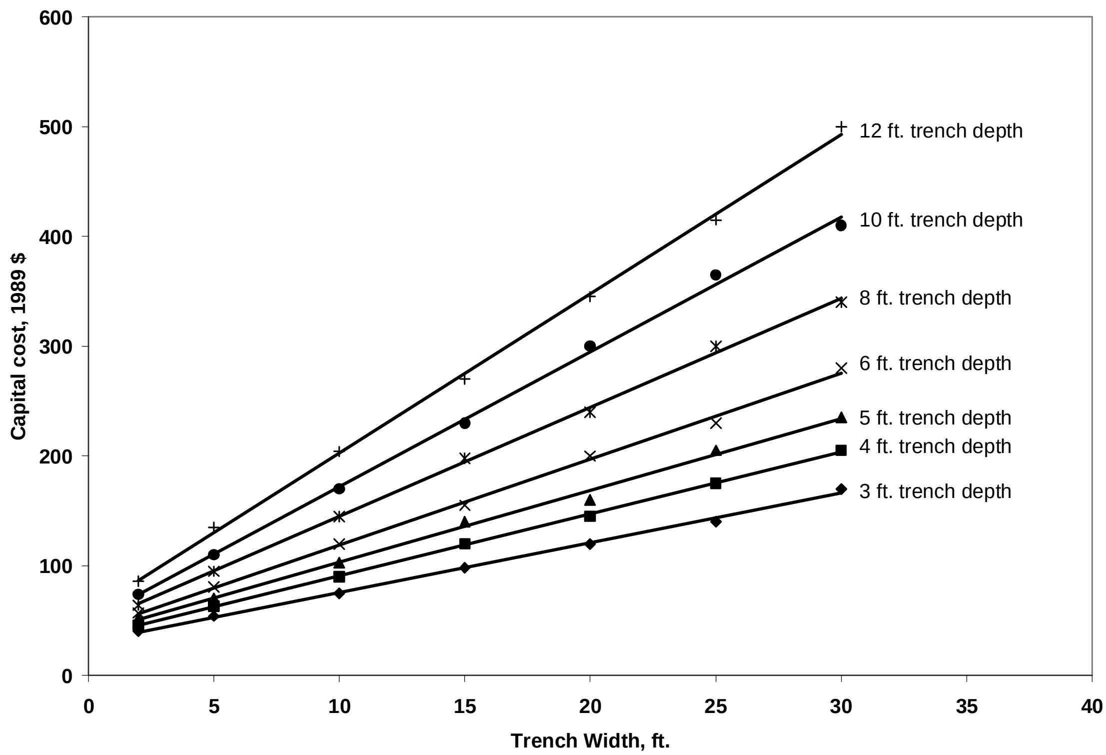


Figure 20. Capital Cost of Biofiltration Device for Different Bottom Widths

First-order polynomial curves best represent the data in Table 77. The equation obtained is of the form:

(2.61) $$C_c = mx + B$$

where

C_c = capital cost, 1989 $,

x = trench width, ft., and

m, B = constants, depends on trench depth

m, B values for different trench depths determined from the linear regression equation are presented in Table 78.

Table 78. m, B Values for Different Depths for Biofiltration Device

Constant	Trench depth, ft						
	3	4	5	6	8	10	12
m	4.52	5.63	6.53	7.82	9.94	12.30	14.50
B	30.53	34.31	38.08	40.78	45.43	48.99	57.67

Table 79 presents the operation and maintenance (O&M) costs for biofiltration device.

Table 79. Summary of O&M Costs for Biofiltration Device,
in Thousands of Dollars (SEWRPC, 1991)

Trench Width, ft.	Trench Depth, ft.						
	3	4	5	6	8	10	12
10	4.50	5.00	5.50	6.00	7.00	8.10	9.20
25	9.20	10.40	11.40	12.80	15.20	17.50	20.05

The O&M costs plotted against trench widths for different depths is shown in Figure 21.

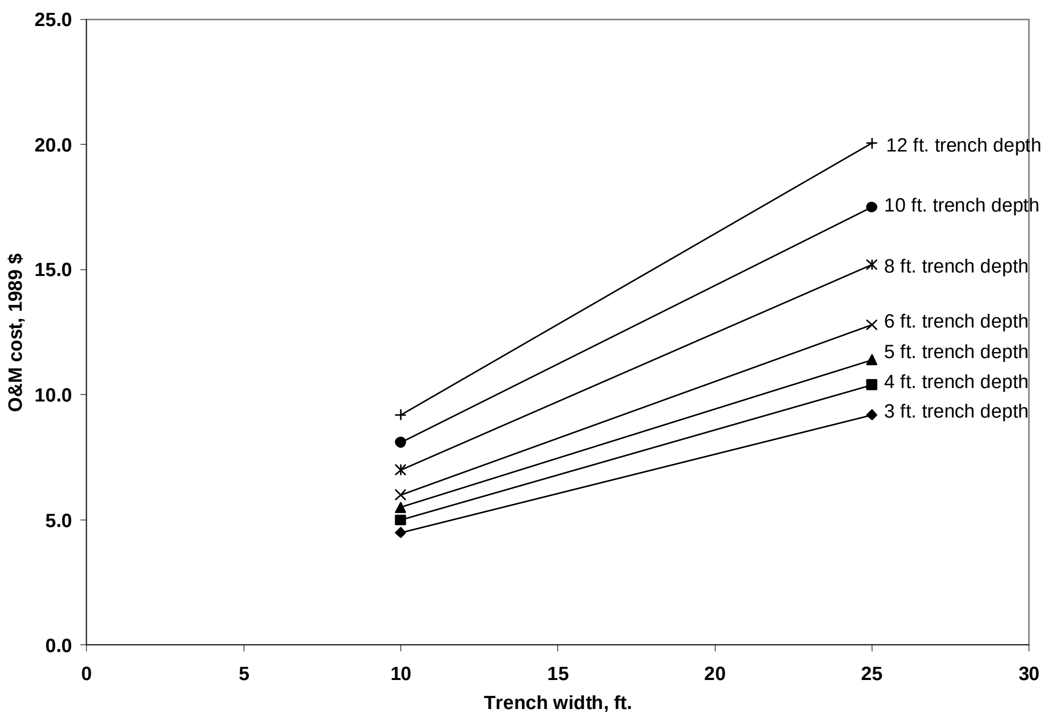


Figure 21. O&M Costs of Biofiltration Devices for Different Trench Widths

This data was plotted and a first-order polynomial regression equation was fitted:

(2.62) $$C_{O\&M} = mx + B$$

where

$C_{O\&M}$ = operation and maintenance cost, 1989 \$,

x = trench width, ft., and

m, B = constants, depends on trench depth, ft.

Table 80 presents the values of the constants m and B in operation and maintenance cost equation for different trench depths.

Table 80. m,B Values for O&M Cost Equation for Biofiltration Device

Constant	Trench depth, ft						
	3	4	5	6	8	10	12
m	0.31	0.36	0.39	0.45	0.55	0.63	0.72
B	1.37	1.40	1.57	1.47	1.53	1.83	1.97

Figure 22 shows the cost data input screen for biofiltration device in WinSLAMM. WinSLAMM adjusts the cost data presented in the tables for the selected city for 2005 by adjusting the m, B values. In this Figure 22, the m, B values are adjusted to 2005 conditions for Birmingham, AL.

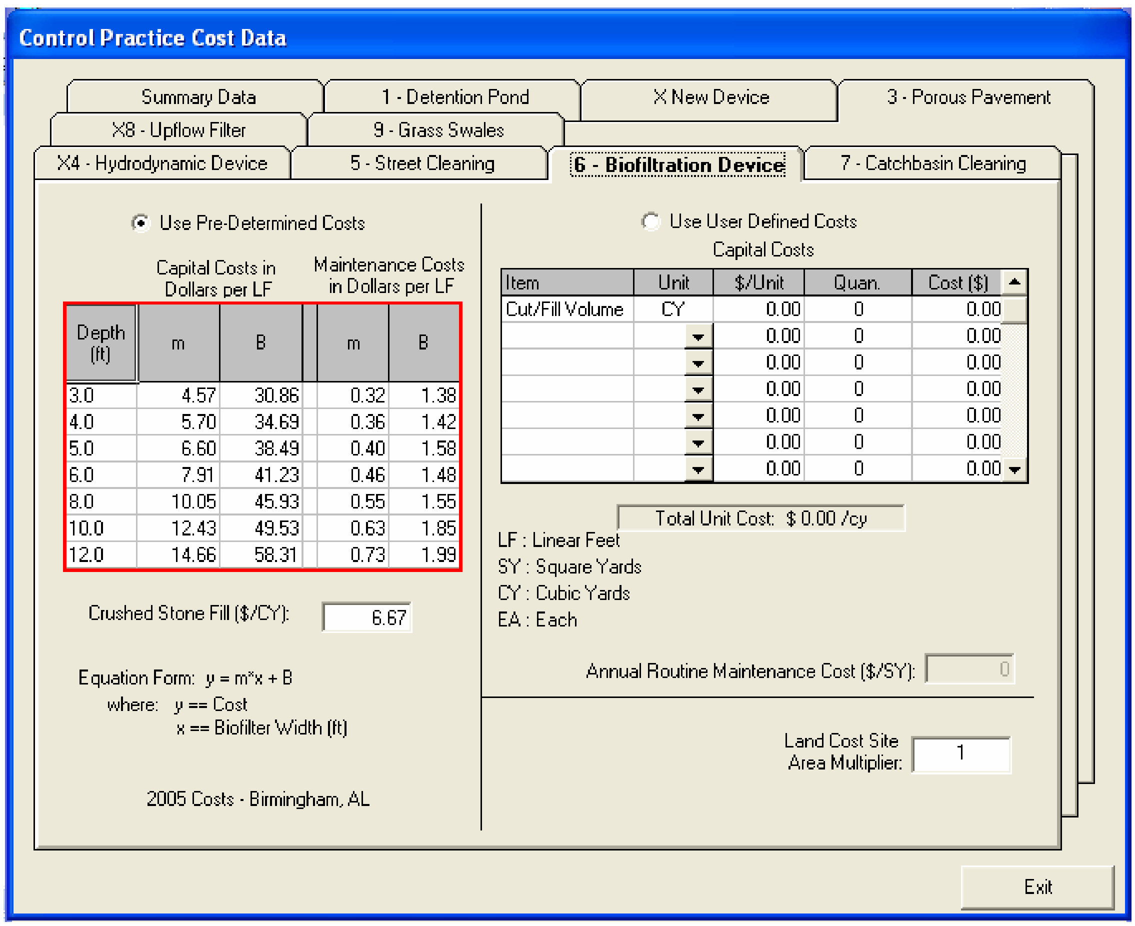


Figure 22. Cost Data Input Screen for Biofiltration Device in WinSLAMM

2.10.5 Green Roofs

A green roof consists of a growing material placed over a waterproofing membrane on a relatively flat roof. A green roof not only provides an attractive roofing option but also uses evapotranspiration to reduce runoff volume, and provides some detention storage. Although green roofs may reduce some pollutants from the rainwater, they usually are significant sources of phosphorus due to leaching from the growing media.

Currently, the initial cost of an extensive green roof in the U.S. starts at about $8 per square foot, which includes materials, preparation work, and installation (http://www.epa.gov/heatisland/strategies/greenroofs.html). Maintenance involves watering, trimming, inspection for drainage and leaks and replacement of roof. An extensive green roof has low lying plants designed to provide maximum groundcover, water retention, erosion resistance, and transpiration of moisture. Extensive green roofs usually use plants with foliage from 2 to 6 inches in height and from 2 to 4 inches of soil. An intensive green roof is intended to be more of a natural landscape, installed on a rooftop. Intensive green roofs may use plants with foliage from 1 to 15 feet tall and may require several feet of soil depth and are therefore not common. The costs for three types of roofs after 31 years of use are shown in Table 81:

Roof #1: A three-ply, asphalt built-up-roofing system with a price of $9.00 per sq. ft. Average life expectancy is 10 years.

Roof #2: A modified hot applied roofing system with a price of $10.00 per sq. ft. Average life expectancy is 20 years.

Roof #3: Two-ply modified bitumen, green roofing system with a price of $12.00 per sq. ft. Average life expectancy is 40 years.

Table 81. Capital, Maintenance and Life Cycle Costs of Green Roofs (W.P.Hickman Systems Inc., 2005)

Cost, $	Roof #1	Roof #2	Roof #3
Initial Capital Expense	225,000	250,000	300,000
Capital Expense/Inflation in year 31	1,154,595 replaced 2x	591,764 replaced 1x	30,000 original roof
Maintenance Costs/Inflation in year 31	26,607	26,607	26,607
Life Cycle Costs in year 31	359,682	283,939	270,447

2.10.6 Bioretention/Rain gardens

Bioretention/rain gardens are landscaped and vegetated filters for stormwater runoff that are incorporated into the landscaping surrounding a building. Stormwater is directed into a shallow, landscaped depression. The bedding material contains a high percentage of sand and smaller amounts of clay, silt and organic material. The recommended organic matter content of the amended soil should be about 5 to 10% to protect groundwater. Stormwater is allowed to pool over this soil and infiltrate through the mulch and prepared soil mix. Excess filtered runoff can be collected in an underdrain or overflow and returned to the storm drain system.

An evaluation of costs and benefits of structural stormwater controls in North Carolina (2003) presented the cost of construction of rain gardens as a function of area of drainage area as shown in Equations 2.43 and 2.44, (2.63) $$C = 10{,}162\,X^{1.088}\text{, in clay soil}$$

(2.64) $$C = 2{,}861X^{0.438}\text{, in sandy soil}$$

where

C = cost, \$, and
X = size of watershed, acres

These cost estimates include labor, installation costs, and a 30% overhead rate. The construction cost does not include the cost of any piping or stormwater conveyance external to the device. Also not included are land costs.

The North Carolina evaluation also showed that the maintenance and inspection of rain gardens involve pruning the shrubs and trees twice a year, mowing seasonally, weeding monthly, remulching 1-2 times over the life time of the device, removing accumulated sediment every 10 to 20 years, and underdrain inspection once a year. These factors were taken into account for estimating the total 20-year maintenance cost presented in Equation 2.45. This cost estimate is the same for clayey and sandy soils.

(2.65) $$C = 3{,}437\,X^{0.152}$$

where

C = cost, \$, and
X = size of watershed, acres

2.10.7 Cisterns and Water Storage for Reuse

Water conservation has many urban water benefits, including reducing wastewater flows and reduced delivery of highly treated and possibly scarce water. A sizeable fraction of the water needs in many areas can be satisfied by using water of lesser quality, such as stormwater. However, the stormwater must be stored for later use. Typical beneficial uses of stormwater include landscape irrigation and toilet flushing. The following is an excerpt of an urban water reuse analysis using WinSLAMM, with some basic cost information. The site being investigated was a new cluster of fraternity housing at Birmingham Southern University.

The runoff from the rooftops is estimated to contribute about 30% of the annual runoff volume for this drainage area. Each building has about 4,000 ft^2 of roof area. One approach was to capture as much of the rainwater as possible, using underground storage tanks. Any overflow from the storage tanks would then flow into rain gardens to encourage infiltration, with any excess entering the conventional stormwater drainage system. The storage tanks can be easily pumped into currently available irrigation tractors, which have 500 gal tanks. The total roof runoff from the six buildings is expected to be slightly more than 100,000 ft^3 (750,000 gal) of water per year. With a cost of about \$1.50 per 100 ft^3, this would be valued at about \$1,500 per year. It is expected that the storage tanks would have a useful life of at least 20 years, with a resultant savings of at least \$30,000 over the tank lifetime, excluding future rising costs of water. One source for plastic underground water storage tanks (Chem-Tainer, New York) lists their tank cost at about \$1,500 for 300 ft^3 units.

Table 82 lists the assumed average irrigation water use, in gal per day, for the roof runoff for each building. This was calculated assuming pumped irrigation near the buildings, with each building irrigating about ½ acre of surrounding turf. If the tanker tractors were used so water could be delivered to other locations on campus, the water use would be greater, and the efficiency of the system would increase, although additional labor and equipment costs would result.

Table 82. Average Water Used from Roof Runoff for Each Building

	Irrigation Needs (inches per month on turf)	Average use for ½ acre (gal/day)
January	1	230
February	1	230
March	1.5	340
April	2	460
May	3	680
June	4	910
July	4	910
August	4	910
September	3	680
October	2	460
November	1.5	340
December	1	230
Total	28	

Table 83 shows the estimated fraction of the annual roof runoff that would be used for this irrigation for different storage tank volumes per building (again assuming pumped irrigation to ½ acre per building):

Table 83. Annual Roof Runoff Used for Irrigation for Different Storage Tank Volumes

Tankage Volume per Building (ft^3)	Fraction of Annual Roof Runoff used for Irrigation
1,000	56%
2,000	56
4,000	74
8,000	90
16,000	98

With this irrigation schedule, there is no significant difference between the utilization rates for 1,000 and 2,000 ft^3 of storage tankage per building, and the water usage tops off at about 8,000 ft^3 of storage. Again, with the tractor rigs, the utilization could be close to 100% for all tanks sizes, depending on the schedule for irrigation for other campus areas: larger tanks would only make the use of the water more convenient and would provide greater reserves during periods of dry weather. Also, small tanks would overflow more frequently during larger rains. For this reason, at least 1,000 ft^3 of tankage (3 or 4 of the 300 ft^3 tanks) per building is recommended for this installation.

2.11 Education Programs

Public education programs are needed for raising public awareness and therefore creating support for stormwater management and water conservation programs. It is difficult to quantify actual pollutant reductions associated with educational efforts. However, public attitude can be gauged to predict how these programs perform. Public education programs include activities like fertilizer and pesticide management, public involvement in stream restoration and monitoring projects, storm drain stenciling and overall awareness of aquatic resources. All education programs aim at reducing pollutant loadings by changing people's behavior and also to make people aware and gain support for programs in place to protect water resources. Some unit costs (1999 dollars) for educational program components (based on two different programs) are included in the Table 84.

Table 84. Unit Program Costs for Public Education Programs (US EPA, 1999)

Item	Cost
Public Attitude Survey	\$1,250-\$1,750 per 1000 households
Flyers	10-25 ¢/flyer
Soil Test Kit*	\$10
Paint	25-30 ¢/SD Stencil
Safety Vests for Volunteers	\$2

Note: * Includes cost of testing, but not sampling

Table 85 provides information on some educational expenditure (a portion of the entire annual budget) in Seattle with a population of 535,000. The city of Seattle has a relatively aggressive public education program for wet weather flow issues, including classroom and field involvement programs.

Table 85. 1997 Budget for Some Aspects of the Public Education Costs in Seattle, Washington, (US EPA, 1999)

Item	Description	Budget ($)
Supplies for Volunteers	Covers supplies for the Stewardship through environmental partnership program	17,500
Communications	Communications strategy highlighting a newly formed program within the city	18,000
Environmental Education	Transportation costs from schools to field visits (105 schools with four trips each)	46,500
Education Services/ Field Trips	Fees for student visits to various sites	55,000
Teacher Training	Covers the cost of training classroom teachers for the environmental education program	3,400
Equipment	Equipment for classroom education, including displays, handouts, etc.	38,800
Water Interpretive Specialist: Staff	Staff to provide public information at two creeks	79,300
Water Interpretive Specialist: Equipment	Materials and equipment to support interpretive specialist program	12,100
Youth Conservation Corps	Supports clean-up activities in creeks	210,900

Table 86 shows the various institutional source controls from the survey conducted by the Water Resources Committee, American Public Works Association, Southern California Chapter in 1992.

Table 86. Costs of Institutional Source Controls (APWA, 1992)

Type of Practice	Area of Benefit	Storm Protection Benefit	Pollutants Controlled	Construction Requirements	Capital Cost	O&M Cost
Public Education (Billing Inserts, News Releases, Radio Public Service Announcements, School Programs and Pamphlets)	Not Applicable	Reduced pollutant load to storm drain system.	Can reduce improper disposal of paints, varnishes, thinners, pesticides, fertilizers, and household cleansers, and chemicals, etc.	None	$200,000/year	$257,000/year
Litter Control	Site dependent	Reduced potential for clogging and discharge	Household and restaurant paper, plastics, and glass.	Increase number of trash receptacles.	$20 per trash receptacle.	$16/acre/year
Recycling Programs	Site dependent	Reduction in potential for clogging and harmful discharge.	Household paper, glass, aluminum, and plastics. Oil and grease from auto maintenance.	Collection and sorting stations.	$200,000/year	$350,000 per 300,000 city population.
"No Littering" Ordinance	Storm drain system and receiving water	Prohibits littering and prevents litter from entering storm drains.	Paper, plastics, glass, food wrappers and containers.	None	$20,000	Potential to be self-supporting by fines.
"Pooper Scooper" Ordinance	Storm drain system and receiving water	Requires animal owners to clean up and properly dispose of animal wastes.	Coliform bacteria and nitrogen/urea.	None	$20,000	Potential to be self-supporting by fines.
Develop and Enact Spill Response Plan	Site dependent	Prevent pollutants from entering storm drain.	Hazardous chemical, harmful chemicals, oil, and grease.	None	$20,000	Not Available

Table 86 – Continued.

Type of Practice	Area of Benefit	Storm Protection Benefit	Pollutants Controlled	Construction Requirements	Capital Cost	O&M Cost
Require Tow Truck Drivers to Clean Up Chemical Spills from Accident Sites.	Site dependent	Prevent hazardous or harmful pollutants from entering storm drain.	Hazardous chemical, harmful chemicals, oil, and grease.	None	Not Applicable	Self-supporting by driver clean-up fees. Not available.
Clean-Up Vacant Lots	Site dependent	Prevent debris from accumulating on lot. Prevent site from appearing as a "dump" for others to use for disposal. Eliminate sources of hazardous waste.	Hazardous and/or harmful chemicals, wind blown for water borne debris.	None	Not Applicable	Self-supporting by City fines to lot owners.
Prohibit Illegal and Illicit Connections and dumping into Storm Drain System	Storm drain system and receiving water	Reduces pollutant load entering storm drains.	Coliform bacteria, nitrogen, contaminants, and toxic or harmful chemicals	None	$2/acre	Self-supporting by fines to illegal/illicit dischargers.
Identify, Locate and Prohibit Illegal or Illicit Discharge to Strom drain system	Area-wide	Halt hazardous and harmful discharges, whether intentional or negligent.	Sewage from cross connections, oil, grease, direct disposal of pesticides and fertilizers, contaminated water, paint, varnish, solvents, water from site dewatering, swimming, pool and spa water, flushing water from radiators and cooling systems, and hazardous or harmful chemicals.	Monitor storm drain system for flows and water quality	$2/acre (Assumes 1 monitor every 5 square mile.)	$50/acre/year (includes TV inspection of storm drains)

Table 86 – Continued.

Type of Practice	Area of Benefit	Storm Protection Benefit	Pollutants Controlled	Construction Requirements	Capital Cost	O&M Cost
Require proper storage, use and disposal of fertilizers, pesticides, solvents, paints and varnishes and other household chemicals (oil, grease and antifreeze, etc)	Site dependent (city, state, or country wide)	Reduce pollutant load to storm system	Household hazardous materials	None	Not applicable	Not available
Restrict paving and use of non-porous cover materials in recharge areas.	Recharge area site	Promotes infiltration to groundwater and reduces runoff volume and velocity. Filters pollutants	Not applicable	Establishment of vegetation or use of recharge/infiltration materials	Not available	None

2.13 Chapter Summary

This chapter presented the capital, operation, and maintenance costs for various stormwater control practices in the form of tables and equations. The costs for educational programs were presented in Section 2.11. Sections 2.12.2, 2.12.3, 2.12.4 and 2.12.5 presented the capital, operation, and maintenance costs for wet detention ponds, permeable pavement, grass swales and biofiltration devices, respectively of varying sizes. The cost data presented in the form of tables were transformed into equations and integrated into WinSLAMM. However, the costs presented in this chapter from various sources represented the regional costs for these controls for a particular year. Cost indices published by ENR for 20 cities within the US were integrated into WinSLAMM to convert the regional cost data to a particular location and year.

Tables 2 and 3 of Section 2.3.1 show the capital cost ($/LF) for corrugated metal pipes and reinforced concrete pipes for different diameters. Sections 2.3.2, 2.3.3, 2.3.4, 2.3.5, 2.3.6 and 2.3.7 presented the capital costs of trench excavation, bedding, backfill, manhole, inlets, and curbs and gutters, respectively. The costs for these stormwater conveyance system components obtained from RS Means Building Construction Costs (2006) were transformed into equations. These equations were then used to develop an Excel spreadsheet model to estimate the cost of conventional stormwater drainage system. The transformed equations along with example calculations are presented in the following Chapter.

Chapter III
Cost Estimation Spreadsheet Model - Conventional Stormwater Conveyance System

3.1 Introduction

The costs of the conventional stormwater drainage system need to be known for comparison to the costs associated with replacement parts of the system with alternatives that also provide water quality benefits. As noted in Chapter II, cost equations have been integrated into WinSLAMM to enable direct calculations of the different water quality controls. This chapter describes a spreadsheet model that was developed as part of this research that calculates the costs associated with the conventional drainage system. These data can then be used in a decision analysis framework to guide in the selection of the best stormwater management system for an area, considering pollutant discharges and flow conditions, along with capital and O&M costs.

Typical stormwater conveyance systems consist of the curb and gutter, drain inlets, and the pipe network system, along with ancillary components such as manholes. Storm sewer systems follow the alignment of the roadway, increasing in size as necessary to accept the flow from a series of inlets. The stormwater conveyance system functions primarily by collecting and conveying the surface runoff to a predetermined outlet to prevent flooding during storms. This chapter presents the working of the Excel spreadsheet model developed to estimate the costs involved in the construction of a conventional stormwater conveyance system. Also presented are equations incorporated into the spreadsheet model developed from unit cost data for stormwater conveyance system component costs such as pipes, excavation trenches, bedding, backfill, inlets, manholes and curb and gutter available in RS Means Building Construction Cost Data, 2006. Examples calculations to illustrate the cost calculations by the spreadsheet model to estimate the costs of individual components of the stormwater conveyance system are shown at the end of each section.

3.2 Cost Estimation Model

An Excel spreadsheet model was developed to estimate the total cost of a conventional stormwater conveyance system. The spreadsheet model includes estimates for the cost of pipe, trench excavation, bedding, backfill, compaction, catchbasin inlets, curbs and gutters, and manholes. Figure 23 shows a conceptual representation of the components of the conveyance system, the variables for these components, and the costs of the components estimated using the variables. The sum of the individual component costs gives the total capital cost of the conventional stormwater conveyance system.

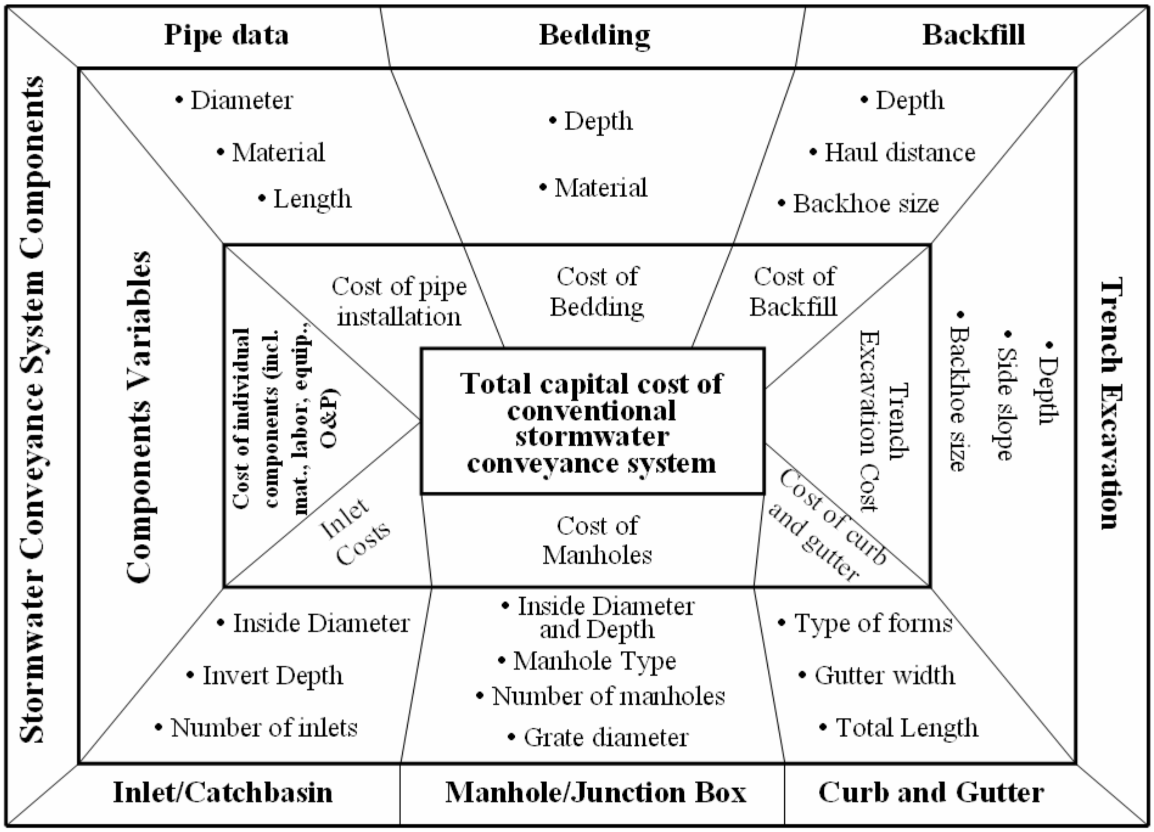


Figure 23. Stormwater Conveyance System Components

The component variables are entered into the Excel spreadsheet model either through drop-down menus or through direct cell entry. The following input variables are selected form the drop-down menu:

- Pipe diameter in inches,
- Selection of pipe material (reinforced concrete or corrugated metal),
- Trench slope,
- Type of backhoe size for excavation,
- Bedding material,
- Backhoe size for backfill,
- Haul distance for backfill material,
- Internal riser diameter of manhole in feet,
- Type of manhole,
- Width of curb and gutter in inches and
- City and year selection for ENR cost index

In addition, the following variables are entered directly into selected non shaded cells on the spreadsheet (the yellow cells are locked to prevent changing the embedded equations which would affect the internal calculations):

- Bedding depth in inches,
- Backfill depth above pipe crown in inches,
- Length of selected pipe in feet,
- Invert depth of inlet in feet,

- Number of inlets,
- Depth of manhole in feet,
- Number of manholes,
- Length of curb in feet,
- Land cost in US dollars,
- Maintenance cost in US dollars,
- Interest rate of debt capital in %,
- Financial period in years of project,
- Expected life of project in years,
- Annual maintenance cost for 1st year in US dollars and
- Anticipated inflation during life of project in %

Figure 24 shows a cross-sectional view of the stormwater conveyance system. Seen in the figure are the following variables: trench top and bottom width, trench depth, bedding depth, backfill depth and pipe diameter.

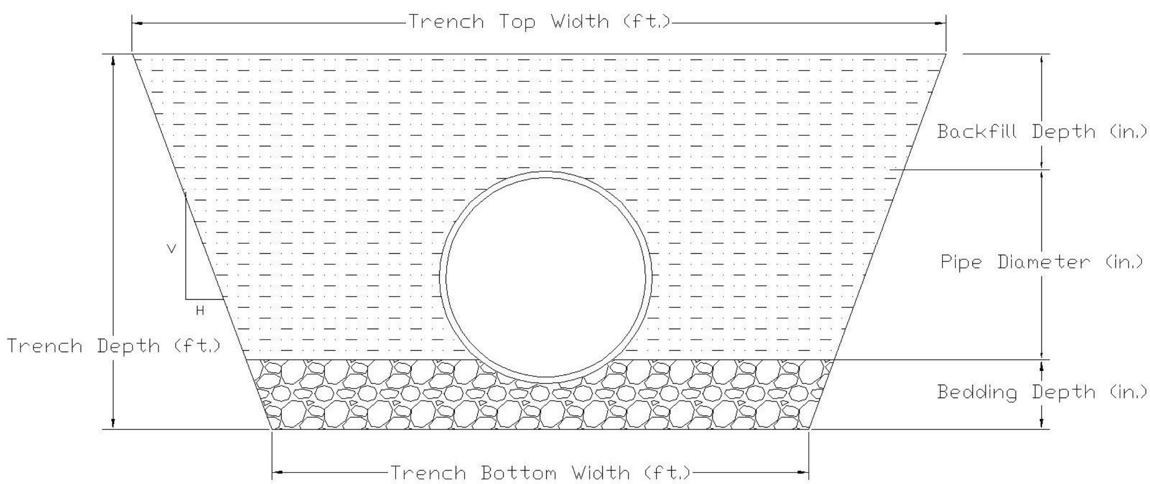
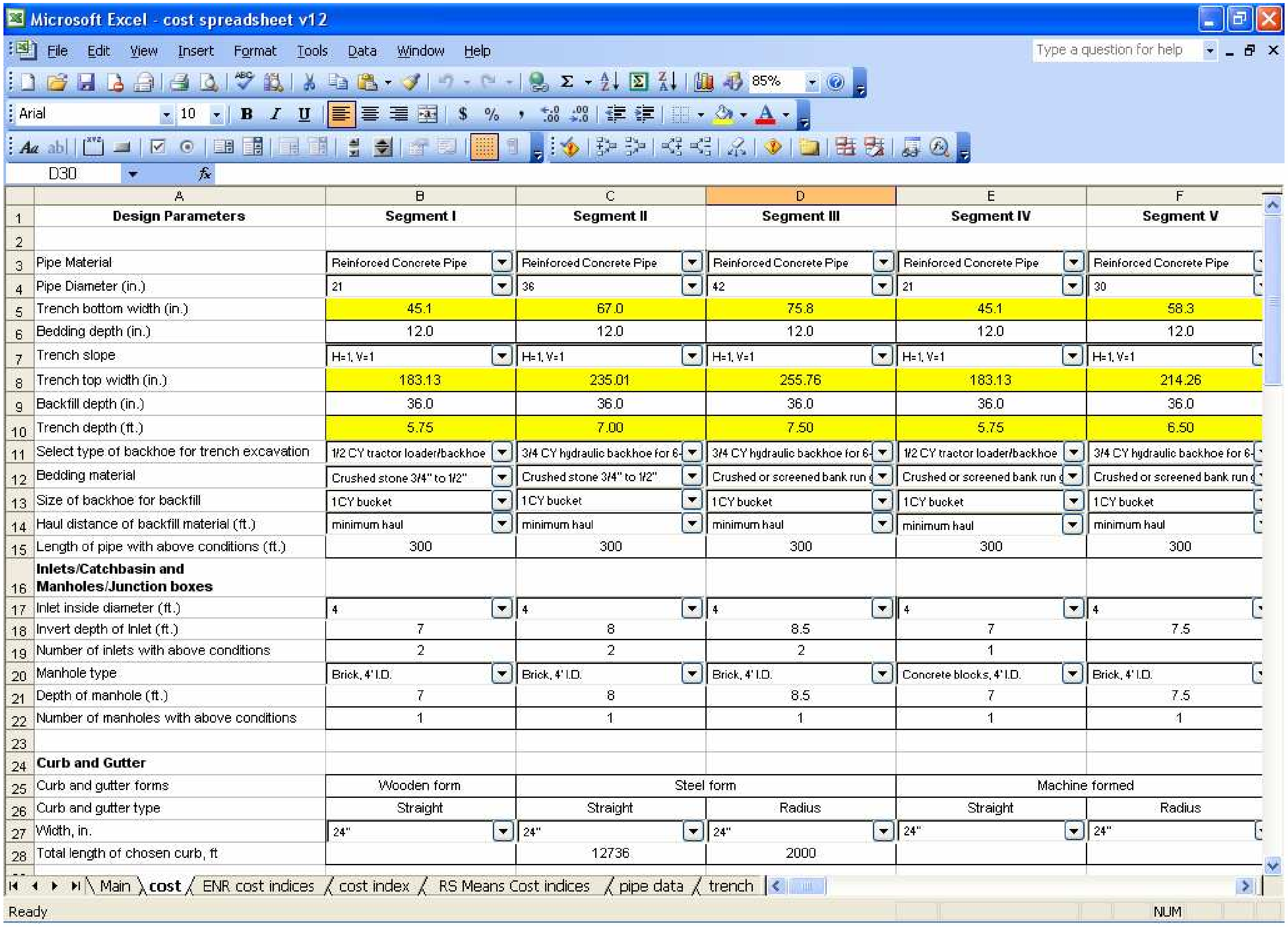


Figure 24. Cross Section View of Stormwater Conveyance System Components

Figure 25 shows the input screen of the spreadsheet model with the various input parameters for each component.



	A	B	C	D	E	F
1	**Design Parameters**	**Segment I**	**Segment II**	**Segment III**	**Segment IV**	**Segment V**
2						
3	Pipe Material	Reinforced Concrete Pipe	Reinforced Concrete Pipe	Reinforced Concrete Pipe	Reinforced Concrete Pipe	Reinforced Concrete Pipe
4	Pipe Diameter (in.)	21	36	42	21	30
5	Trench bottom width (in.)	45.1	67.0	75.8	45.1	58.3
6	Bedding depth (in.)	12.0	12.0	12.0	12.0	12.0
7	Trench slope	H=1, V=1	H=1, V=1	H=1, V=1	H=1, V=1	H=1, V=1
8	Trench top width (in.)	183.13	235.01	255.76	183.13	214.26
9	Backfill depth (in.)	36.0	36.0	36.0	36.0	36.0
10	Trench depth (ft.)	5.75	7.00	7.50	5.75	6.50
11	Select type of backhoe for trench excavation	1/2 CY tractor loader/backhoe	3/4 CY hydraulic backhoe for 6-	3/4 CY hydraulic backhoe for 6-	1/2 CY tractor loader/backhoe	3/4 CY hydraulic backhoe for 6-
12	Bedding material	Crushed stone 3/4" to 1/2"	Crushed stone 3/4" to 1/2"	Crushed or screened bank run	Crushed or screened bank run	Crushed or screened bank run
13	Size of backhoe for backfill	1CY bucket	1CY bucket	1CY bucket	1CY bucket	1CY bucket
14	Haul distance of backfill material (ft.)	minimum haul	minimum haul	minimum haul	minimum haul	minimum haul
15	Length of pipe with above conditions (ft.)	300	300	300	300	300
16	**Inlets/Catchbasin and Manholes/Junction boxes**					
17	Inlet inside diameter (ft.)	4	4	4	4	4
18	Invert depth of Inlet (ft.)	7	8	8.5	7	7.5
19	Number of inlets with above conditions	2	2	2	1	
20	Manhole type	Brick, 4' I.D.	Brick, 4' I.D.	Brick, 4' I.D.	Concrete blocks, 4' I.D.	Brick, 4' I.D.
21	Depth of manhole (ft.)	7	8	8.5	7	7.5
22	Number of manholes with above conditions	1	1	1	1	1
23						
24	**Curb and Gutter**					
25	Curb and gutter forms	Wooden form	Steel form		Machine formed	
26	Curb and gutter type	Straight	Straight	Radius	Straight	Radius
27	Width, in.	24"	24"	24"	24"	24"
28	Total length of chosen curb, ft		12736	2000		

Figure 25. Portion of the Input Screen of Spreadsheet Model

The spreadsheet can calculate the total costs for up to 100 different segments of pipe. The data used in the spreadsheet model were obtained from *RS Means Building Construction Cost Data* (2006). These values are available in the form of look-up tables. However, to incorporate the data into the spreadsheet model, equations were fitted to this data to calculate the cost with one or more of the parameters as the variable. The transformed equations and the graphs are presented for each section. These values and tables are repeated in this section from Chapter II to show how data was used in the model. Figure 26 shows a flowchart representing the steps involved in the spreadsheet model to estimate the costs involved in the construction of a stormwater conveyance system.

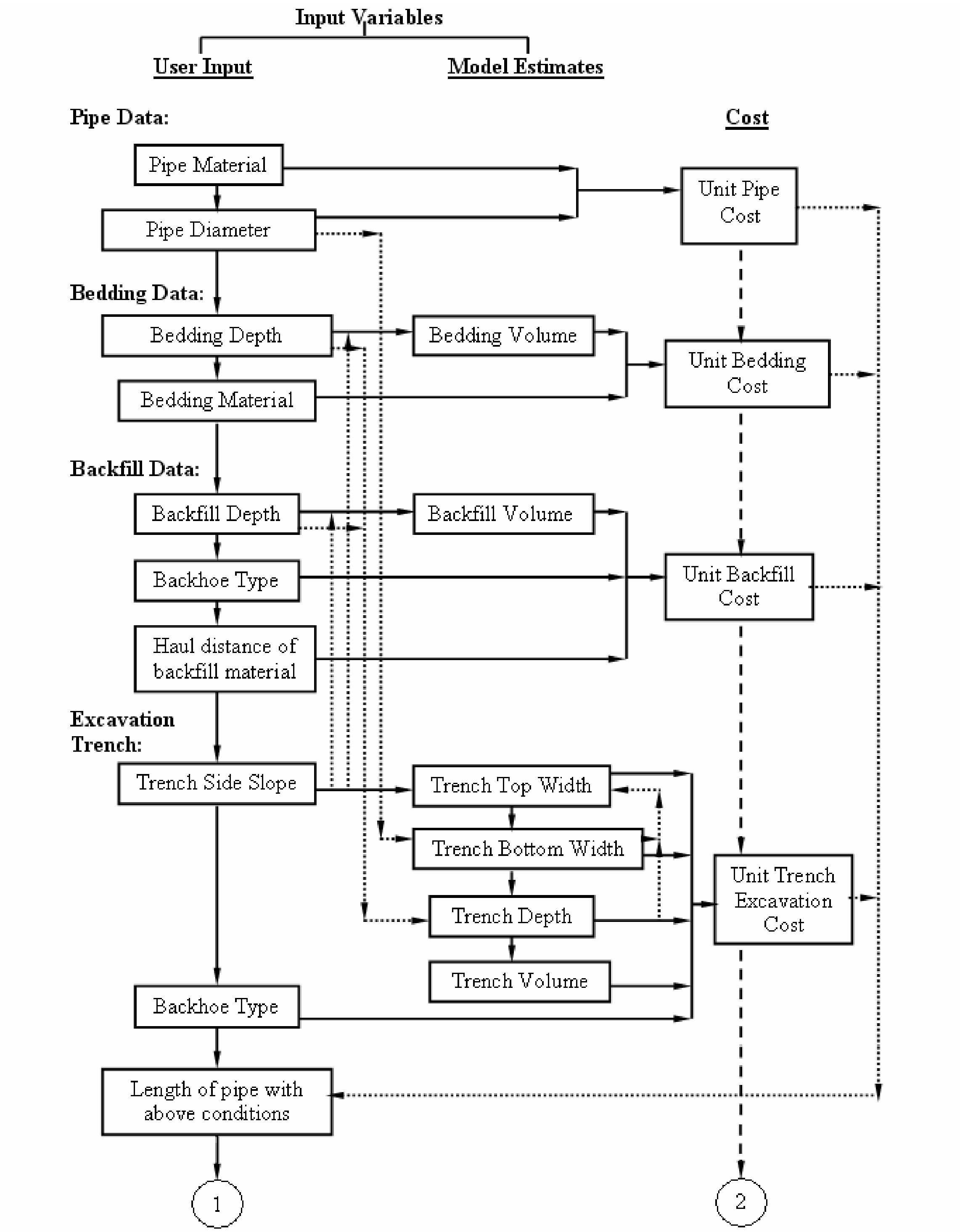


Figure 26. Flowsheet Representation of Spreadsheet Model

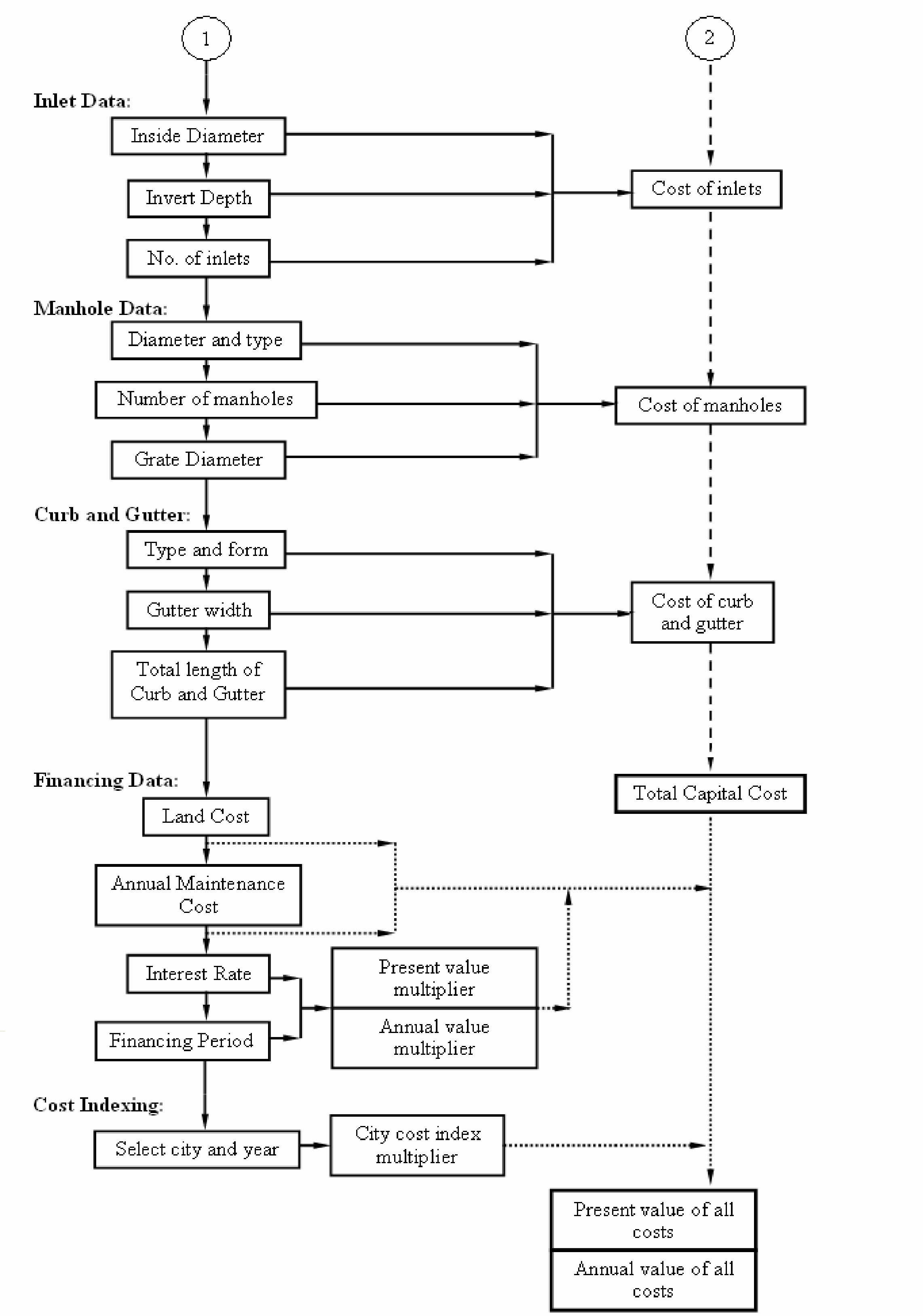


Figure 26 – Continued.

3.2.1 Pipe Costs

The available choice of pipe diameters (inches) in the spreadsheet for *Corrugated Metal Pipe* (CMP) are 8, 10, 12, 15, 18, 24, 30, 36, 48, 60, and 72 inches and for *Reinforced Concrete Pipe* (RCP) are 12, 15, 18, 21, 24, 27, 30, 36, 42, 48, 60, 72, 84, and 96 inches. The pipe costs were calculated as a function of pipe diameter, pipe material and total length of pipe used. Figures 27 and 28 show the pipe parameter input cells.

Figure 27. Pipe Material Input Cells

Figure 28. Pipe Diameter Input Cells

Tables 2 and 3 in Chapter II show the cost of RCP and CMP pipe per linear foot. Figure 29 shows the cost of stormwater conveyance pipelines considering pipe diameter and type (not depth). The magnitudes of the possible errors are also shown in the figure when these equations are fitted to published R.S. Means cost estimating values. The labor costs are the average rates for 30 major U.S. cities. Excavation, backfill and bedding costs are discussed in the next subsections and are in addition to these costs.

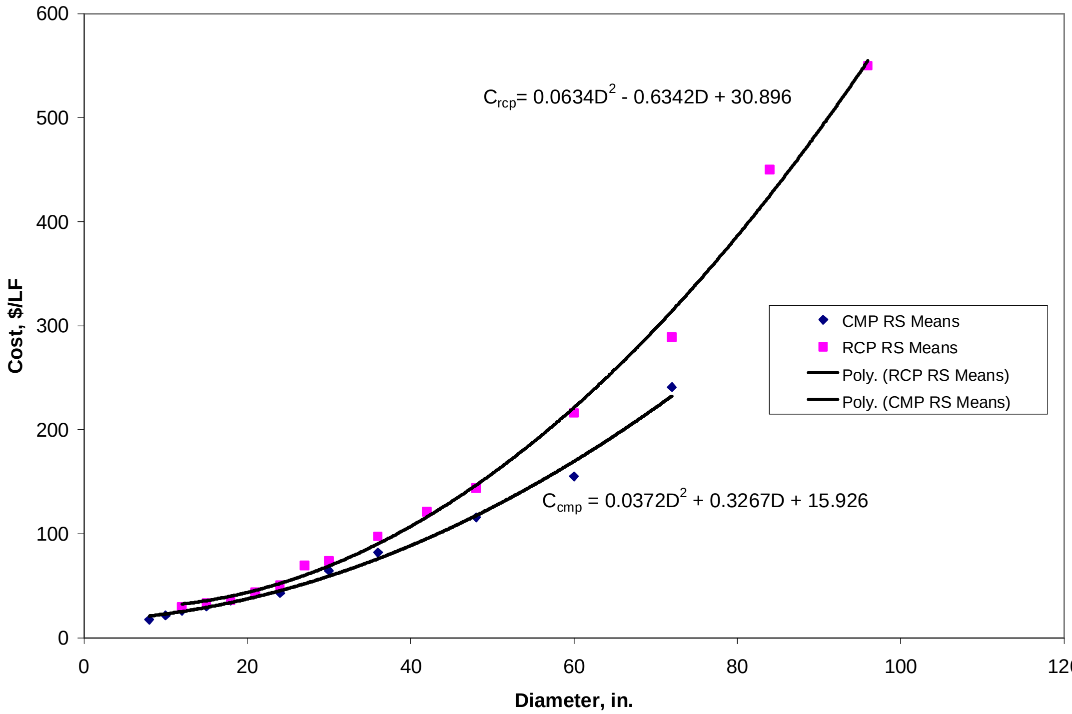


Figure 29. Stormwater Conveyance Pipe Costs for Different Diameter

A second-order polynomial equation was fitted to the data. The equation below is for corrugated metal pipe (CMP) and reinforced concrete pipe (RCP), using RS Means data:

(3.1) $C_{cmp} = 0.0372D^2 + 0.3267D + 15.926$, for CMP

(3.2) $C_{rcp} = 0.0634D^2 - 0.634D + 30.896$, for RCP

where

C = construction cost, \$/ft, and

D = pipe diameter, in.

These equations were incorporated into the spreadsheet model. The diameter and the pipe material are chosen from the drop-down menu in the spreadsheet model to calculate the cost of the pipe in dollars per linear foot. When the total length of the desired pipe is entered, the spreadsheet calculates the cost in U.S. dollars for that segment of the chosen pipe material and diameter.

Example Calculation:

Pipe material = Reinforced concrete pipe (RCP)

Pipe diameter = 24 in.

Length of chosen pipe = 200 ft.

Model estimate:

Cost of RCP per linear foot = $0.0634D^2 - 0.634D + 30.896$

= $(0.0634 * 24^2) - (0.634 * 24) + 30.896$

= \$ 52.11 per linear foot

Total cost of pipe = Length of pipe * \$/LF

= 200 * 52.11

= \$ 15,632

3.2.2 Excavation Trench Cost

The bottom width of the trench is calculated based on pipe diameter. The *Means Estimating Handbook* gives trench bottom widths for various outside diameters of buried pipes (Table 87).

Table 87. Trench Bottom Width for Outside Diameters of Buried Pipes (RS Means Company, 1990)

Outside Diameter, (in.)	Trench Bottom Width, (ft.)
24	4.1
30	4.9
36	5.6
42	6.3
48	7.0
60	8.5
72	10.0
84	11.4

When this data is plotted on a graph (Figure 30) a straight line is fitted to this data and relates trench bottom width and pipe diameter, as shown in Equation 3.3.

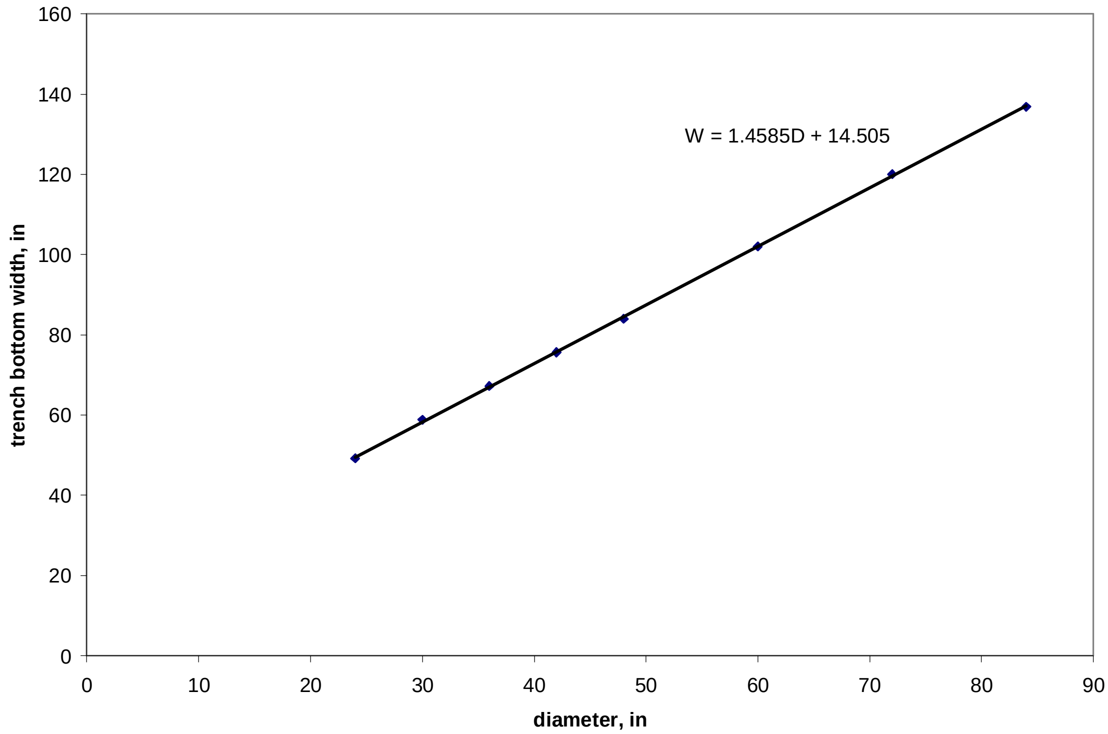


Figure 30. Trench Bottom Widths for Different Pipe Diameters

The pipe outside diameter (inches) and trench bottom width are related by the following equation:

(3.3)

$$W = 1.4585D + 14.505$$

where

W = trench bottom width, in., and

D = pipe outside diameter, in.,

This equation was then used in the cost spreadsheet model to estimate the trench bottom width from the pipe diameter selected for the segment. The equation was also used to estimate the trench bottom widths for other pipe diameters not shown in the Table 86.

Trench excavation costs for different trench depths and backhoe sizes are shown in Table 5. Trench side slope options available in the spreadsheet model are 0, 0.5, 1, 1.5, and 2. Based on the user's choice of trench slope and the total trench depth, the top width of the trench is calculated by the spreadsheet. The total depth of the trench is calculated as the summation of pipe diameter selected from the drop down menu, the bedding depth in inches, and backfill depth in inches (height from crown of the pipe to the top of the trench), as shown in Figure 31. These values are entered manually depending on conditions at the location of the trench.

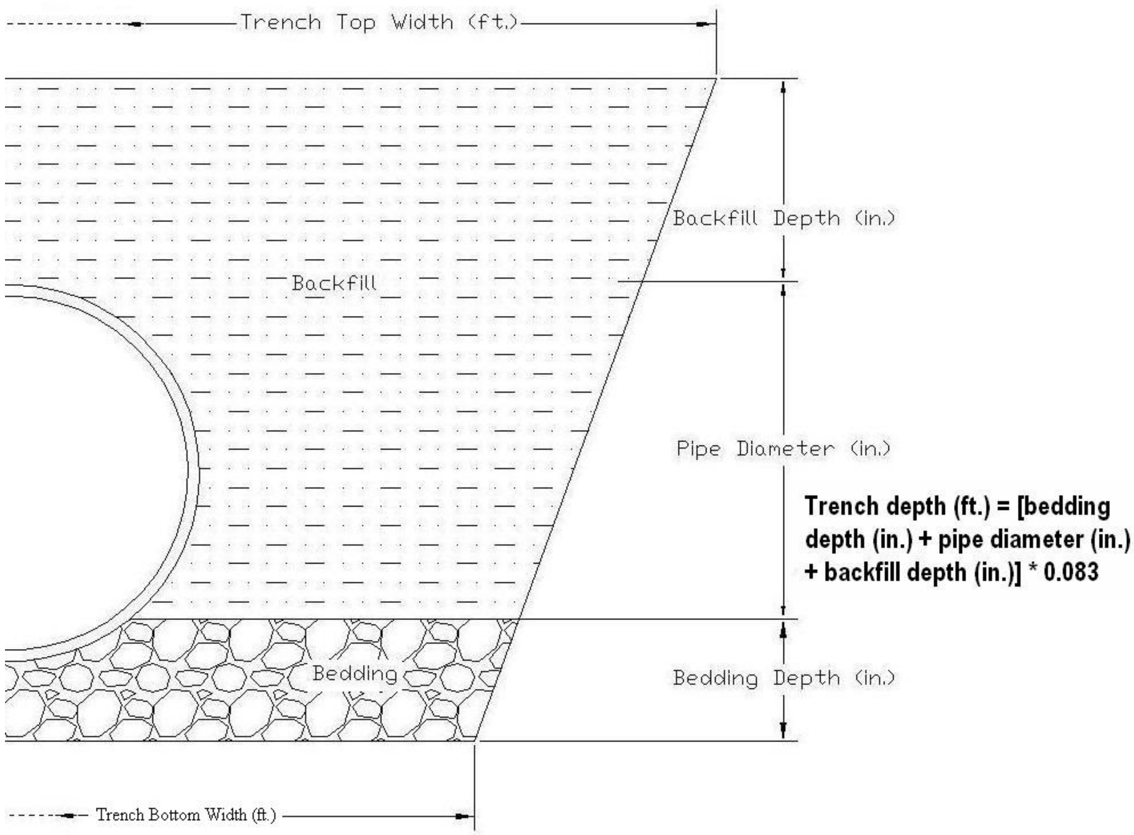


Figure 31. Transverse View of Excavation Trench Showing Components

The volume of the trench is calculated as the product of the area of the cross-section trapezoid and the total length of the trench. Also, the choice of different backhoe sizes for different trench depths are available from the drop-down menu and, depending on the total volume of trench, the trench excavation cost is calculated. Figure 32 shows the rows in the spreadsheet model where the trench data is entered.

5	Trench bottom width (in.)	45.1
6	Bedding depth (in.)	12.0
7	Trench slope	H=1, V=1
8	Trench top width (in.)	183.13
9	Backfill depth (in.)	36.0
10	Trench depth (ft.)	5.75
11	Select type of backhoe for trench excavation	1/2 CY tractor loader/backhoe

Figure 32. Trench Parameter Input Values

RS Means gives the cost of trench excavation in dollars per cubic yard based on depth of trench in feet and backhoes size in cubic yard.
Example calculation:
Diameter of pipe = 24 in.
Pipe material = Corrugated Metal Pipe
Selected trench slope (H/V) = 1
Bedding depth = 12 in.
Backfill depth = 36 in.
Model estimates:
Total trench depth = pipe diameter + bedding depth + backfill depth
= 24 + 12 + 36
= 6 ft.
Bottom width of trench, $W = 1.4585D + 14.505$
= (1.4585 * 24) + 14.505
= 4.1 ft.
The trench top width for a slope of 1:1, trench depth of 72 inches and bottom width of 49.5 inches = 49.5 + 72 + 72 = 193.5 inches
The volume of the trench was calculated using the trapezoid formula,

$$V = \frac{1}{2} * H * (B_1 + B_2) * L \qquad (3.4)$$

where

V = volume of trench, cu.in.,
H = depth of trench, in.,
B_1 = bottom width of trench, in.,
B_2 = top width of trench, in., and
L = length of trench for considered pipe segment, in.

Volume of the trench using trapezoid formula = [0.5 * 72 * (49.5 + 193.5)] * (200*12)
= 20,995,200 cu.in.
= 441 CY

The model gives different choices of backhoe sizes based on total depth of trench. From the RS Means cost data, for a trench depth of 6 feet, the available choice of backhoe sizes in the spreadsheet model are ½ CY tractor/backhoe, 5/8 CY hydraulic backhoe and ¾ CY hydraulic backhoe. For a 5/8 CY hydraulic backhoe, the trench excavation cost is 4.94 $/CY.
Total cost of digging this trench = 441 CY * 4.94 $/CY = $ 2,178

3.2.3 Bedding Cost

Crushed or screened bank run gravel, crushed stone ¾” to ½,” and sand, gravel or bank are the materials available for the bedding options in the model. Bedding costs in $/LCY are shown in Table 6 (RS Means, 2006) in Chapter II. The user enters the desired bedding depth, which is used to calculate the bedding volume. The cost of the bedding is then calculated based on the bedding material chosen. Row 6 of the spreadsheet accepts the bedding depth in inches and row 12 has the dropdown to enter bedding material as shown in Figure 33.

6	Bedding depth (in.)	12.0
7	Trench slope	H=1, V=1
8	Trench top width (in.)	183.13
9	Backfill depth (in.)	36.0
10	Trench depth (ft.)	5.75
11	Select type of backhoe for trench excavation	1/2 CY tractor loader/backhoe
12	Bedding material	Crushed stone 3/4" to 1/2"

Figure 33. Bedding Parameter Input Cells

Example Calculation:
Depth of bedding = 12 in.
Slope of trench = 1:1
Trench bottom width = 49.5 in.
Bedding material = crushed stone ¾ in. to ½ in.
Model Estimates:
The top width of the bedding is calculated using side slope of the trench and bottom width.
Top width of bedding = 49.5 + 12 + 12 = 73.5 in.
The volume of bedding is calculated as the volume of the trapezoid.
Volume of bedding = [0.5 * 12 * (49.5 + 73.5)] * 200 * 12
= 535,610.88 cu.in.
= 37.2 CY
Cost of bedding using crushed stone ¾ in. to ½ in. = 39.5 $/CY
Cost of bedding = 37.2 * 39.5 = $ 1,469

3.2.4 Backfill Cost

RS Means (2006) presents the backfill cost in dollars per cubic yard as a function of backhoe size and haul distance for the backfill material. The volume of the backfill required is calculated in the spreadsheet model by subtracting the volume occupied by the pipe and the bedding volume from the trench volume. The volume calculations for the bedding and trench are shown in the previous sections. The data shown in Table 7 (SEWRPC, 2006) in Chapter II, along with the backfill depth (inches) is used in the spreadsheet to calculate the total cost of backfill. Figure 34 shows the input screen to enter these parameters.

9	Backfill depth (in.)	36.0
10	Trench depth (ft.)	5.75
11	Select type of backhoe for trench excavation	1/2 CY tractor loader/backhoe
12	Bedding material	Crushed stone 3/4" to 1/2"
13	Size of backhoe for backfill	1 CY bucket
14	Haul distance of backfill material (ft.)	minimum haul

Figure 34. Backfill Data Input Cells

Example Calculation:
Volume of trench = 441 CY
Volume of bedding = 37.2 CY
Backhoe size for trench backfill = 2-1/4 CY bucket
Haul distance = 100 feet haul
Model Estimate:

Volume of pipe = $\frac{\pi D^2}{4} L$

$= 3.14 * 2^2 * 0.25 * 200$

= 23.24 CY

Volume of backfill = Trench volume – (Bedding Volume + Pipe Volume)

= 441 – (37.2 + 23.24)

= 380 CY

Cost of backfill per linear cubic yard = 2.36 $/LCY
Cost of backfill = 2.36 * 380 = $ 898

3.2.5 Inlet and Catchbasin Costs

Stormwater inlets intercept stormwater on the ground surface or in a roadway gutter and convey it to the storm sewer piping system. An inlet consists of a grating at the surface and a subsurface box that supports the inlet grating and connects to the subsurface piping system. Figure 35 shows a diagrammatic representation of a stormwater inlet with a small sump, making it a catchbasin (the sump depth should be about 3 ft deep to be an effective sediment trap). Without this sump, this would be termed a standard box inlet.

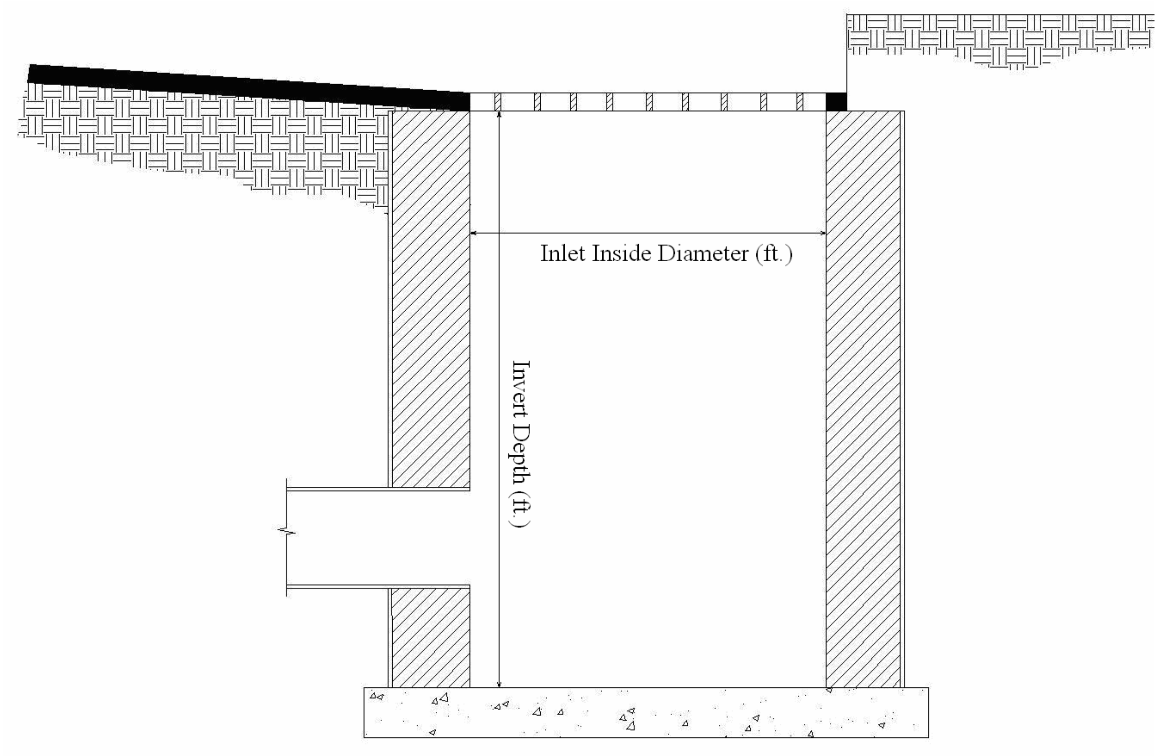


Figure 35. Stormwater Catchbasin Inlet

The costs for unit precast inlets for different inside diameters and depths are provided in *RS Means Building Construction Cost Data* (Table 12 in Chapter II); the cost does not include the cost of footing, excavation, backfill, frame, and grating cover. This data is plotted on Figures 36, 37 and 38 and fitted equations for 4, 5 and 6 feet internal diameters, as shown by Equations 3.5, 3.6 and 3.7, respectively.

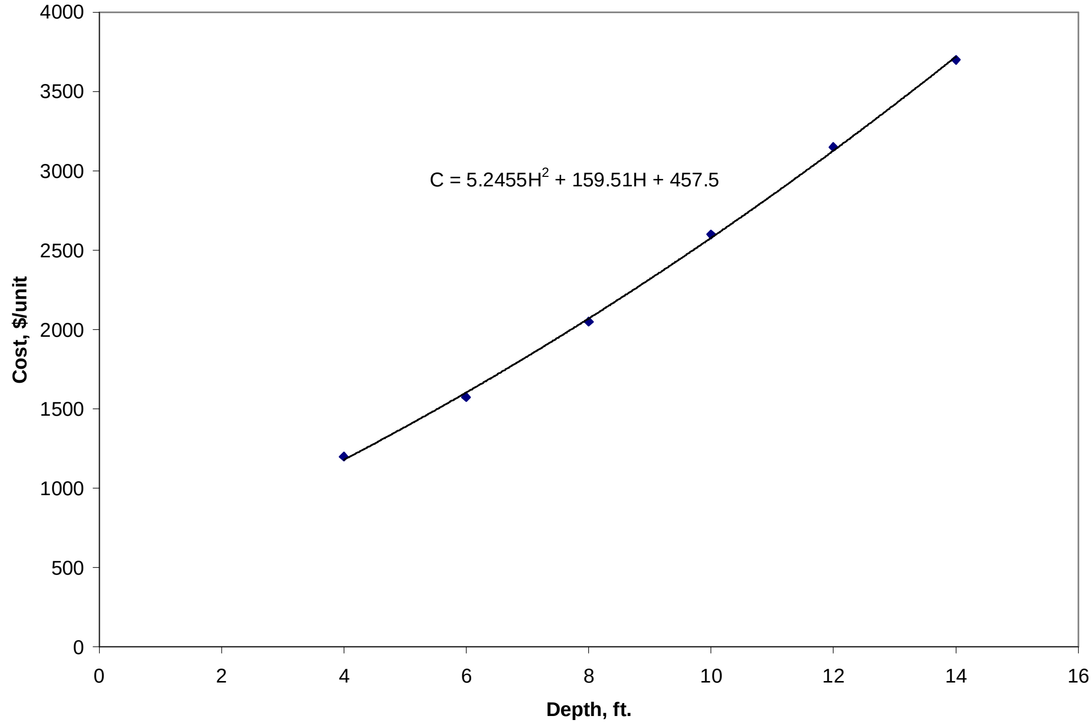


Figure 36. Capital Cost for Catchbasin Inlet of 4 ft. ID

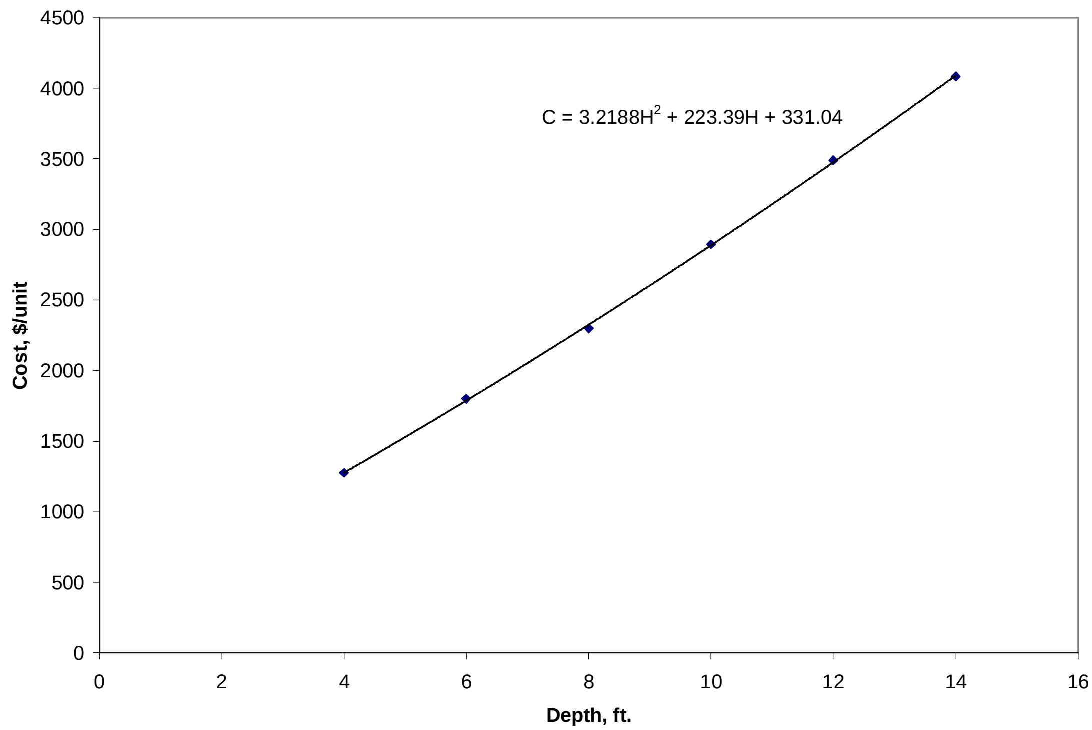


Figure 37. Capital Cost for Catchbasin Inlet of 5 ft. ID

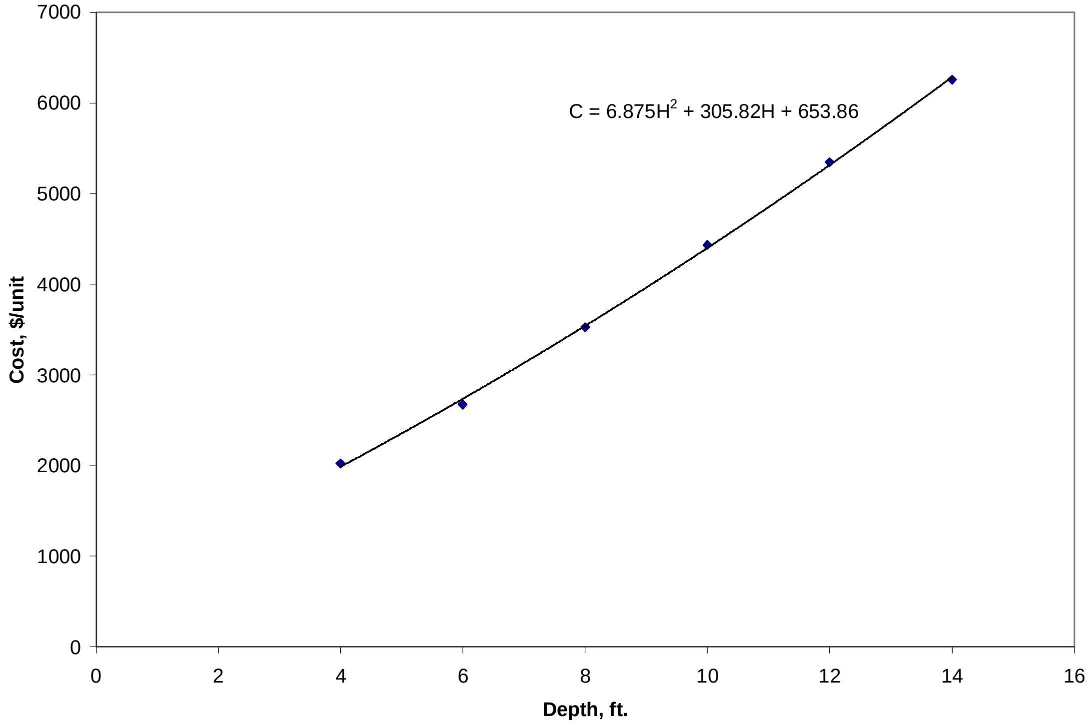


Figure 38. Capital Cost for Catchbasin Inlet of 6 ft. ID

(3.5) $C_{i,4} = 5.2455H^2 + 159.51H + 457.5$, for 4 ft inside diameter

(3.6) $C_{i,5} = 3.2188H^2 + 223.39H + 331.04$, for 5 ft. inside diameter

(3.7) $C_{i,6} = 6.875H^2 + 305.82H + 653.86$, for 6 ft. inside diameter

where

C_{mh} = cost of manhole, \$, and
H = depth of manhole, ft

Figure 39 shows the data input cells in the model.

16	**Inlets/Catchbasin and Manholes/Junction boxes**	
17	Inlet inside diameter (ft.)	4
18	Invert depth of Inlet (ft.)	7
19	Number of inlets with above conditions	2
20	Manhole type	Brick, 4' I.D.
21	Depth of manhole (ft.)	7
22	Number of manholes with above conditions	1

Figure 39. Inlet and Manholes Input Cells

Example Calculation:
Internal diameter = 5 ft.
Depth of inlet = 7 ft.
Number of inlets = 3

The model displays the following error message in a pop-up window if a depth lesser than depth of trench is entered.
“Error! Depth of inlet must be greater than trench depth”. A screenshot of the error display screen is shown in Figure 40.

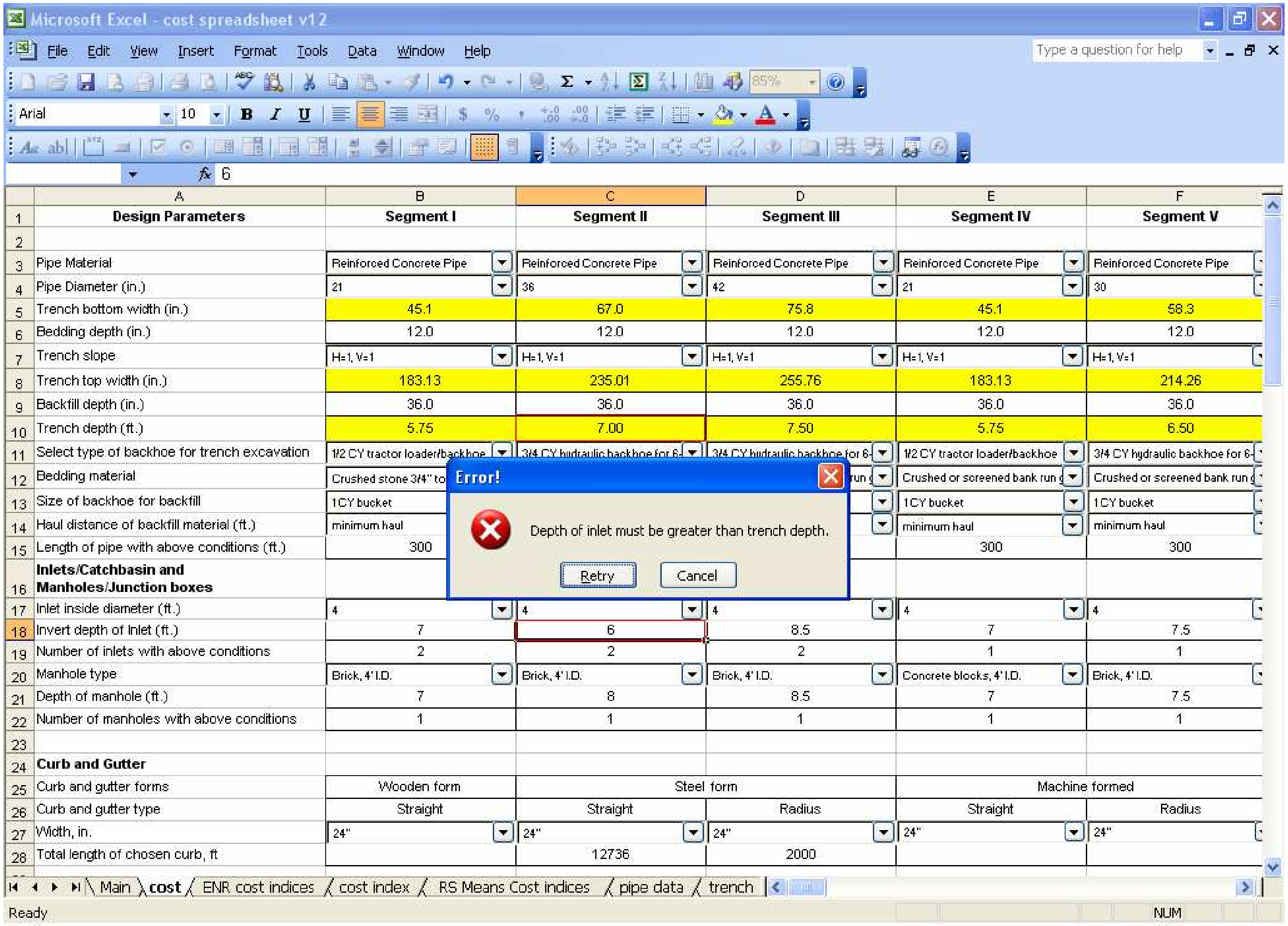


Figure 40. Error Display if Inputted Inlet Depth is Smaller than Trench Depth

Model Estimate:

Cost per inlet = $3.2188H^2 + 223.39H + 331.04$

= $(3.2188 * 7^2) + (223.39 * 7) + 331.04$

= $ 2,052

Cost of 3 inlets = 3 * 2,052

= $ 6,157

3.2.6 Manhole Cost

Like inlets, manholes provide access to the sewer system for routine inspection and maintenance. Manholes are usually installed at places of change in horizontal pipe direction or pipe slope, where several pipes join, or when pipe size changes. Manholes should be installed to provide regular access intervals along straight sections of sewer. Illustration of a precast manholes is shown in Figure 41.

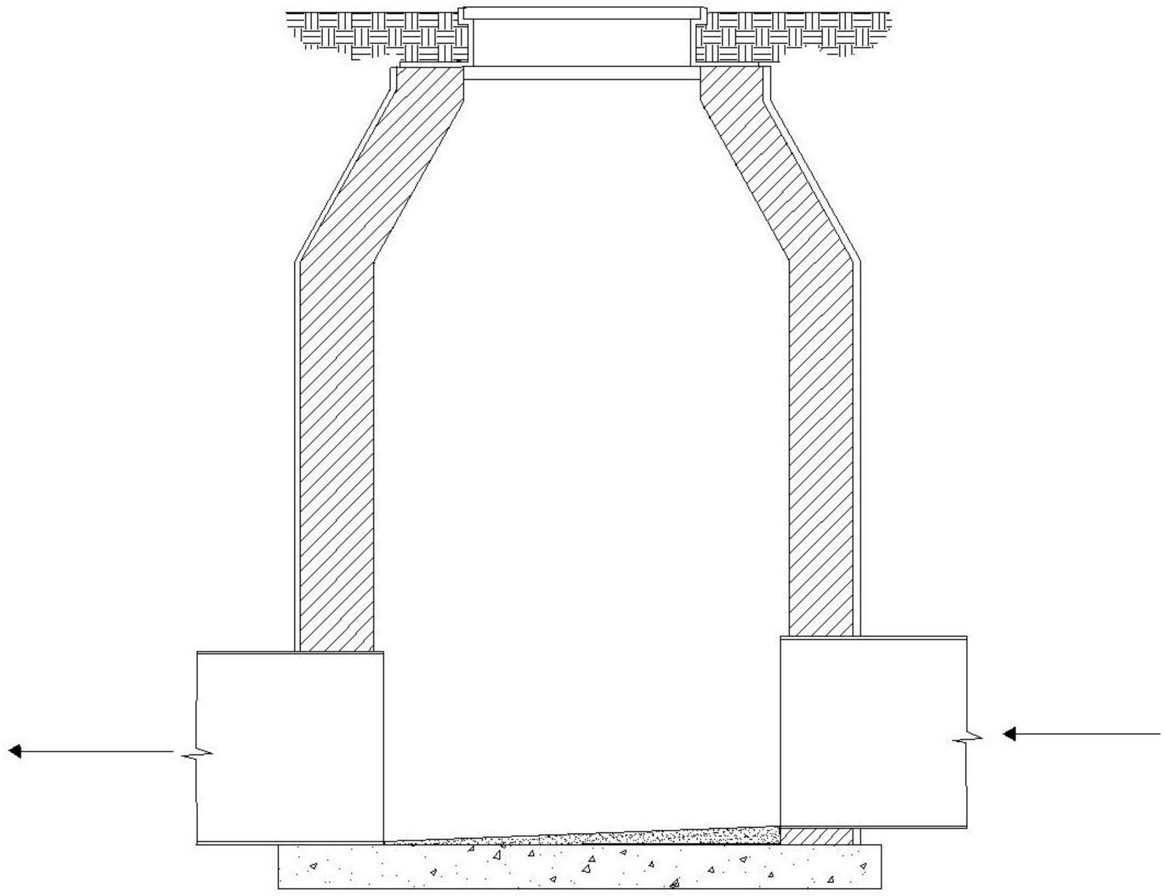


Figure 41. Cross Section View of Manhole

RS Means Building Construction Cost Data (2006) provides manhole costs per unit as a function of standard internal riser diameter and the invert depth (Table 8 in Chapter II). The cost does not include the cost of footing, excavation, backfill, frame and cover. RS Means gives the cost of three types of manholes: brick manholes of 4 feet internal diameter, concrete blocks manhole of 4 feet internal diameter and concrete cast in place manhole of 4 ft. × 4 ft., and 8 inches thick. Figures 42, 43 and 44 illustrate the construction costs of the manholes plotted against their depths, and as shown in Equations 3.8, 3.9 and 3.10.

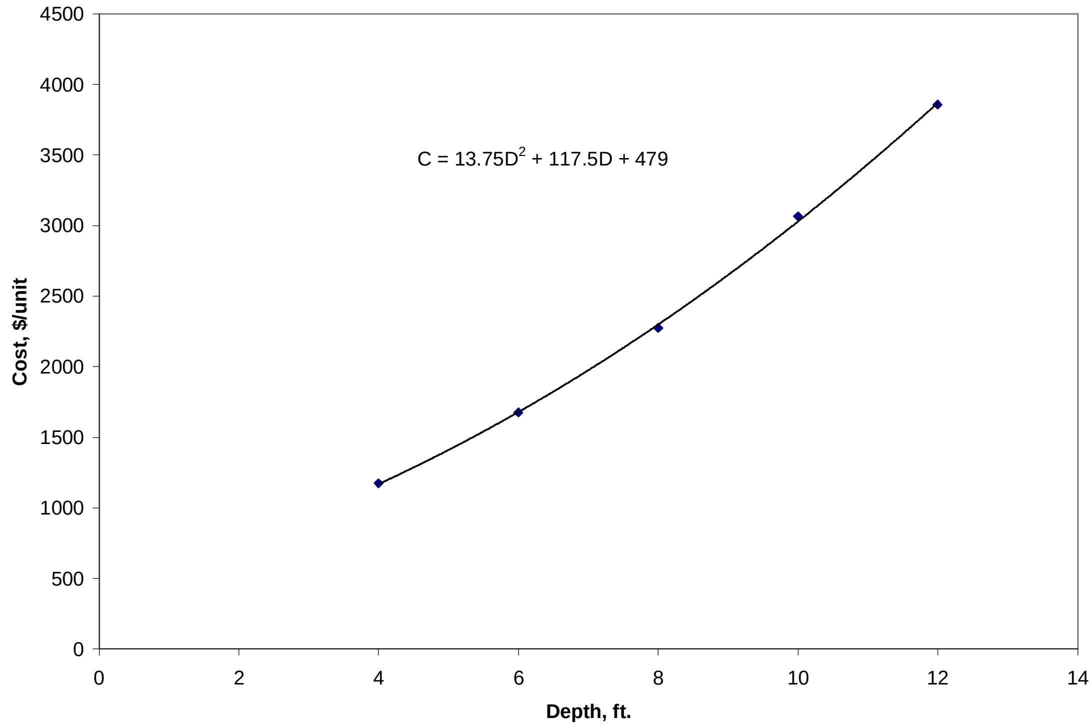


Figure 42. Capital Cost of 4 ft. ID Brick Manhole

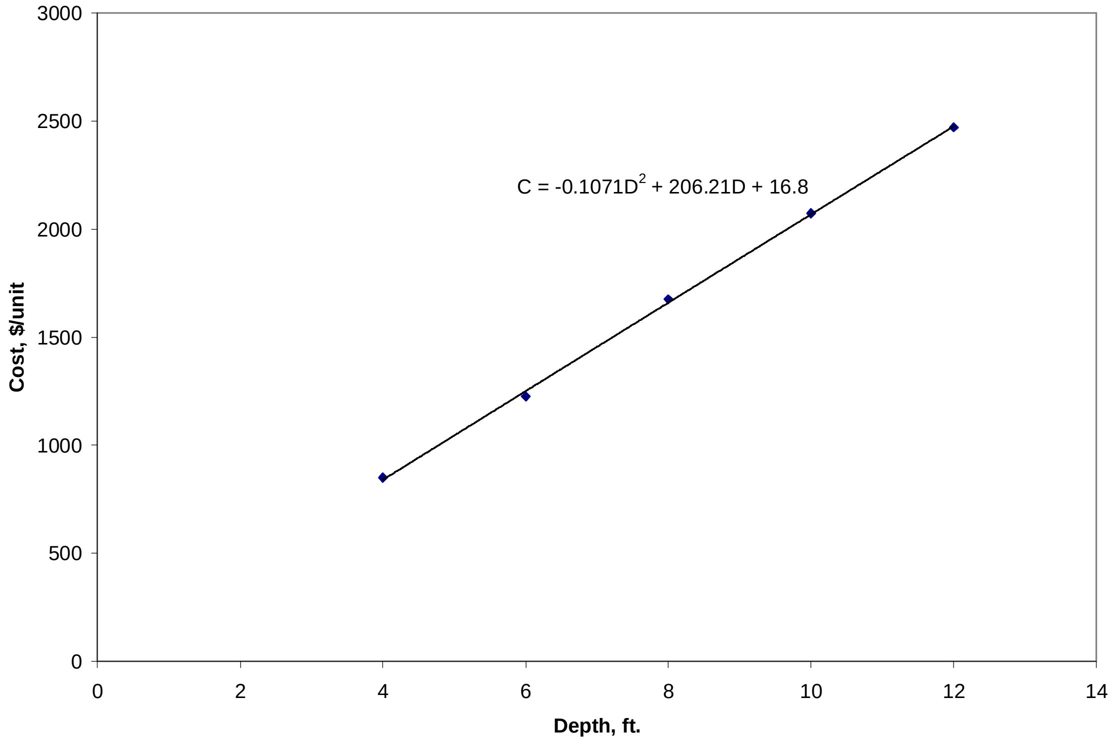


Figure 43. Capital Cost of 4 ft. ID Concrete Manhole

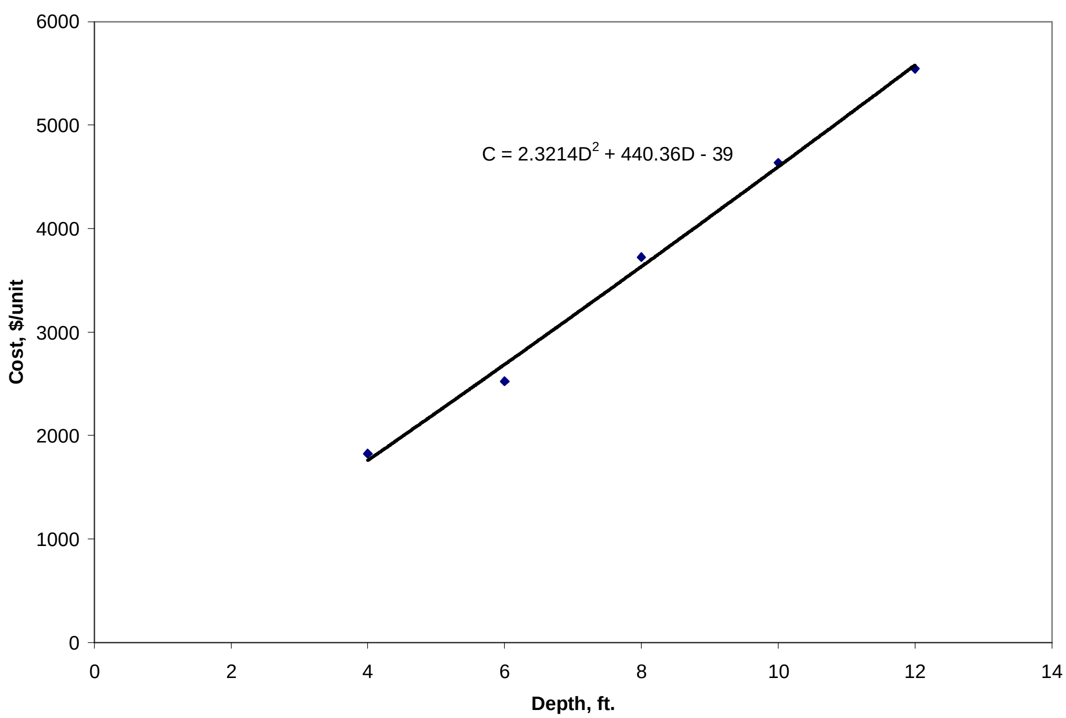


Figure 44. Capital Cost of 4 ft. * 4 ft., 8 in. Thick Concrete Cast-in-place Manhole

For brick manhole 4 ft. inside diameter,

$$C_{mh,brick} = 13.75D^2 + 117.5D + 479$$

For concrete blocks manhole (radial) for 4 ft. inside diameter,

$$C_{mh,concrete} = -0.1071D^2 + 206.21D + 16.8$$

For concrete, cast in place manhole, 4 ft. × 4 ft., 8 in. thick

$$C_{mh,cast-in-place} = 2.321D^2 + 440.36D - 39$$

where

C_{mh} = cost of manhole, $, and

D = depth of manhole, ft

Figure 45 shows the manhole parameter input cells on the spreadsheet model.

16	**Inlets/Catchbasin and Manholes/Junction boxes**	
17	Inlet inside diameter (ft.)	4
18	Invert depth of Inlet (ft.)	7
19	Number of inlets with above conditions	2
20	Manhole type	Brick, 4' I.D.
21	Depth of manhole (ft.)	7
22	Number of manholes with above conditions	1

Figure 45. Manhole/Junction Box Input Cells

Example Calculation:
Type of manhole = brick, 4' I.D.
Depth of manhole = 7 ft.
Number of manholes with this condition = 5
The spreadsheet does not allow a manhole depth lesser than the trench depth. In case a lesser depth is inputted, the model gives an error message.
Model Estimate:
Cost per manhole = $(13.75 * 7^2) + (117.5 * 7) + 479$
= $ 1,975
Cost of 5 manholes = 5 * 1,975
= $ 9,876

3.2.7 Manhole Grating Cover

Cast iron manhole frame and cover costs for different diameters are provided in RS Means (Table 9 in Chapter II). The spreadsheet model calculates the total cost of the manhole depending on the choice of type and diameter. Figure 46 shows the input screen of the spreadsheet model to choose the manhole grating type and its corresponding diameter.

23	**Manhole Frames and Covers, C.I.**					
24	Type	For light traffic	For heavy traffic	Mass. State standard	Watertight	Others
25	Diameter	18" diameter, 100 lb	24" diameter, 400 lb	26" diameter, 475 lb	24" diameter, 350 lb	24" square, 500 lb
26	Total number of each unit	10	5	0	25	

Figure 46. Manhole Grating Cover Selection Cells

From the above line 25 on the spreadsheet model; watertight manholes of 24 inch diameter. The spreadsheet model estimates the capital cost as follows:

Cost of manhole grating cover = 25 units * 595 $/unit
= $ 14,875

3.2.8 Curbs and Gutters

Figure 47 is a section of curb and gutter placed alongside a road providing a side-street channel to convey water to the storm drainage inlets.

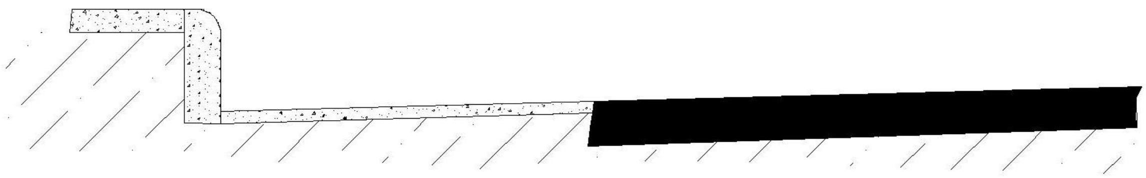


Figure 47. Illustration of Curb and Gutter

Curb and gutter costs are provided in RS Means for wood forms, steel forms, machine formed and precast 6 in. × 18 in. gutters for two different widths and straight and radial patterns for 6 inch high curbs and 6 inch thick gutters (Table 13 in Chapter II). The spreadsheet model calculates the costs of curb and gutter for the selected type of form, width and geometry. Figure 48 shows the input screen for curbs and gutters in the spreadsheet model.

24	**Curb and Gutter**							
25	Curb and gutter forms	Wooden form	Steel form		Machine formed		Precast, 6" × 8"	
26	Curb and gutter type	Straight	Straight	Radius	Straight	Radius	Straight	Radius
27	Width, in.	24"	24"	24"	24"	24"		
28	Total length of chosen curb, ft		12736	2000		2000		

Figure 48. Curb and Gutter Input Cells

For a curb and gutter constructed with steel forms, 30 inches wide, that is straight for 150 feet in length, and having a 50 feet radius alignment, the cost is estimated as follows:
Cost of curb and gutter = (150 * 11.85) + (50 * 16.7)
= $ 2,612

3.3 Total Drainage System Cost

The costs for up to 100 pipe segment categories, plus the manhole costs, are summed in the spreadsheet. This total cost is then converted to current costs based on the financing period and interest rate selected. The ENR construction cost indices from 1976 through 2006 are also incorporated into the spreadsheet for 20 different cities in the US. The RS Means cost indices are also incorporated into the spreadsheet for these 20 cities. The model estimates the total capital cost, present value of all costs, and annualized value of all costs during the financing period.

The land cost and the maintenance cost need to be directly entered into the spreadsheet in their respective cells. The city and the year selection can be made from the drop-down menus. The model gives the city cost index multiplier and the multiplication factor using the RS Means values that can be multiplied with the final cost estimates. Figure 49 shows the output screen of the spreadsheet model displaying the individual component costs and the total costs involved in the construction of the conventional stormwater conveyance system.

31	**Capital costs estimated using 2006 RS Means Building Construction Cost Data**					
32	Cost of pipe installation, $	8994.09	8869.20	8835.89	8994.09	8912.03
33	Trench Excavation Cost, $/CY	4.85	5.70	5.70	4.85	5.70
34	Trench Excavation Cost, $	2887.53	5466.19	6428.71	2887.53	4579.94
35	Cost of Bedding, $/LCY	39.50	39.50	31.50	31.50	31.50
36	Cost of Bedding, $	2047.34	2831.31	2507.96	1632.69	2007.81
37	Cost of backfill, $/LCY	1.47	1.47	1.47	1.47	1.47
38	Cost of backfill, $	759.77	1189.05	1383.99	759.77	1007.39
39	Inlet Cost, $	3662.20	4138.58	4384.64	1831.10	3897.77
40	Manhole Cost, $	1975.25	2299.00	2471.19	1465.52	2133.69
41	Total cost for individual segment, $	20326.18	24793.34	26012.37	17570.70	22538.61
42	Total cost of curb and gutter, $	163691.20				
43						
44	**Land Cost (if applicable), $**	0.00				
45	**Capital Cost, $**	645,635.17				
46	**Annual Maintenance Cost, $**	4,000.00				
47						
48	**ENR Construction Cost Index**					
49	Select City	Birmingham, AL				
50	Select Year	2005				
51	Current City cost Index	5135.56				
52	Baseline National Cost Index	7314.74				
53	City Cost Index Multiplier using ENR	0.70				
54						
55	Interest rate on debt capital, %	4.00				
56	Financing Period, years	20				
57						
58	Present Value Multiplier	13.59				
59	Annual value of present amount	0.0736				
60						
61						
62	**Present value of all costs, $**	**491,456.14**				
63	**Annualized value of all costs during financing period, $**	**36,162.20**				

Figure 49. Estimated Costs by Spreadsheet Model

Example Calculation:
Interest rate on debt capital = 4%
Project life = 20 years
Capital cost of project = $ 645,600
Land cost = $ 0
Annual maintenance cost = $ 4,000/year

Present value of annual amount = $\frac{(1+i)^N - 1}{i(1+i)^N}$

Present value of annual amount (or) present value multiplier = $\frac{(1+0.04)^{20} - 1}{0.04(1+0.04)^{20}}$
= 12.46

Present value of all costs = [Capital cost of project + land cost of project + present value of the annual maintenance and operation cost] * city cost index multiplier
= [$645,600 + $0 + (12.46 * $4,000)] * 0.70
= $ 486,800

Annual value of present amount = $\frac{i(1+i)^N}{(1+i)^N - 1}$

Annual value of present amount (or) annual value multiplier = $\frac{0.04(1+0.04)^{20}}{(1+0.04)^{20} - 1}$
= 0.0802

Annualized value of all costs during the finance period = [Annualized value of (capital cost of project + land cost of project) + annual maintenance and operation cost] * city cost index multiplier
= [0.0802 * ($645,600 + $0) + $4,000] * 0.70
= $ 39,000 per year

Chapter IV
Example Application of Spreadsheet for Calculating Traditional Drainage System Costs

4.1 Introduction

This chapter is an example showing the use of the spreadsheet model to calculate the conventional storm drainage costs associated with a 250 acre industrial site in Huntsville, Alabama. The design tasks for calculating the cost of conventional stormwater conveyance are the following:

1. Determine the quantity of stormwater – the peak flow resulting from a storm of a certain return period for the Huntsville Industrial Park (the level of service).
2. Establish a sewer capacity to convey the design peak flow of stormwater.
3. Enter the calculated pipe diameters, lengths, burial depths, plus inlet and manhole characteristics into the spreadsheet model to calculate the costs involved with the entire network.

The IDF curves were constructed for Huntsville from the following Hydro-35 graphs published by the National Weather Service: 2-year 5-minute precipitation, 2-year 15-minute precipitation, 2-year 50-minute precipitation, 100-year 5-minute precipitation, 100-year 15-minute precipitation, 100-year 60-minute precipitation. Table 88 shows the intensity (in/hr) of rainfall for different durations (minutes). Figure 50 shows the corresponding intensity duration frequency curves for Huntsville, AL.

Table 88. IDF Curve Values for Huntsville, Alabama

Frequency	Intensity, (in/hr)				
	5	10	15	30	60
2	5.76	4.65	3.92	2.69	1.72
5	6.63	5.47	4.64	3.29	2.15
10	7.30	6.08	5.18	3.72	2.45
25	8.31	6.98	5.97	4.34	2.88
50	9.11	7.69	6.58	4.83	3.22
100	9.90	8.40	7.20	5.32	3.55

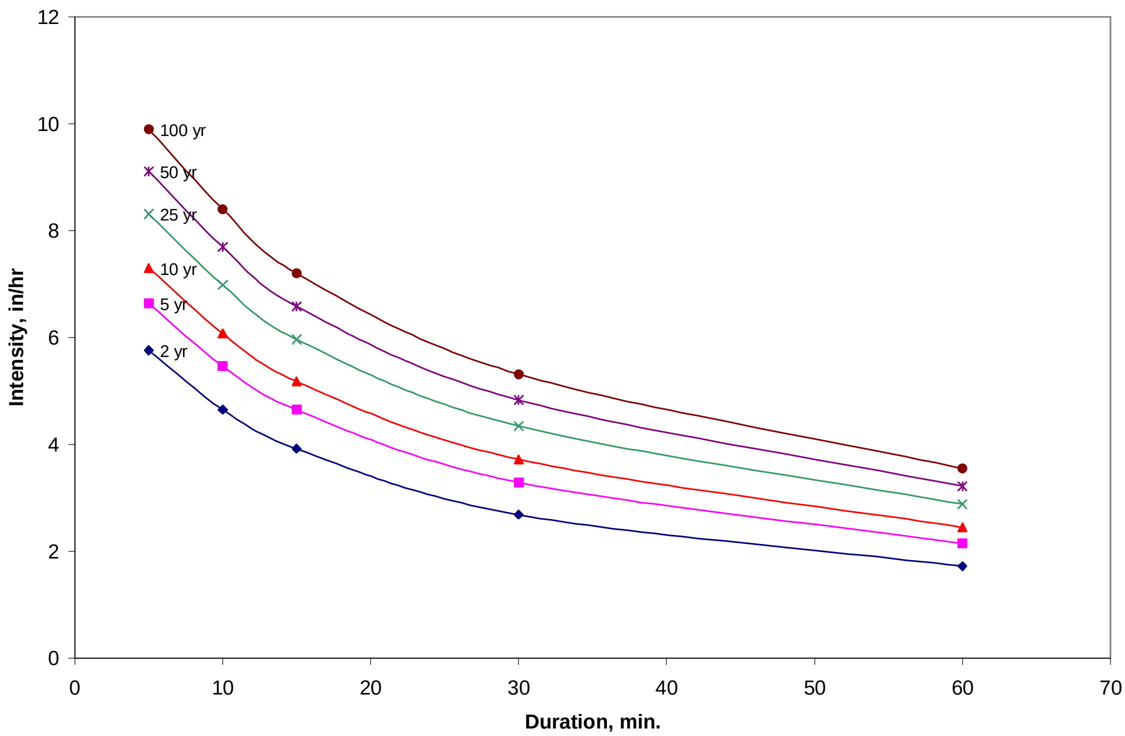


Figure 50. IDF Curves for Huntsville, Alabama

The Rational method was used to estimate the design discharges Q in cubic feet per second, obtained by the following equation,

(4.1) $$Q = CIA$$

where

C = coefficient of runoff,
I = average intensity of rainfall in inches per hour from the Huntsville IDF curve for a given storm frequency and the duration equal to time of concentration, and
A = drainage area in acres.

4.2 Site Characteristics

The site consisted of 50 plots each with each having areas varying between 1.86 to 3.97 acres, plus a large undeveloped area which did not drain to the storm drainage system. Each of these plots were 70% impervious and had a sandy-loam soil. An inlet time of concentration of 5 minutes was determined for each of the plots. The site was divided into four subareas depending on the direction of the flow based on ground slope and outlet locations. Subareas A and B drained into Pond 1, subarea C drains into Pond 2 and Subarea D drains into Outlet 1. Figure 51 is a map of the industrial site showing the individual plots, subareas, the direction of flow of stormwater in the pipes, inlet locations and the outlets.

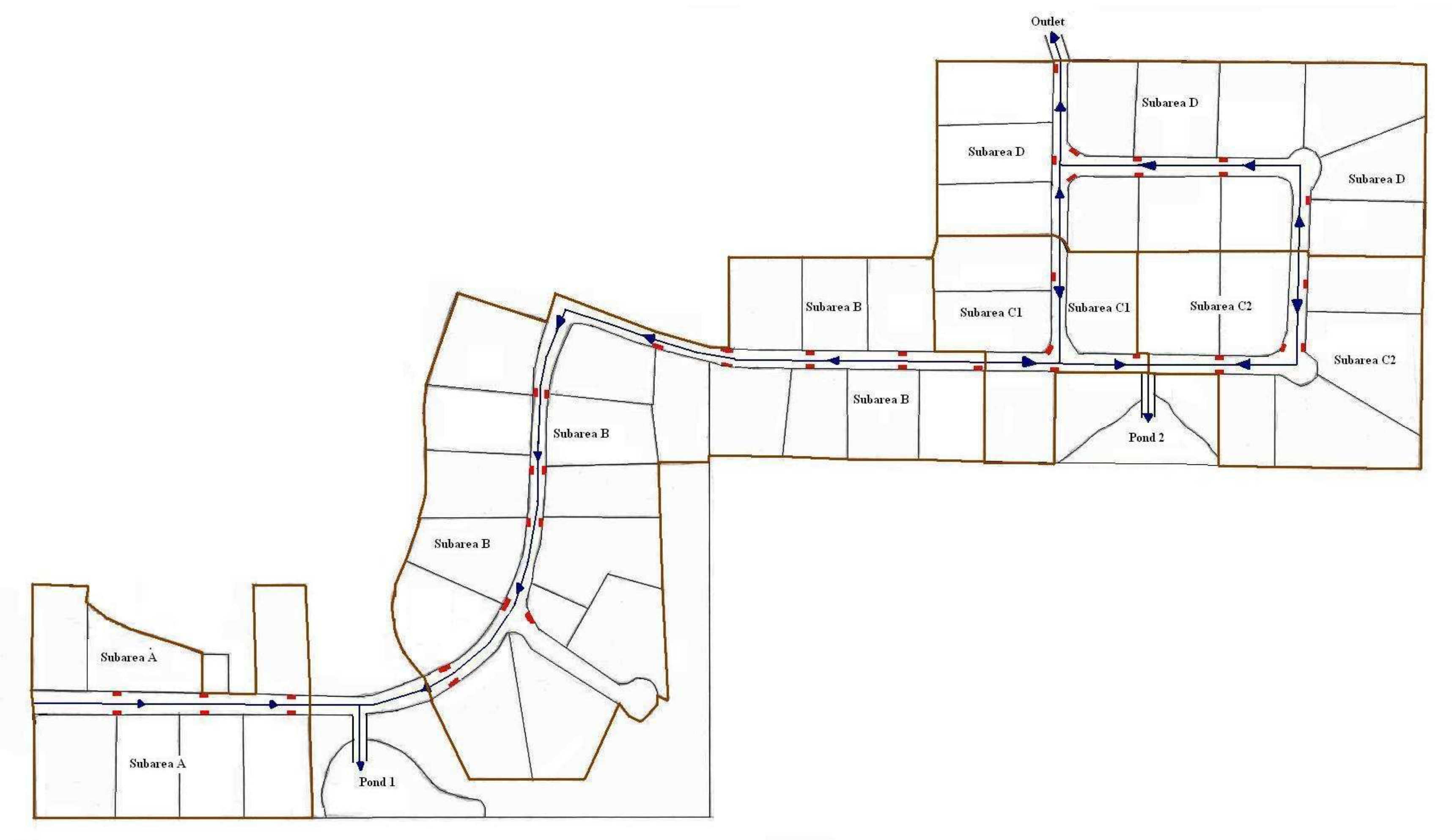


Figure 51. Map of the Industrial Site in Huntsville, Alabama Showing the Direction of Flow and Inlet Locations

4.3 Design Computations

The following steps were followed to design the stormwater conveyance system for the site.

1. The design was started at the upper end of the storm sewer system and proceeded downstream following the direction and pathway of the road.
2. Inlets were located at every 300 feet on one or either side of the road depending on the direction towards which the plots drained.
3. Pipes were laid from roadside inlet to inlet and considered separate segments.
4. The total drainage area contributing to each inlet was first calculated.
5. The inlet time of concentration, $T_{c,}$ of 5 minutes was determined for each of the plots based on the flow path lengths, slopes, and surface covers. The actual T_c values were less than 5 minutes, but drainage design methods and the IDF curves assume a 5 minute minimum T_c value. The total time of concentration for each intercept point including the sewer flow time in the upstream pipes that had been already designed and was used to calculate the intensity from the IDF curves.
6. The peak flow resulting from the design storm including the flow in the upstream section was calculated using the Rational method.
7. The natural ground slope was assumed as the underlying pipe slopes. The pipe sizes necessary to carry the peak flows were then estimated using the slope of surface vs. flow graph.
8. For the estimated diameter and the slope, the flow rate for full pipe was used to calculate the actual Q/Q_f values. This was then used to estimate the V/V_f values.
9. The desired velocity in each pipe section was between a minimum velocity of 3 fps to minimize deposition of grit, and a maximum velocity of 15 fps. The slopes were adjusted to result in acceptable flow ranges.
10. With the lengths for the pipe downstream (from inlet to inlet) and velocity calculated, the time of concentration and peak flow at next pipe segment down slope was determined.
11. Manholes were then provided at locations of change in diameters of pipes and at intersections, as needed.

For an industrial site with 70% imperviousness and sandy-loam soil the following values of runoff coefficients were used: C = 0.9 for impervious surface and C = 0.1 for pervious surface. The cumulative runoff coefficient for each plot was calculated using the formula,

(4.2) $$C = \frac{\sum (A_i * C_i)}{\sum A_i}$$

Tables 89 to 93 present the estimated pipe diameters and the hydrologic calculations for the four different subareas.

Table 89. Diameter Calculations for Subarea A

Inlet	Area(ac.) Served by Inlet	C	T_c	I (in/hr)	Q (cfs)	Slope (%)	Calculated diameter (in.)	Chosen diamete r (in.)	Q_f (cfs)	Q/Q_f	A_f (sq.ft)	V_f (fps)	V/V_f	V (fps)	L (ft.)	T_t (mins)
A,1	4.05	0.66	5	8.39	24.71	4	21	21	32	0.77	2.40	13.31	1.1	14.64	300	0.34
A, 3	10.65	0.66	5.28	8.27	63.96	2.0	33	36	99	0.65	7.07	14.01	1.06	14.85	300	0.34
A, 4	14.73	0.66	5.62	8.13	86.99	1.5	42	42	130	0.67	9.62	13.52	1.07	14.47	300	0.35

Table 90. Diameter Calculations for Subarea B

Inlet	Area(ac.) served by inlet	C	T_c	I (in/hr)	Q (cfs)	Slope (%)	Calculated diameter (in)	Chosen diameter (in.)	Q_f (cfs)	Q/Q_f	A_f (sq.ft)	V_f (fps)	V/V_f	V (fps)	L (ft.)	T_t (mins)
A	2.01	0.66	5	8.39	11.13	0.83	21	21	14.5	0.77	2.40	6.03	1.11	6.69	300	0.75
B	6.03	0.66	5.75	8.08	32.17	0.83	30	30	39	0.82	4.91	7.95	1.12	8.90	300	0.56
C	10.07	0.66	6.31	7.88	52.35	0.83	36	36	63	0.83	7.07	8.92	1.125	10.03	300	0.50
D	13.88	0.66	6.81	7.71	70.60	0.9	42	42	101	0.70	9.62	10.50	1.07	11.24	383	0.57
E	16.33	0.66	7.37	7.53	81.15	1	42	42	105	0.77	9.62	10.92	1.11	12.12	390	0.54
	16.33	0.66	7.91	7.37	79.47	1	42	42	103	0.77	9.62	10.71	1.11	11.89	300	0.42
F	20.62	0.66	8.33	7.26	98.78	1	42	42	130	0.76	9.62	13.52	1.1	14.87	300	0.34
G	26.62	0.66	8.67	7.17	125.97	1	48	48	150	0.84	12.56	11.94	1.13	13.50	300	0.37
H	32.88	0.66	9.04	7.08	153.58	1	54	60	280	0.55	19.63	14.27	1.02	14.55	300	0.34
I	36.85	0.66	9.38	6.99	170.11	0.9	54	60	265	0.64	19.63	13.50	1.06	14.31	300	0.35
J	43.49	0.66	9.73	6.91	198.42	0.7	60	60	240	0.83	19.63	12.23	1.13	13.82	390	0.47

Table 91. Diameter Calculations for Subarea C1

Inlet	Area(ac.) Served by inlet	C	T_c (min)	I (in/hr)	Q (cfs)	Slope (%)	Calculated diameter (in.)	Chosen Diameter (in.)	Q_f (cfs)	Q/Q_f	A_f (sq.ft)	V_f (fps)	V/V_f	V (fps)	L (ft.)	T_t (mins)
A	2.05	0.66	5	8.39	11.36	0.8	21	21	22	0.52	2.40	9.15	1.02	9.33	300	0.54
B	6.32	0.66	5.54	8.17	34.06	0.8	30	36	62	0.55	7.07	8.78	1.025	9.00	300	0.56
C	8.4	0.66	6.09	7.95	44.10	1	33	36	70	0.63	7.07	9.91	1.05	10.40	100	0.16

Table 92. Diameter Calculations for Subarea C2

Inlet	Area(ac.) Served by inlet	C	T_c (min)	I (in/hr)	Q (cfs)	Slope (%)	Calculated Diameter (in.)	Chosen Diameter (in.)	Q_f (cfs)	Q/Q_f	A_f (sq.ft)	V_f (fps)	V/V_f	V (fps)	L (ft.)	T_t (mins.)
D	2.12	0.66	5	8.39	11.74	0.8	21	21	14.5	0.81	2.40	6.03	1.12	6.76	300	0.74
E	7.5	0.66	5.74	8.09	40.03	1.6	30	30	55	0.73	4.91	11.21	1.08	12.11	300	0.41
F	12.3	0.66	6.15	7.93	64.39	2.4	30	30	66	0.98	4.91	13.45	1.15	15.47	205	0.22

Table 93. Diameter Calculations for Subarea D

Inlet	Area(ac.) served by inlet	C	T_c (min)	I (in/hr)	Q (cfs)	Slope (%)	Calculated Diameter (in.)	Chosen Diameter (in.)	Q_f (cfs)	Q/Q_f	A_f (sq.ft)	V_f (fps)	V/V_f	V (fps)	L (ft.)	T_t (mins.)
A	7.75	0.66	5	8.39	42.93	1	33	36	70	0.61	7.07	9.91	1.05	10.40	300	0.48
B	12.4	0.66	5.48	8.19	67.02	1.7	33	36	90	0.74	7.07	12.74	1.08	13.76	300	0.36
C	17.32	0.66	5.84	8.05	91.98	0.5	48	48	110	0.84	12.56	8.76	1.13	9.90	300	0.51
D	26.69	0.66	6.35	7.86	138.49	1	48	48	150	0.92	12.56	11.94	1.14	13.61	300	0.37
E	29.03	0.66	6.72	7.74	148.24	1	48	48	155	0.96	12.56	12.34	1.14	14.07	200	0.24

4.4 Cost Estimation Using Spreadsheet Model

A total of 25 pipe segment categories were obtained for this site. The estimated pipe diameters, the desired pipe material, bedding depth, backfill depth, inlet, manhole dimensions and other input variables were entered into the spreadsheet either manually or selected form drop-down menus.

All pipes were assumed to be reinforced concrete pipes (RCP) and the calculated diameters ranged from 21 inches to 60 inches. The yard inlets were assumed to be reinforced concrete pipes with a diameter of 21 inches and about 150 feet long for each plot. Each of these plots were fitted with two yard inlets to convey the runoff from the plot to the inlets. The total length of the yard inlets for the 50 plots was calculated to be 15,000 ft. A bedding depth of 1 feet and a backfill depth of 3 feet over the crowns of he pipes was assumed at all locations along the length of the pipe. Based on the estimate of the total trench depth, the model determined a selection of backhoe sizes for trench excavations for different depths. For trench depths between 4 feet and 6 feet, a ½ cubic yard tractor/backhoe was selected and for trench depths between 6 feet and 10 feet, a ¾ cubic yard backhoe was selected. Crushed or screened bank run gravel was used as the bedding material, a 1 CY bucket was selected as the backhoe size for bedding and a minimum haul distance of bedding material was assumed.

Inlets were designed with invert depths 3 feet deeper than trench depths and with an inside diameter of 4 feet. A total of 42 inlets were located in the site. Manholes depths were also designed at depths at least 1 foot greater than the trench depth. A total of 25 manholes were located at the site in the middle of the road joining two inlets on either side, at places of change in diameter and at intersections.

The total length of curb and gutter was calculated as twice the length of the pipe length. The total length was estimated as 14,736 feet. But, 2,000 feet of this curb run along curves of the road and require radial forms. The curb and gutter was designed with steel forms with 6 in. × 6 in. curbs and 24 inch wide gutter.

Yard drains are used to drain runoff from areas near buildings directly to the main pipeline, without surface flows to the gutters. As an example, yard drains of 21 inches in diameter made of reinforced concrete pipe, with each plot having two yard drains were used in this example. Table 94 summarizes the input data used in the spreadsheet model.

Table 94. Summary of Input Data Used in the Spreadsheet Model

Pipe	
Pipe material	Reinforced Concrete Pipe
Total length of pipe	7,368 feet
Estimated pipe diameters	21 - 60 inches
Trench	
Trench Slope	H=1, V=1
Bedding	
Bedding depth	1 feet
Bedding material	Crushed or screed bank run gravel
Backhoe size for bedding	1 CY bucket
Bedding material haul distance	Minimum
Backfill	
Backfill depth	3 feet
Backhoe selection	1/2 CY backhoe for 4-6 ft deep trench
	3/4 CY backhoe for 6-10 ft deep trench
Inlets	
Number of inlets	42
Depth of inlets	trench depth + 3 feet
Manholes	
Number of manholes	25
Depth of manhole	trench depth + 1 feet
Number of manhole grates	25
Type	Watertight, 24 inch diameter
Curb and gutter	
Total length of curb and gutter	14736 feet
Curb and gutter dimensions	Steel forms, 6 in. × 6 in. curbs, 24 inch wide gutter
Yard Inlets	
Yard inlet material	Reinforced Concrete Pipe
Typical yard inlet length	150 feet
Number of yard inlets per plot	2
Total length of yard inlet	15,000 feet

A maintenance cost of $ 4,000 per year, interest rate on debt capital of 5 % and a financing period of 20 years was used to estimate the costs. When these parameters were entered into the model, the model calculated the present value of all costs as $ 1,811,700 and the annualized value of all costs during the financial life of the project as $ 145,400. Table 95 summarizes these costs as estimated by the spreadsheet model.

Table 95. Summary of Estimated Costs using the Spreadsheet Model

Interest rate on debt capital, (%)	5
Financing period, (yrs)	20
Present value multiplier	13.59
Annual value of present amount	0.0736
Capital cost, ($)	1,766,500
Present value of all costs, ($)	1,811,700
Annualized value of all costs, ($)	145,400

4.5 Grass Swales as an Alternative Stormwater Conveyance System

Grass swales can be used as an alternate form of stormwater conveyance system for the Huntsville industrial site. The site is divided into four main drainage subareas labeled as A, B, C, and D. There are several additional minor drainage subareas that will remain undeveloped and do not drain to one of the designated stormwater ponds.

4.5.1 Subarea A

There is one long regional drainage swale in this subarea that collects the sheetflows from the bioretention swales from each site and directs the excess water to the ponds on the southern property edge. This swale is about 1,700 feet long, on about a 2.6% slope, and will be 50 ft wide. It will also have 3 to 1 (H to V) side slopes, or less, and have 1 inch per hour infiltration rates. The bottom of the swale will be deep vibratory cultivated during proper moisture conditions to increase the infiltration rate, if compacted. This swale will also have limestone check dams every 100 ft to add alkalinity to the water and to encourage infiltration. The vegetation in the drainage should be native grasses having deep roots and be mowed to a height of about 6 inches, or longer. Any cut grass should be left in place to act as a mulch which will help preserve infiltration rates. The swale should have a natural buffer on each side at least 50 ft wide. Any road or walkway crossings over the grassed waterway areas should be on confined to a narrow width.

4.5.2 Subarea B

This subarea comprises about 60 acres, with about 35 acres industrial and 25 acres open space. This area is noteworthy due to the natural double drainways that currently drain the area. These will be left in undeveloped land and used for site drainage.

4.5.3 Subarea C

This subarea has about 24 acres (16 acres industrial, 4 acres residential, and about 4 acres open space). About 7 industrial sites are also located in this area, including some partial sites.

4.5.4 Subarea D

This site subarea is the most developed, having about 33 acres of industrial land and about 6 acres of undeveloped land. The natural drainage directs the runoff from this area to adjacent city-owned land and to a future wet detention pond.

4.6 Costs for Grass Swales Estimated Using WinSLAMM

WinSLAMM was used to estimate the capital cost and annual operation and maintenance costs of the grass swales for the Huntsville industrial site. Figure 52 shows the input screen in WinSLAMM for entering the swale dimensions and properties. Figure 53 shows the cost data input screen in WinSLAMM for grass swales.

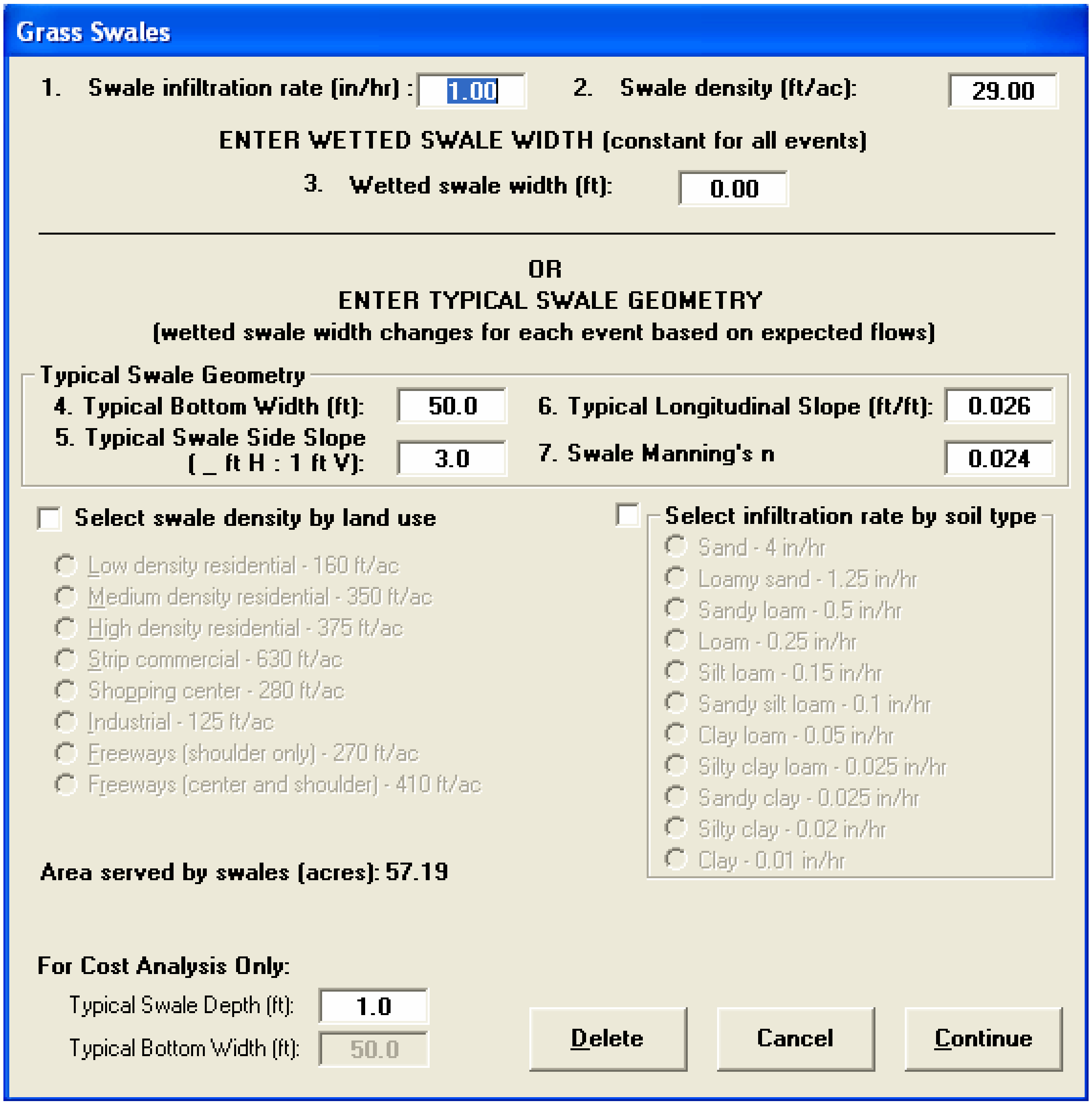


Figure 52. WinSLAMM Grass Swales Input Parameters Screen

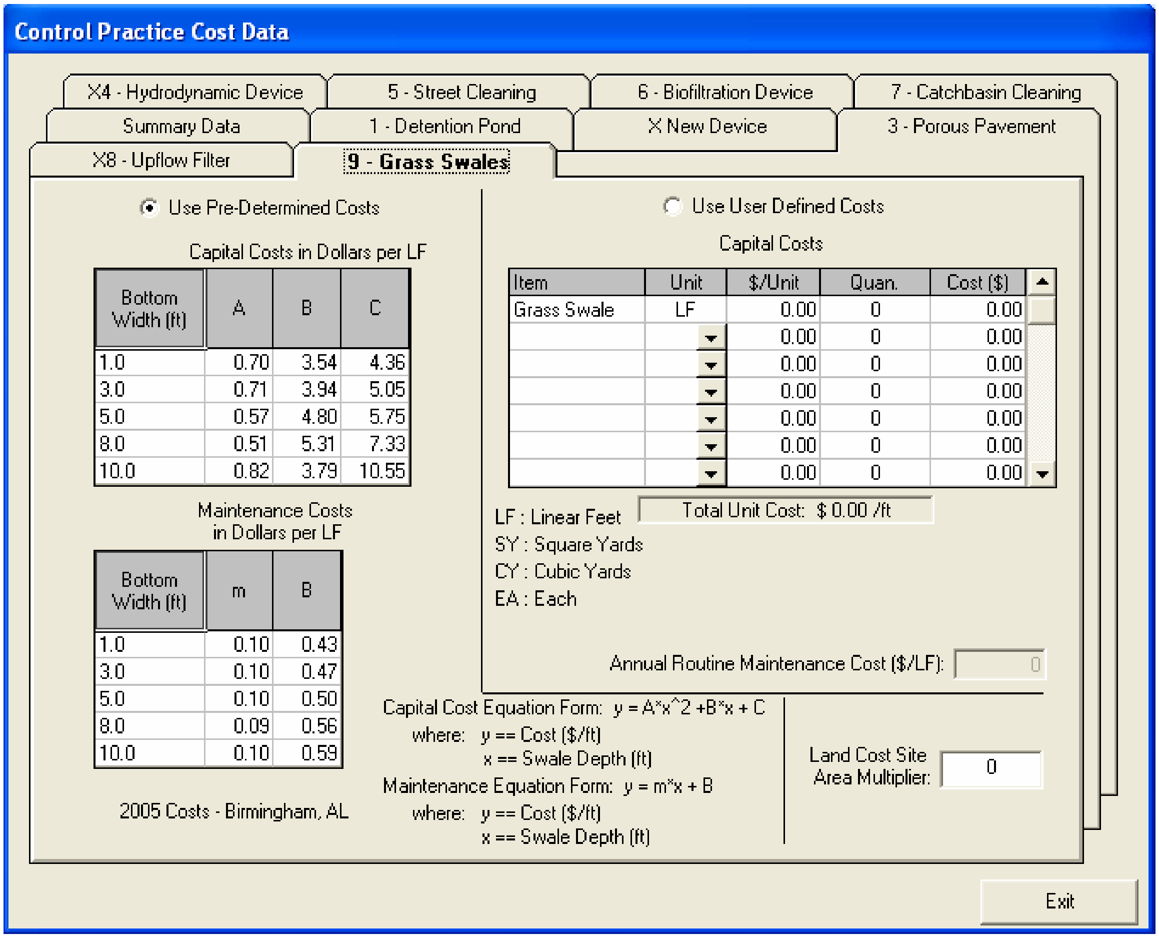


Figure 53. Cost Data Selection Screen for Grass Swales in WinSLAMM

For site C, the example calculations done by WinSLAMM are presented below:
Swale depth (x) = 2 ft.
Bottom width = 20 ft.
Capital cost, $y = Ax^2 + Bx + C$
$= (0.82 * 4) + (3.79 * 2) + 10.55$
$= 21.41$ $/LF
Maintenance Cost, $y = mx + B$
$= (0.1*2) + 0.59$
$= 0.79$ $/LF
Note: The constants A, B, C values in the capital cost equation and the m, B values in the maintenance cost equations are adjusted to 2005 costs.
Total drainage area = 23.9 ac
Swale density = 406 ft/ac
Total length of swale = 9703.4 ft
Capital cost = 9703.4 * 21.41 = $207,750
Adjusting to cost index = $207,750 / 1.49 = $139,300
Maintenance cost = 9703.4 * 0.79 = $7,666
Adjusting to cost index = $5,100

Figure 54 shows the WinSLAMM output screen showing the total control practice costs for construction of grass swales at subarea C.

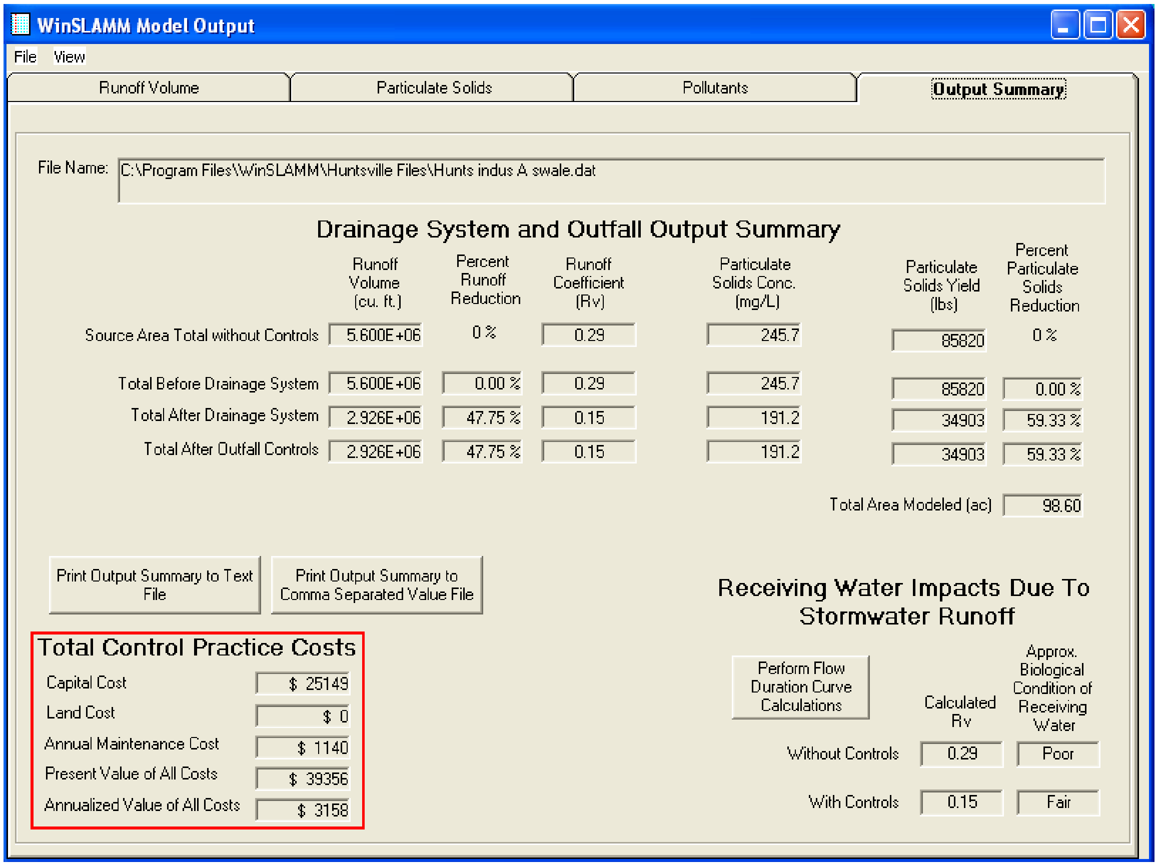


Figure 54. WinSLAMM Output Screen Showing Costs for Grass Swale for Subarea C

Table 96 shows the costs associated with the construction of grass swales for each of the subareas estimated by WinSLAMM.

Table 96. Costs of Grass Swales for Each Subarea

	Subarea A	Subarea B	Subarea C	Subarea D
Capital Cost ($)	40,600	25,100	139,300	22,700
Annual Maintenance Cost ($)	1,500	1,100	5,100	1,300
Present Value of All Costs ($)	59,200	39,400	202,700	50,100
Annualized Value of All Costs ($)	4,700	3,200	16,300	4000

4.7 Comparison of Costs for Swales and Conventional Pipes

The data obtained from the literature sources that were reviewed and the fitted equations were incorporated into the WinSLAMM model to estimate the capital costs and the annual operation and maintenance costs for the stormwater control practices (wet detention ponds, grass swales, and biofiltration devices) for the example site conditions. The equations derived from the published unit cost data for conventional drainage systems were used in the spreadsheet model to estimate the costs involved in the construction and operation of a conventional stormwater conveyance system for comparison. WinSLAMM and the spreadsheet model are used together to estimate the capital costs, annual maintenance costs, present value of all costs and the annualized value of all costs of the stormwater drainage and the stormwater management systems. The total control practice cost output screen from WinSLAMM and the spreadsheet are shown in Figures 55 and 56 respectively.

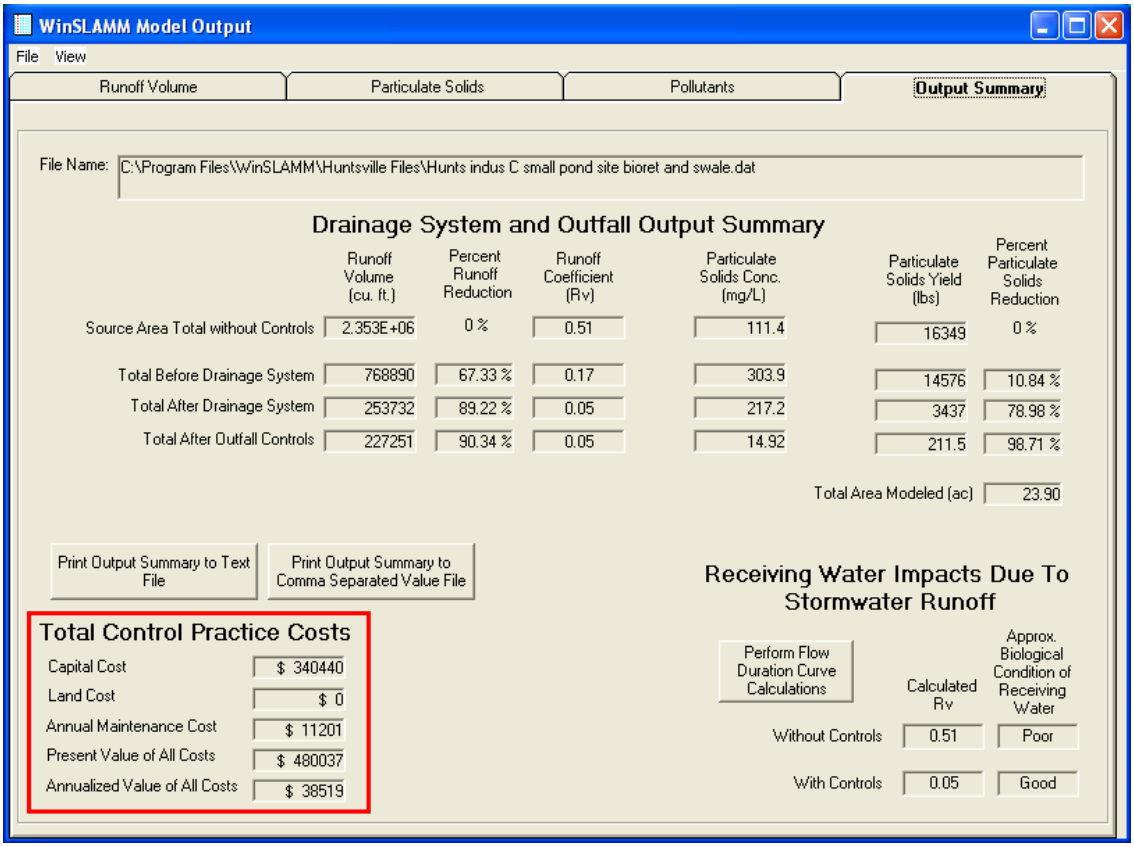
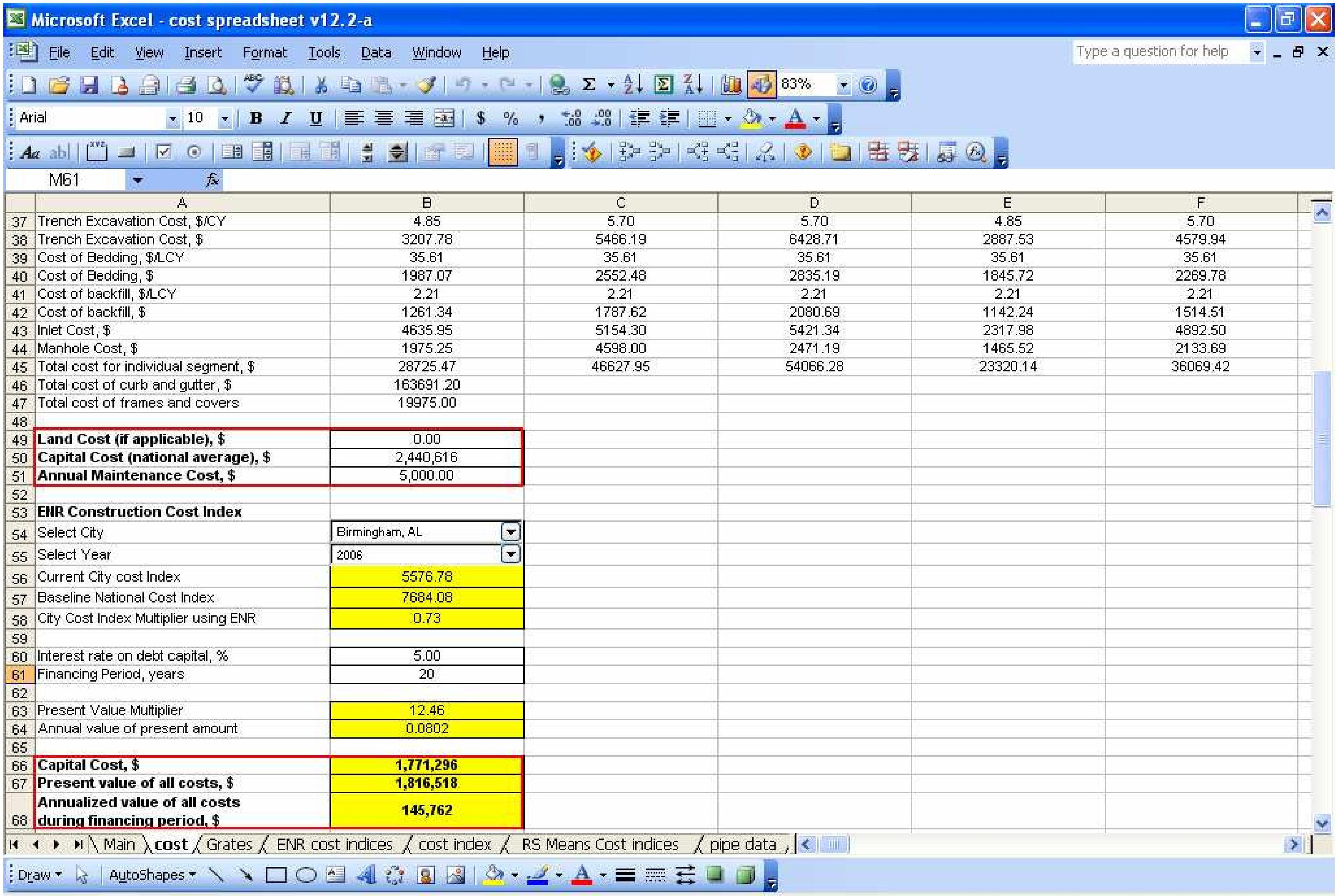


Figure 55. Total Control Practice Costs Output Screen in WinSLAMM



	A	B	C	D	E	F
37	Trench Excavation Cost, $/CY	4.85	5.70	5.70	4.85	5.70
38	Trench Excavation Cost, $	3207.78	5466.19	6428.71	2887.53	4579.94
39	Cost of Bedding, $/LCY	35.61	35.61	35.61	35.61	35.61
40	Cost of Bedding, $	1987.07	2552.48	2835.19	1845.72	2269.78
41	Cost of backfill, $/LCY	2.21	2.21	2.21	2.21	2.21
42	Cost of backfill, $	1261.34	1787.62	2080.69	1142.24	1514.51
43	Inlet Cost, $	4635.95	5154.30	5421.34	2317.98	4892.50
44	Manhole Cost, $	1975.25	4598.00	2471.19	1465.52	2133.69
45	Total cost for individual segment, $	28725.47	46627.95	54066.28	23320.14	36069.42
46	Total cost of curb and gutter, $	163691.20				
47	Total cost of frames and covers	19975.00				
48						
49	**Land Cost (if applicable), $**	0.00				
50	**Capital Cost (national average), $**	2,440,616				
51	**Annual Maintenance Cost, $**	5,000.00				
52						
53	**ENR Construction Cost Index**					
54	Select City	Birmingham, AL				
55	Select Year	2006				
56	Current City cost Index	5576.78				
57	Baseline National Cost Index	7684.08				
58	City Cost Index Multiplier using ENR	0.73				
59						
60	Interest rate on debt capital, %	5.00				
61	Financing Period, years	20				
62						
63	Present Value Multiplier	12.46				
64	Annual value of present amount	0.0802				
65						
66	**Capital Cost, $**	**1,771,296**				
67	**Present value of all costs, $**	**1,816,518**				
68	**Annualized value of all costs during financing period, $**	**145,762**				

Figure 56. Stormwater Conveyance System Total Costs Display Screen in Spreadsheet Model

A 250-acre industrial site located in Huntsville, Alabama, was used in the comparison of costs for construction of a conventional stormwater conveyance system (using the spreadsheet model) and the costs for construction and operation of alternative grass swales (using WinSLAMM). The costs estimated by WinSLAMM and by the spreadsheet model are shown in Table 97. The conventional stormwater conveyance system was observed to be more than three times costlier than the grass swales for conveyance, considering capital and swale maintenance costs. About $118,000 per year, or $3,350,000 over the 20 year financing period, would be saved using the grass swale alternative.

Table 97. Summary of Costs from WinSLAMM and the Spreadsheet Model

Cost ($)	Conventional Stormwater Conveyance System	Grass Swale
Capital Cost	1,771,296	227,700
Annual Maintenance Cost	0	9,000
Present Value of All Costs	1,816,518	351,400
Annualized Value of All Costs	145,762	28,200

Decision analysis techniques can be used to select the most appropriate program for an area, based on many performance objectives and cost restraints. Further analysis of the pollutant loadings and runoff volumes from a site and the desired reductions can be used to identify the set of control practices that could be implemented at a site. WinSLAMM is capable of estimating these loads for a broad range of pollutants, such as solids, nutrients (phosphorous, nitrate, TKN), metals (chromium, copper, lead, zinc), COD, ammonia, bacteria, and runoff volume for a variety of stormwater control practices and development options (including base conditions).

Chapter V
Conclusions

This research discussed the costs associated with the construction and operation of various stormwater control and conveyance practices. The costs for these stormwater control practices were presented in Chapter II in the form of tables and figures available from published literature sources. Also presented were equations derived from these data and from RS Means published unit cost data. The spreadsheet model developed as part of this research includes ENR construction cost index values available starting from 1978 to the present, for 20 cities in the US, along with the national average index values. These index values were used to convert regional cost data collected during specific past years to current conditions. The ENR cost index values for these years are presented in Appendix A. Also presented are graphs showing the variation in the construction cost index for each of the 20 cities from 1978 through 2005. Using an estimated future inflation rate, the cost estimated from the model can also be used to predict the costs for future years. The spreadsheet model estimates the costs specifically associated with the construction, operation, and financing of a conventional stormwater conveyance system. The spreadsheet model is easier to use compared to other programming-based cost estimating tools.

Cost summaries and equations for conventional stormwater control practices are presented in Chapter II from several sources. The comprehensive cost data obtained by the Southeastern Wisconsin Regional Planning Commission (1991) were used to describe the relative component costs of several major controls, as summarized in the following paragraphs.

<u>Wet Detention Ponds</u>

General excavation, contingencies, pond outlets, pond inlets, and clearing are the major cost components for wet detention ponds. However, the relative order of these components depends on the size of the wet detention pond. For wet detention ponds of 0.25 acres, the cost of construction of the pond outlet is about 24% of the total capital costs. This is followed by the cost of construction of the pond inlet (20%), and the contingency fee (20%). However, the general excavation costs contribute about 12% of the total capital cost associated with a 0.25-acre pond. Figure 57 shows the data presented earlier in Table 21 for the percentage cost contributions for each component of the wet detention pond.

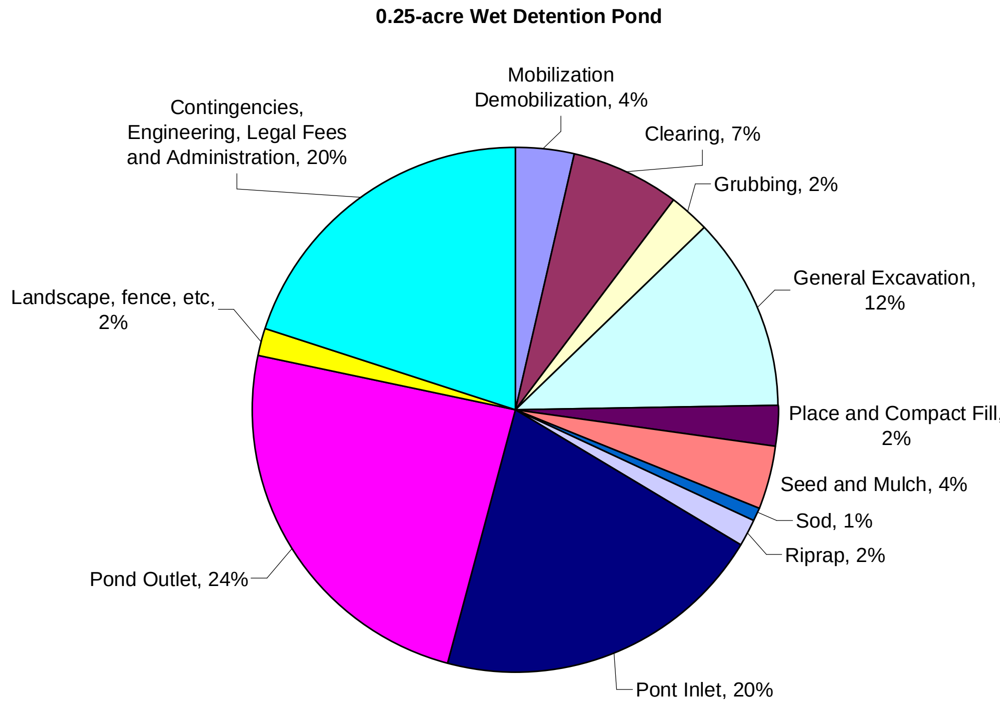


Figure 57. Distribution of Total Capital Cost for a 0.25-acre Wet Detention Pond

For a larger wet detention pond of 1 acre, the cost of excavation increases to around 28% of the total capital cost. This is followed by the contingency fee which is about 20% of the total capital cost. Clearing costs are nearly 10-12% of the total capital cost, followed by the pond outlet costs and the pond inlet costs. Figure 58 shows the data presented earlier in Table 22 for a 1-acre wet detention pond.

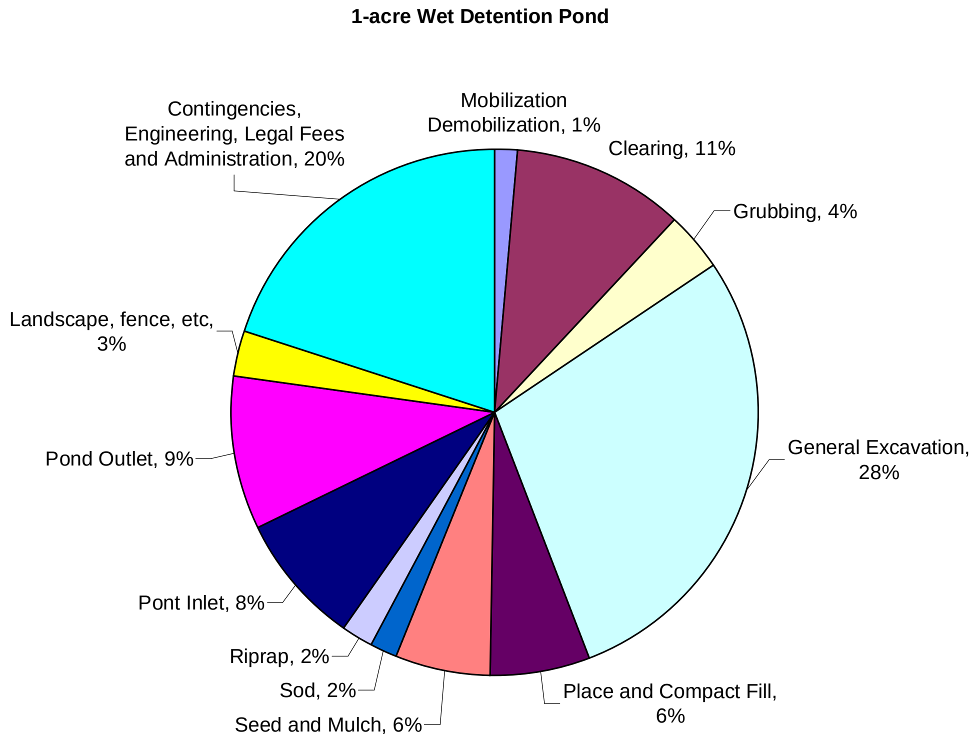


Figure 58. Distribution of Total Capital Cost for a 1-acre Wet Detention Pond

For a wet detention pond area of 3 acres, the order of the components contributing towards the total capital cost is the same as the 1-acre detention pond. However, the cost of excavation increased by 10% compared to the 1-acre wet detention pond to a total of 38% of the total capital cost. Contingencies are 20% of the total capital cost. However, the cost of clearing increased to 11% for the 3-acre pond. With the increased area of the pond, the site preparation and site development activities such as placing and compacting fill, seeding and mulching and grubbing are all larger than the cost of construction of the pond inlet and outlet structures. Table 59 shows the distribution of the total median capital costs for the components for a 3-acre wet detention pond.

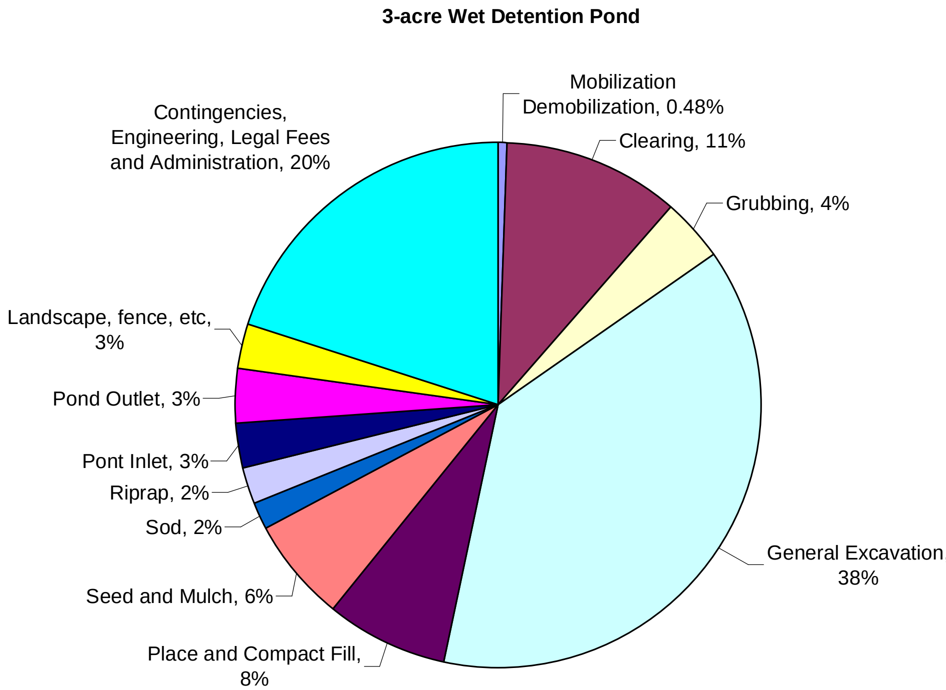


Figure 59. Distribution of Total Capital Cost for a 3-acre Wet Detention Pond

Similar distributions of costs were also seen for a 5-acre wet detention pond. Figure 61 shows the distribution of the total median capital cost for a 5-acre wet detention pond.

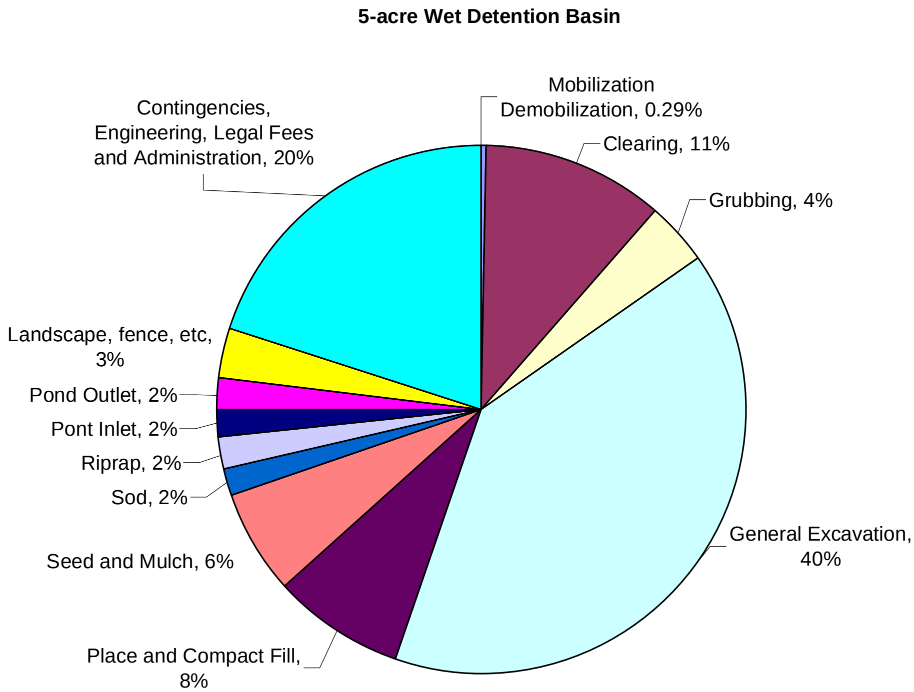


Figure 60. Distribution of Total Capital Cost for a 5-acre Wet Detention Pond

The average annual operation and maintenance cost for a 0.25-acre wet detention pond is about 4.7% of the estimated capital cost, 3.4% for a 1-acre wet detention pond, 2.7% for a 3-acre pond and 2.5% for a 5-acre wet detention pond.

Infiltration Pond

The infiltration pond inlet, general excavation, and sodding contribute the most towards the total capital cost of an infiltration pond, apart from the assumed 20% contingency cost. For a 0.25-acre infiltration pond, the cost of construction of the pond inlet contributes 25% of the total capital cost, while the general excavation contributes 13% towards the total capital costs. For an infiltration pond of 1-acre, the cost of general excavation increases to 22% of the total capital cost, while the cost for the pond inlet is reduced to 8%. Figures 69 and 70 show the distribution of the total capital cost components for a 0.25-acre and 1-acre infiltration pond.

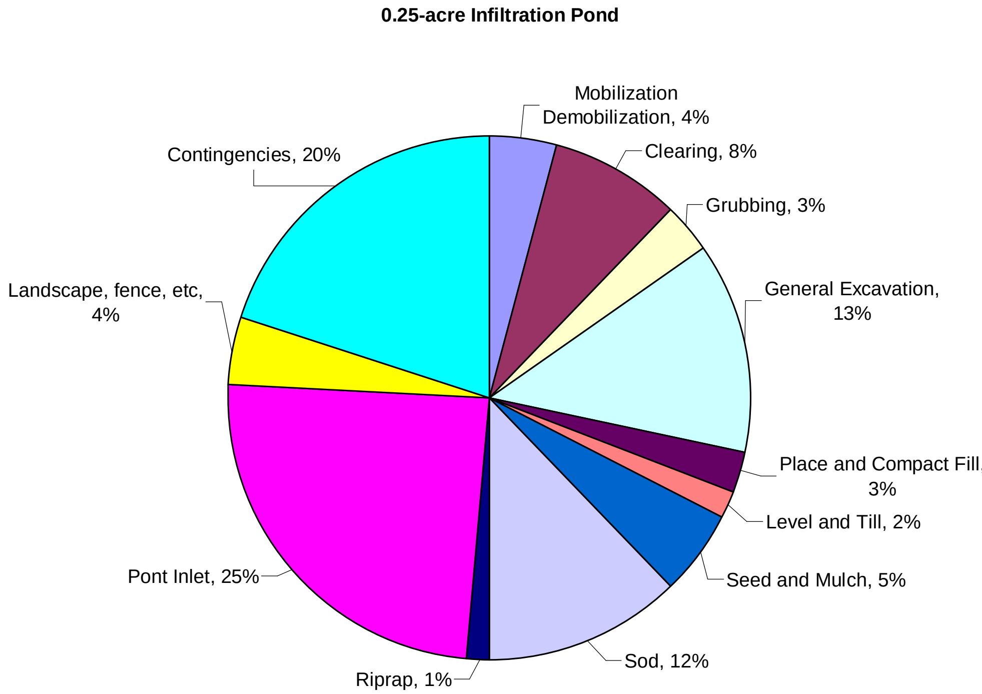


Figure 61. Distribution of the Total Capital Cost for a 0.25-acre Infiltration Pond

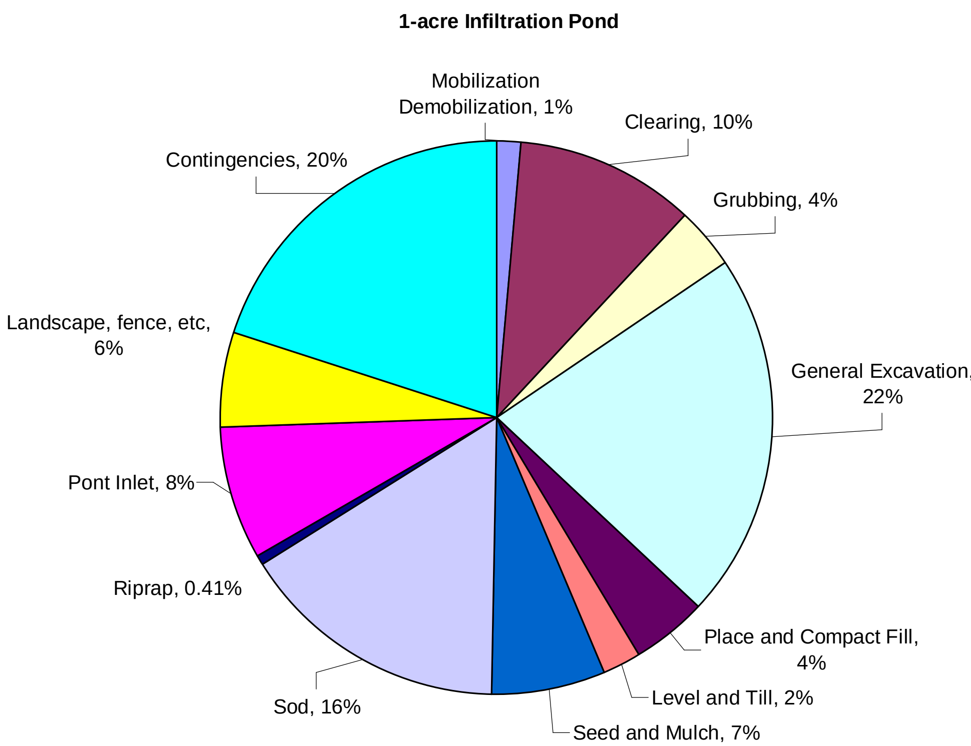


Figure 62. Distribution of the Total Capital Cost for a 1-acre Infiltration Pond

For outfall stormwater control practices, such as wet detention and infiltration ponds, site preparation activities (general excavation) contribute the most towards the total capital costs. This is followed by the cost for site development activities (pond inlet and outlet structures and sodding).

<u>Grass Filter Strips</u>

Sodding (25%), grubbing (23%), contingencies (20%), clearing (17%), and seeding and mulching (11%) contribute towards the total capital costs of a grass filter strip in this same relative order for all filter strip sizes. Figures 66, 67, and 68 show the cost distribution among the components for a 25 feet, 50 feet and 100 feet wide grass filter strip.

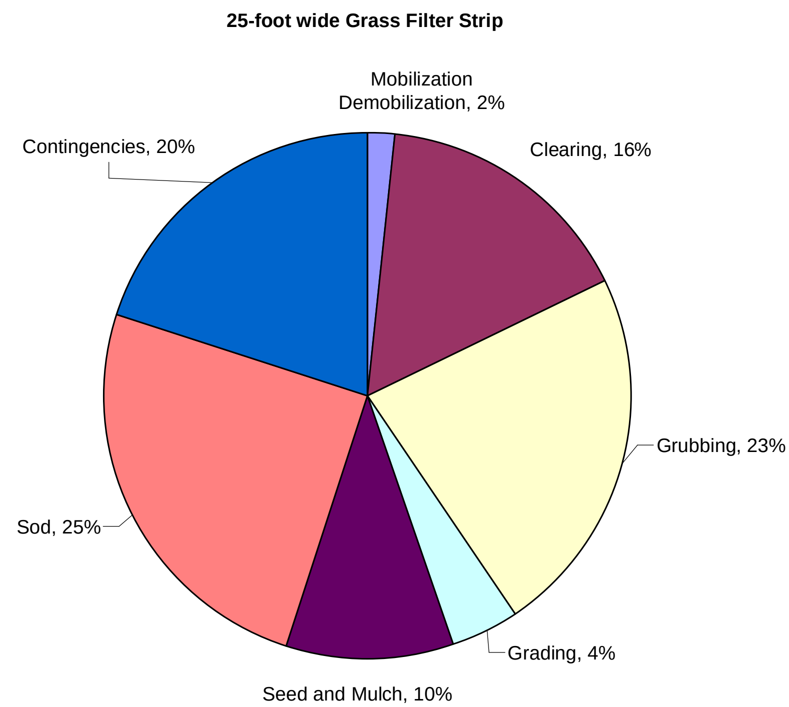


Figure 63. Distribution of the Total Capital Cost for a 25-feet Wide Grass Filter Strip

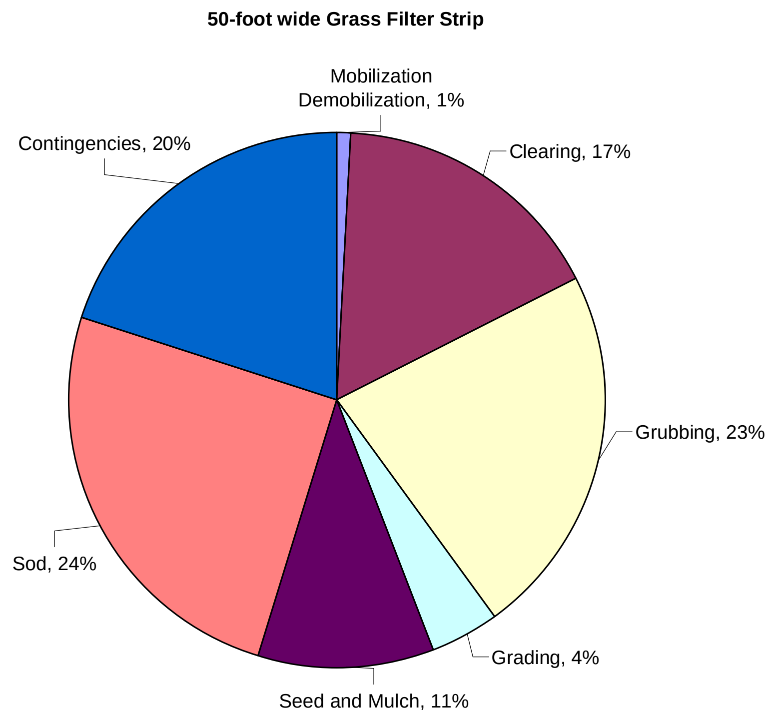


Figure 64. Distribution of the Total Capital Cost for a 50-feet Wide Grass Filter Strip

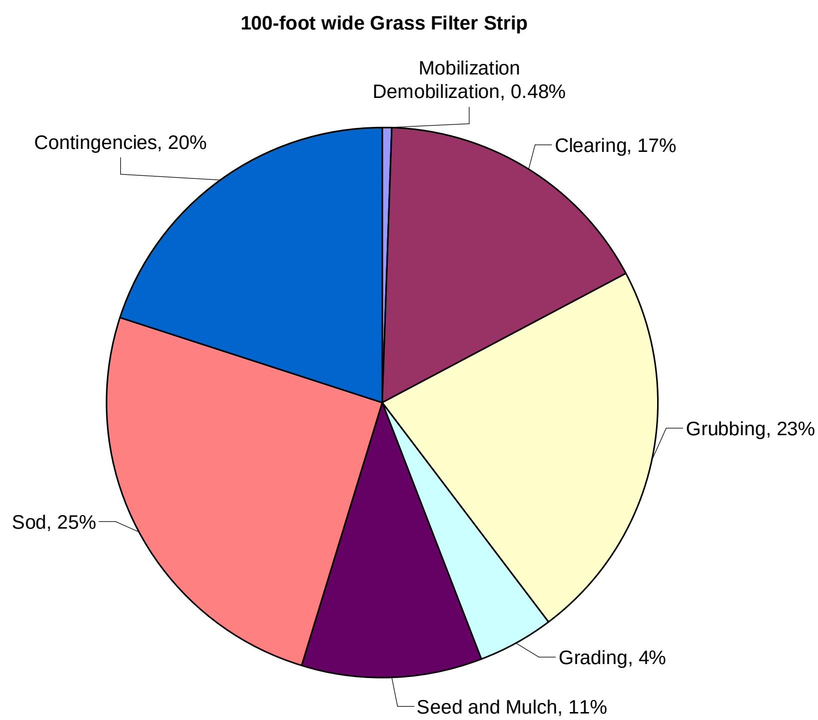


Figure 65. Distribution of the Total Capital Cost for a 100-feet Wide Grass Filter Strip

Grass Swales

In case of grass swales, sodding, clearing, and general excavation contribute the most towards the total capital costs. However, the order of these components depends on the depth and width of the grass swale. With the increase in swale depth from 1.5-foot deep to 3-foot deep, and width from 10 feet to 21 feet, the relative cost of general excavation increases from 12% to 25% of the total capital costs. The percentage contribution of each component of the grass swale towards the capital cost is shown in Figures 62 and 63 for two different swale dimensions. The relative cost of grubbing and contingencies remain the same with the increase in size. However, the relative cost of clearing, sodding, seeding and mulching decreases with the increase in grass swale area.

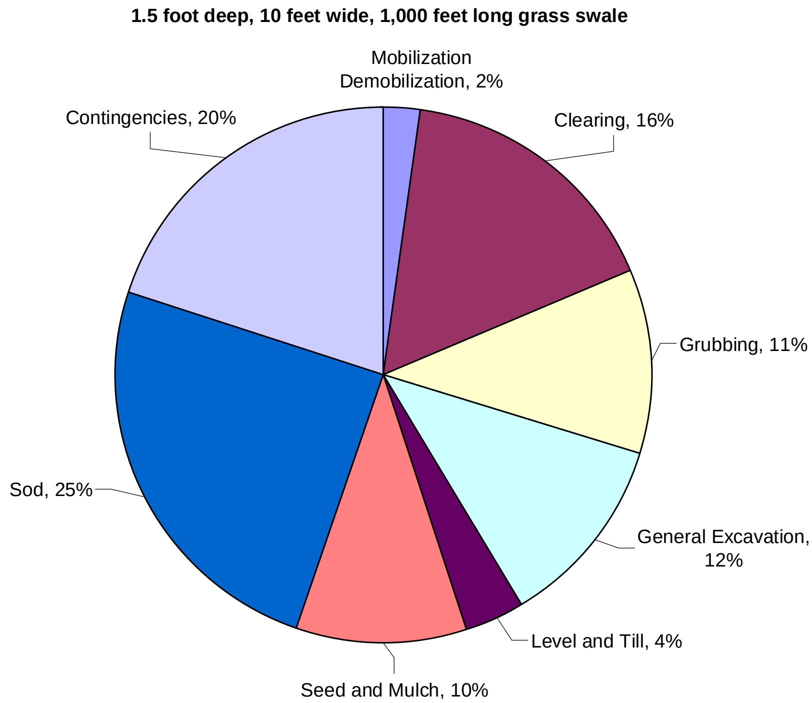


Figure 66. Distribution of Total Capital Cost for a 1.5-foot Deep, 10-feet Wide Grass Swale

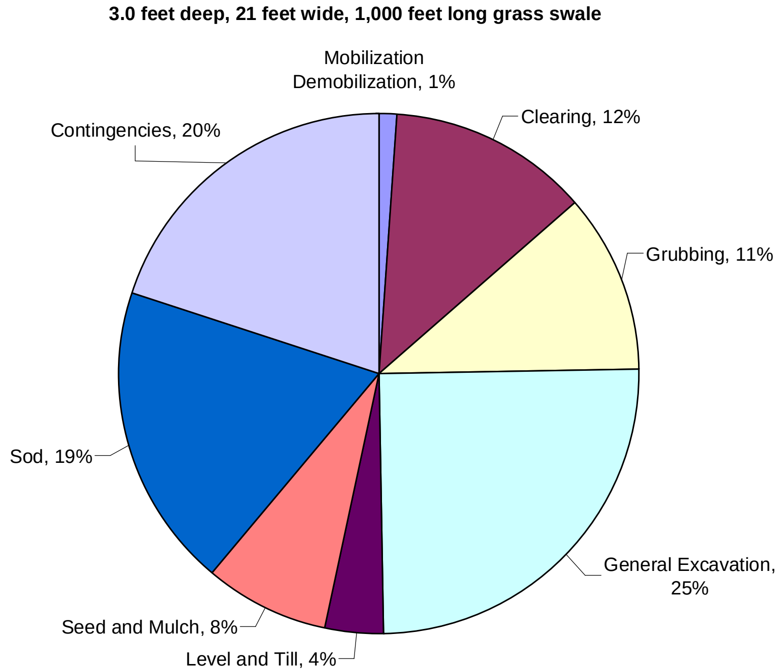


Figure 67. Distribution of Total Capital Cost for a 3-foot Deep, 21-feet Wide Grass Swale

For conservation design controls such as grass filter strips and grass swales, the costs for sodding, clearing and grubbing influence the total capital cost the most. In the case of grass swales which also involve excavation, the general excavation costs become an important factor that significantly influences the total capital cost.

Permeable Pavement

Crushed stone and the geotextile fabric contribute the most towards the total capital cost of permeable pavement installations. Crushes stone contributes nearly 50% of the total capital costs, while the geotextile fabric contributes 17% of the total capital costs for a 1-acre permeable pavement. Current designs for permeable pavement usually do not use geotextile fabrics due to their history of clogging. Figure 71 shows the distribution in components capital costs for a 1-acre permeable pavement installation.

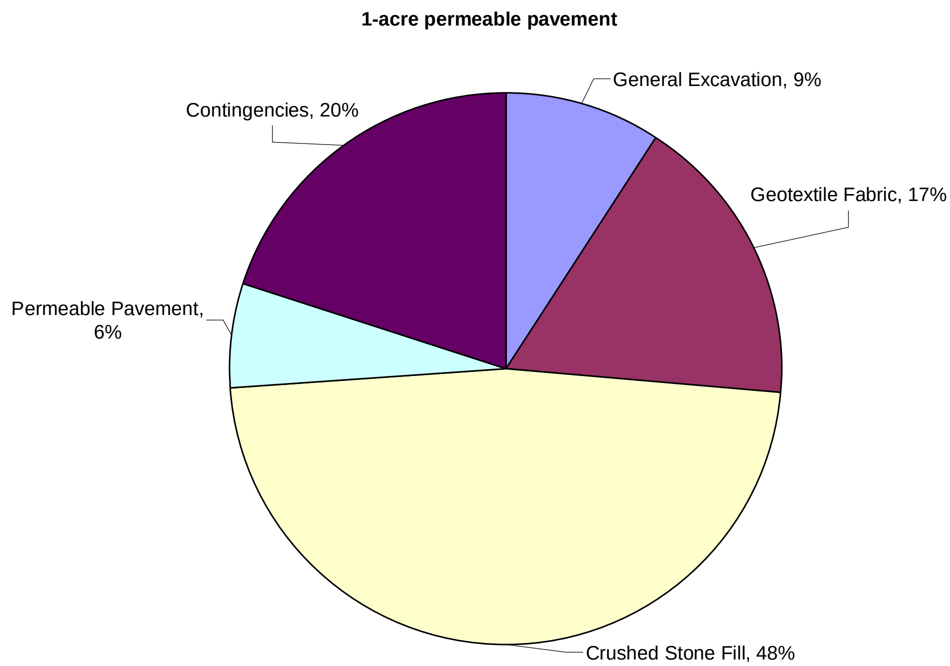


Figure 68. Distribution of Total Capital Cost for a 1-acre Permeable Pavement Installation

Infiltration Trench

Sodding, crushed stone fill, and shallow observation wells are the factors, apart from the contingency costs. that affect the total capital costs the most for an infiltration trench. For a 3-feet deep and 4-feet wide trench, sodding costs are nearly 21% of the total capital costs and the costs of crushed stone fill is about 17% of the total capital costs. For an infiltration trench 6-feet deep and 10-feet wide, the relative costs of sodding reduced to 9% of the total capital cost, while the relative costs of crushed stone fill increased to 37% of the total capital costs. However, the costs of the geotextile fabric remained the same in both infiltration trench sizes. Figures 64 and 65 shows the component costs for an infiltration trench that is 3-feet deep and 4-feet wide trench and for a trench that is 6-feet deep and 10-feet wide. The relative cost of the trench excavation increased by about 5% when the trench size was increased, while the relative costs of the shallow observation wells decreased from 13% to 9%.

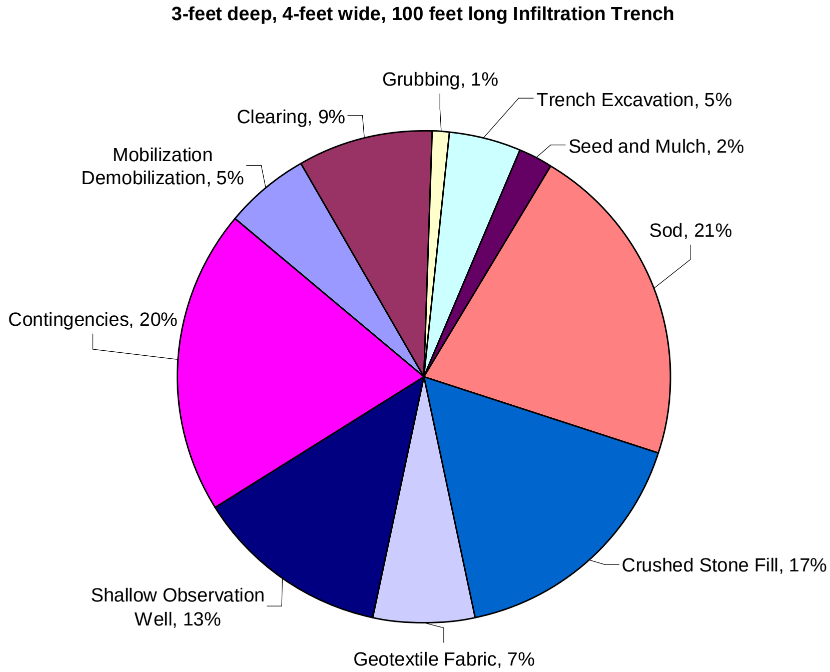


Figure 69. Distribution of Total Capital Cost for a 3-feet Deep, 4-feet Wide, 100-feet Long Infiltration Trench

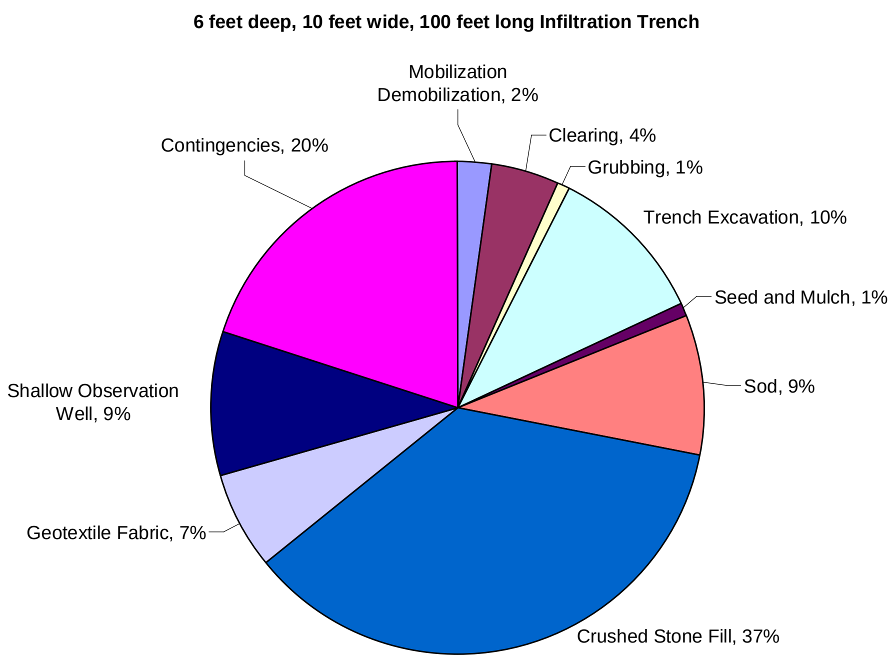


Figure 70. Distribution of Total Capital Cost for a 6-feet Deep, 10-feet Wide, 100-feet Long Infiltration Trench

In case of stormwater control practices crushed stone fill, the stone influences the capital costs the most. In case of infiltration trenches, this is followed by the costs for sodding and the costs for shallow observation wells.

Conventional Stormwater Conveyance

The spreadsheet model shows that for a given pipe diameter, the capital cost of a conveyance system is influenced most by the cost of pipe installation. This is followed by the cost of trench excavation, bedding and the backfill. The cost for pipe installation is nearly three to four times greater than the cost for trench excavation.

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Appendix – A
ENR Cost Indices

A1. Cost Adjustments for Different Locations and Dates

This report presented the costs involved in the construction, operation and maintenance of several stormwater controls. These costs are representative of costs incurred in a specific year or in a specific period of time, and location. To determine the cost of construction of these stormwater controls in 2005, or in any other particular year or location, the corresponding cost index values are used from the attached cost index chart.

These Cost Index values are prepared by McGraw Hill, the publisher of the *Engineering News Record* (ENR) and are available from www.ENR.com. ENR has price reporters covering 20 U.S. cities who check prices locally. The prices are quoted from the same suppliers each month. ENR computes its latest indexes from these figures and local union wage rates. The 20 cities are: Atlanta GA, Baltimore MD, Birmingham AL, Boston MA, Chicago IL, Cincinnati OH, Cleveland OH, Dallas TX, Denver CO, Detroit MI, Kansas City MO, Los Angeles CA, Minneapolis MN, New Orleans LA, New York NY, Philadelphia PA, Pittsburgh PA, San Francisco CA, Seattle WA, St. Louis MO. The Construction Cost Index values for these 20 cities in the US from 1978 to 2005 are shown in Table A1. Also, shown are the 20-city averaged construction cost index, materials price index, common labor index and building cost.

For determining the cost index for cities not listed in the chart, the index value can be obtained by averaging the costs of the nearest cities. Figures A1- A20 show the variation in the construction cost index from 1978 to 2006 for the 20 cities listed above. Figure A21 is a US map showing the 20 cities with Thiessen Polygons drawn around each city. These polygons define the closest areas of influence around each of the 20 cities. They were constructed by joining perpendicular bisectors between each pair of cities.

Table A1. ENR Construction Cost Index Values for Different Cities

Year	Atlanta, GA	Baltimore, MD	Birmingham, AL	Boston, MA	Chicago, IL	Cincinnati, OH	Cleveland, OH
1978	2172.6	2396.39	2283.3	2772.83	2981.85	3088.21	3267.97
1979	2358.43	2719.34	2431.67	3096.16	3266.78	3349.05	3565.5
1980	2535.72	2904.39	2558.45	3173.98	3497.25	3609.93	3860.76
1981	2801.31	3060.78	2768.12	3659.88	3749.45	4045.44	4379.04
1982	3034.47	3097.4	2853.6	3993.72	4106.45	4234.64	4669.64
1983	2909	3107.35	2983.6	4204.75	4235.73	4398.6	4847.04
1984	2898.53	3158.77	3074.83	4497.4	4319.75	4437.58	5073.08
1985	2909.71	3236.9	3037.76	4685.85	4367.28	4548.2	4992.32
1986	3018.67	3372.26	3083.92	4722.66	4495.88	4567.24	5061.56
1987	3094.92	3560.91	3251.65	4941.39	4686.53	4647.13	5251.44
1988	3107.63	3576.83	3331.21	5137.58	4844.48	4700.51	5237.37
1989	3141.55	3707.18	3413.76	5373.14	4957.69	4877.51	5161.68
1990	3191.55	3884.43	3426.41	5614.79	4998.8	4933.91	5368.82
1991	3224.67	3858.19	3466.21	5722.5	5384.16	5011.1	5450.25
1992	3348.42	3997.47	3665.33	5973.33	5643.78	5209.18	5501.09
1993	3389.89	4171.75	3919.97	6380.25	5962.58	5344.53	5752.29
1994	3430.97	4198.95	3940.28	6404.34	6177.81	5504.43	5922.53
1995	3381.41	4324.86	4069.43	6407.28	6333.93	5450.56	6018.52
1996	3601.31	4544.51	4264.98	6772.2	6743.46	5488.81	6187.09
1997	3690.27	4502.11	4310.28	6747.28	6625.83	5585.21	6264.58
1998	3772.43	4534.38	4230.88	6921.04	7086.96	5641.21	6347.97
1999	3849.39	4564.19	4472.05	7103.92	7464.71	5888.56	6462.03
2000	4105.86	4532.08	4504.66	6986.61	7747.96	6044.89	6733.83
2001	4045.52	4542.29	4716.58	7042.39	7679.62	5858.12	6920.63
2002	4189.12	4580.15	4686.49	7546.61	7965.18	6155.81	7067.13
2003	4374.69	4818.78	4904.07	7976.09	8348.45	6286.9	7229.01
2004	4533.6	4978.88	5125.83	8216.29	8927.07	6587.24	7468.96
2005	4678.48	5277.70	5308.60	8684.81	9603.47	7031.37	7763.33

Table A1 – Continued.

Year	Dallas, TX	Denver, CO	Detroit, MI	Kansas City, MO	Los Angeles, CA	Minneapolis, MN	New Orleans, LA
1978	2082.95	2564.77	3223.97	3039.64	3421.25	2902.6	2346.65
1979	2427.24	2739.14	3492.04	3256.47	3638.81	3154.37	2693.75
1980	2683.34	2947.14	3798.23	3551.83	4102.37	3238.86	2792.99
1981	2975.25	3200.57	4138.17	3838.22	4530.96	3612.6	3087.99
1982	3192.54	3445.7	4244.91	4069.74	4934.14	3924.98	3294.66
1983	3263.61	3690.22	4375.55	4199.38	5063.89	4322.45	3444.58
1984	2950.4	3106.45r	4331.1	4200.58	5259.93	4209.93	3427.64
1985	2997.36	3316.24	4468.09	4337.4	5446.69	4303.33	3411.86
1986	3152.84	3503.37	4674.95	4485.48	5452.2	4406.75	3513.96
1987	2985.85	3506.95	4859.89	4599.98	5474.14	4494.16	3572.49
1988	3184.72	3538.26	5092.67	4667.26	5770.84	4582.99	3571.19
1989	3208.39	3641.78	5171.88	4719.9	5789.77	4804.75	3590.13
1990	3195.21	3668.2	5153.9	4763.94	5994.55	4798.61	3602.41
1991	3336.53	3715.34	5244.65	4762.18	6090.12	4932.67	3638.65
1992	3476.69	3833.64	5395.34	4955.79	6348.55	5133.25	3730.37
1993	3570.97	4012.02	5917.92	5224.43	6477.84	5395.05	3764.21
1994	3640.03	4008.74	5979.62	5304.63	6532.95	5776.85	3831.08
1995	3641.12	4087.82	6135.27	5369.96	6526.22	5909.05	3833.36
1996	3870.81	4334.09	6428.7	5652.65	6558.44	6298.52	3973.26
1997	3935.95	4329.24	6619.64	5909.18	6663.55	6434.11	4013.79
1998	3960.19	4470.35	6817.65	5981.26	6851.95	6628.38	3994.93
1999	3968.5	4498.45	6943.56	5999.65	6825.97	6878.53	3945.01
2000	3985.86	4766.74	7100.4	6221.07	7068.04	6995.02	4016.26
2001	3854.32	4663.08	7378.92	6477.21	7226.92	7317.41	3984.38
2002	3895.46	4744.3	7654.06	6782.21	7402.75	7620.66	3906.42
2003	4044.04	5015.43	7860.94	6971.96	7531.77	7999.46	3899.73
2004	4207.65	5310.42	8191.41	7494.32	7899.48	8329.93	4257.45
2005	4528.39	5476.76	8585.49	8022.29	8330.11	8858.57	4391.00

Table A1 – Continued.

Year	New York, NY	Philadelphia, PA	Pittsburgh, PA	San Francisco, CA	Seattle, WA	St.Louis, MO
1978	3325.43	2839.24	2945.44	3412.2	3197	3105.71
1979	3580.5	3183.93	3180.57	3806.14	3497.64	3344.2
1980	3774.64	3233.59	3383.37	4371.96	3909.16	3578.4
1981	4125.68	3603.48	3653.46	4592.45	4230.36	3834.64
1982	4553.93	3858.5	3894.97	4993.3	4490.38	4107.49
1983	4887.55	4175.74	4077.51	5122.74	4559.55	4325.69
1984	5160.95	4437.81	4234.49	5049.13	4546.01	4511.37
1985	5388.08	4549.62	4208.63	5055.04	4563.1	4733.37
1986	5621.15	4678.78	4280.39	5508.43	4585.4	4827.92
1987	5961.27	4883.56	4311.93	5732.37	4684.28	5056.78
1988	6231.12	5064.2	4331.7	5734.48	4738.35	5061.56
1989	6453.56	5299.78	4425.57	5932.57	4898.01	5132.97
1990	6846.49	5431.26	4580.56	6055.61	4933.39	5090.94
1991	7110.37	5616.96	4696.93	6222.06	5120.63	5172.41
1992	7367.49	5682.35	4988.38	6294.84	5320.37	5315.67
1993	7737.11	6022.23	5287.87	6477.95	5630.25	5765.31
1994	8117.64	6224.86	5485.79	6530.35	5818.49	5947.05
1995	8378.68	6431	5648.52	6558.16	5924.09	6053.67
1996	8554.47	6599.25	5984.29	6629.61	6086.77	6302.04
1997	8742.88	7057.36	5889.15	6731.08	6639.85	6474.56
1998	8899.59	7297.87	5976.05	6845.59	6957.81	6598.82
1999	9355.77	7487.01	6068.33	6816.7	7137.17	6806.23
2000	9379.14	7600.26	6198.9	7447.99	7368.25	6851.3
2001	10101.24	7960.76	6252.6	7399.07	7335.24	7047.92
2002	10009.06	8226.27	6419.37	7644.46	7561.98	7197.19
2003	10386.73	8403.02	6512.58	7788.8	7866.58	7414.09
2004	11279.53	8701.1	6884.92	8091.66	8014.67	7797.3
2005	11810.41	8743.07	7035.58	8298.84	8264.59	8181.54

Table A1 – Continued.

Year	Construction Cost Index, 20 City Average	Materials Cost Index, 20 City Average	Common Labor Index, 20 City Average	Building Cost Index, 20 City Average
1978	2776	NA	NA	1654
1979	3003	NA	NA	1919
1980	3237	NA	NA	1941
1981	3535	NA	NA	2097
1982	3825	NA	NA	2234
1983	4066	1650.75	NA	2384
1984	4146	1620.83	NA	2417
1985	4195	1617.08	NA	2428
1986	4295	1634.17	NA	2483
1987	4406	1659.00	NA	2541
1988	4519	1694.00	NA	2598
1989	4615	1693.33	NA	2634
1990	4732	1720.17	9645.75	2702
1991	4835	1708.83	9935.17	2751
1992	4985	1760.92	10243.42	2834
1993	5210	1953.17	10524.75	2996
1994	5408	2068.17	10855.92	3111
1995	5471	1992.83	11146.25	3111
1996	5620	2045.83	11443.83	3203
1997	5826	2225.92	11697.33	3364
1998	5920	2179.25	12024.42	3391
1999	6059	2184.08	12382.58	3456
2000	6221	2195.08	12789.67	3539
2001	6343	2112.83	13242.25	3574
2002	6538	2043.67	13870.67	3623
2003	6694	1980.75	14385.67	3693
2004	7115	2295.83	14977.58	3984
2005	7444			

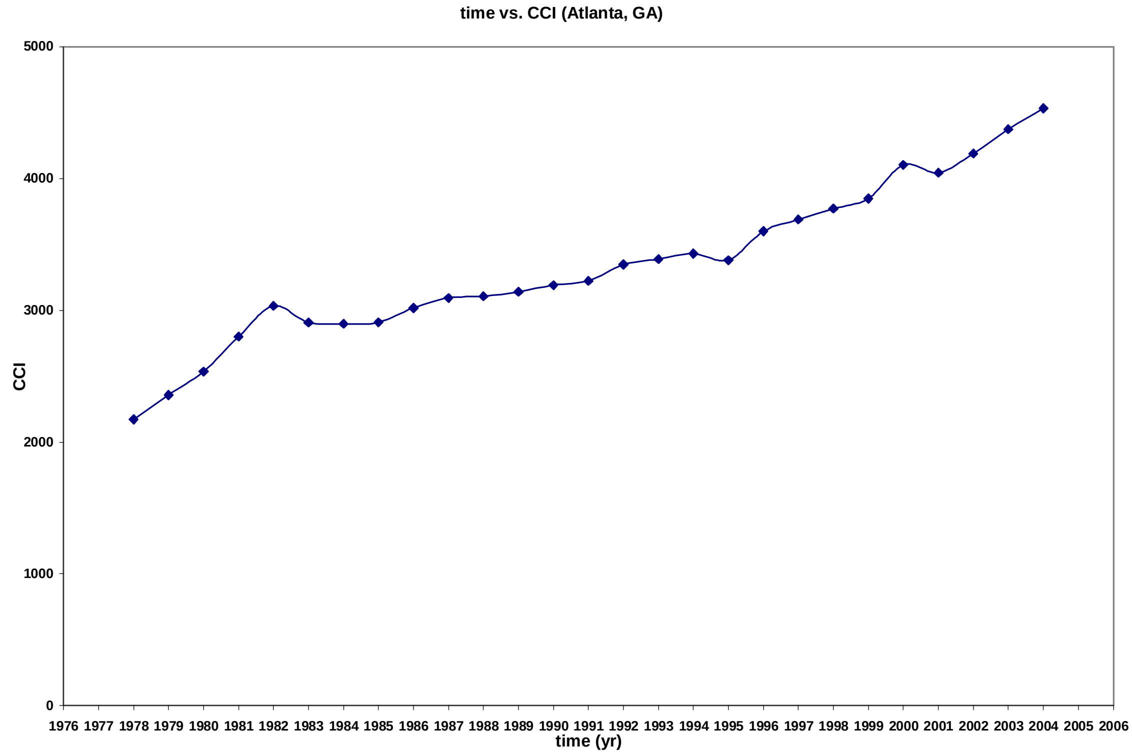

Figure A1. Variation in CCI from 1978 to 2005 for Atlanta, GA

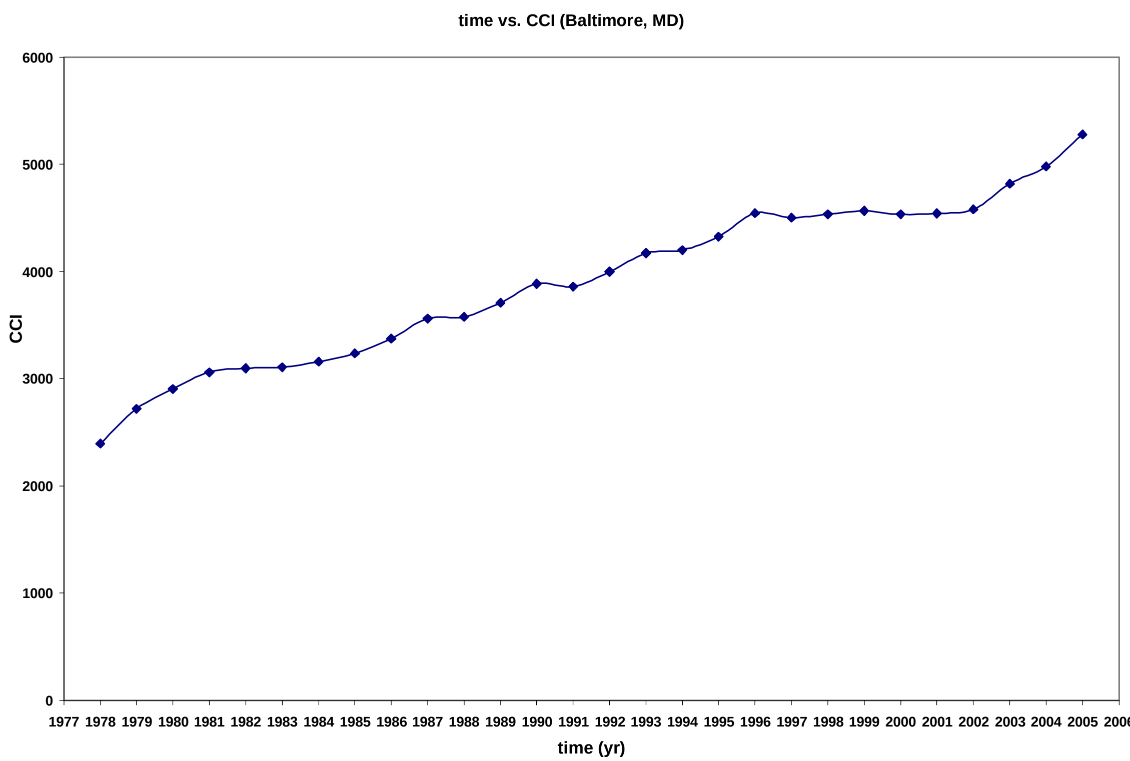

Figure A2. Variation in CCI from 1978 to 2005 for Baltimore, MD

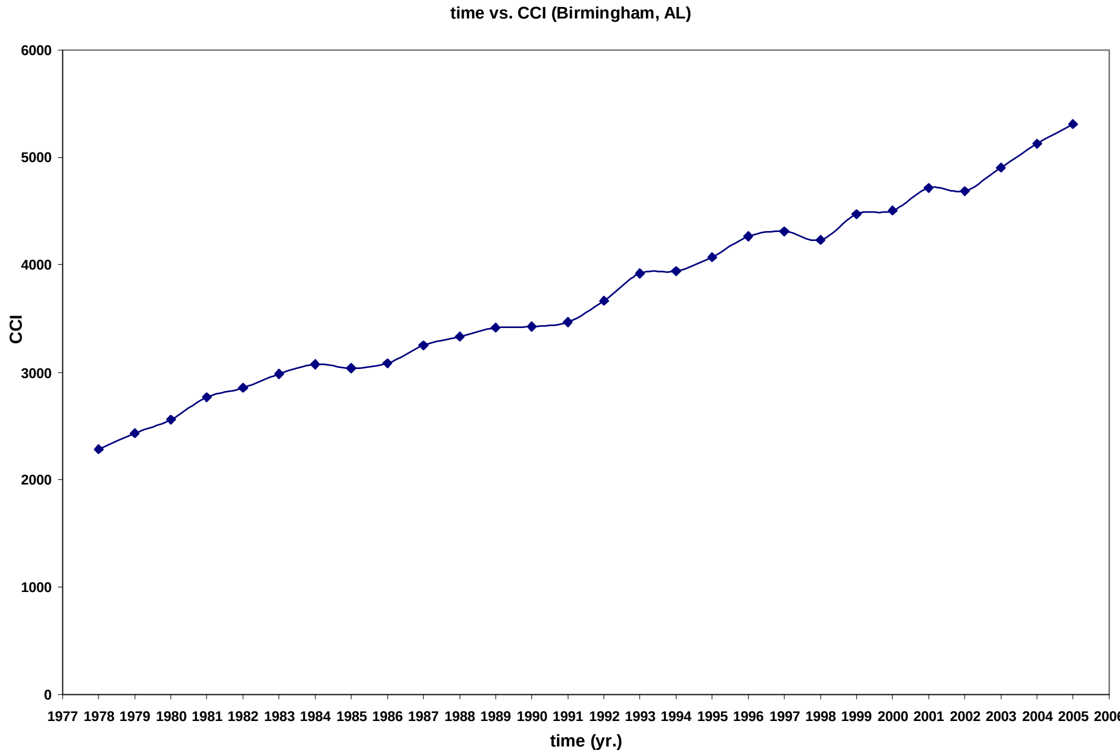

Figure A3. Variation in CCI from 1978 to 2005 for Birmingham, AL

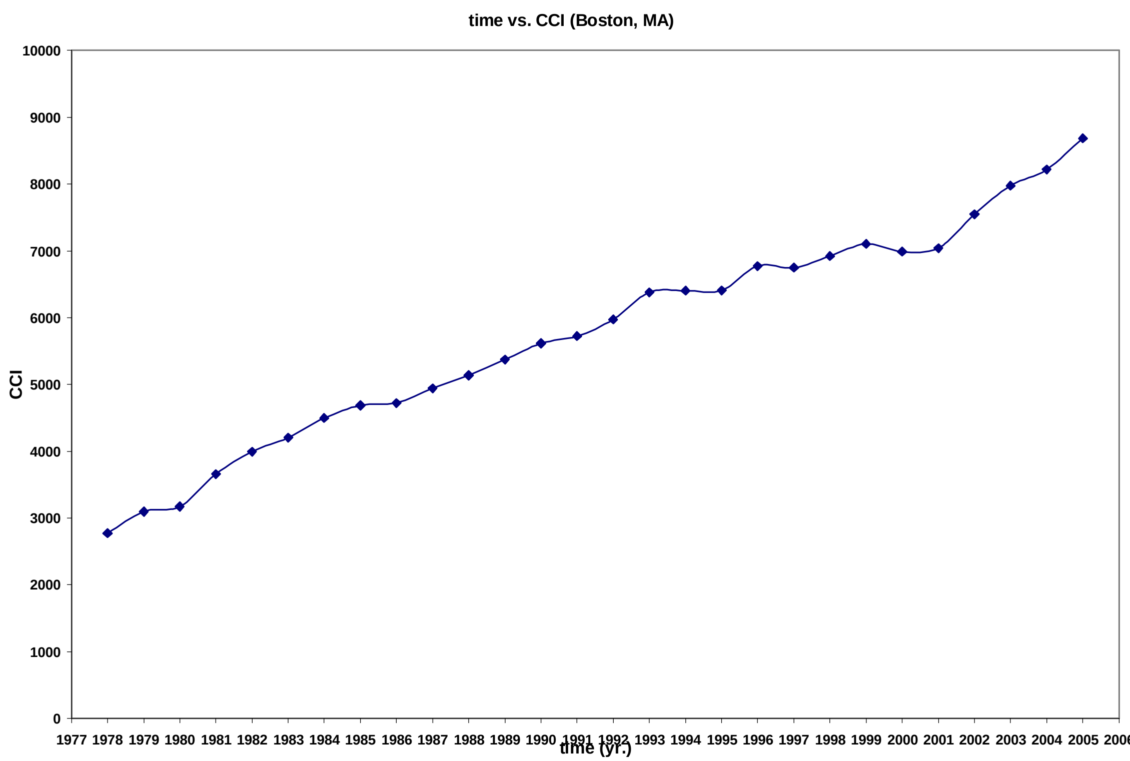

Figure A4. Variation in CCI from 1978 to 2005 for Boston, MA

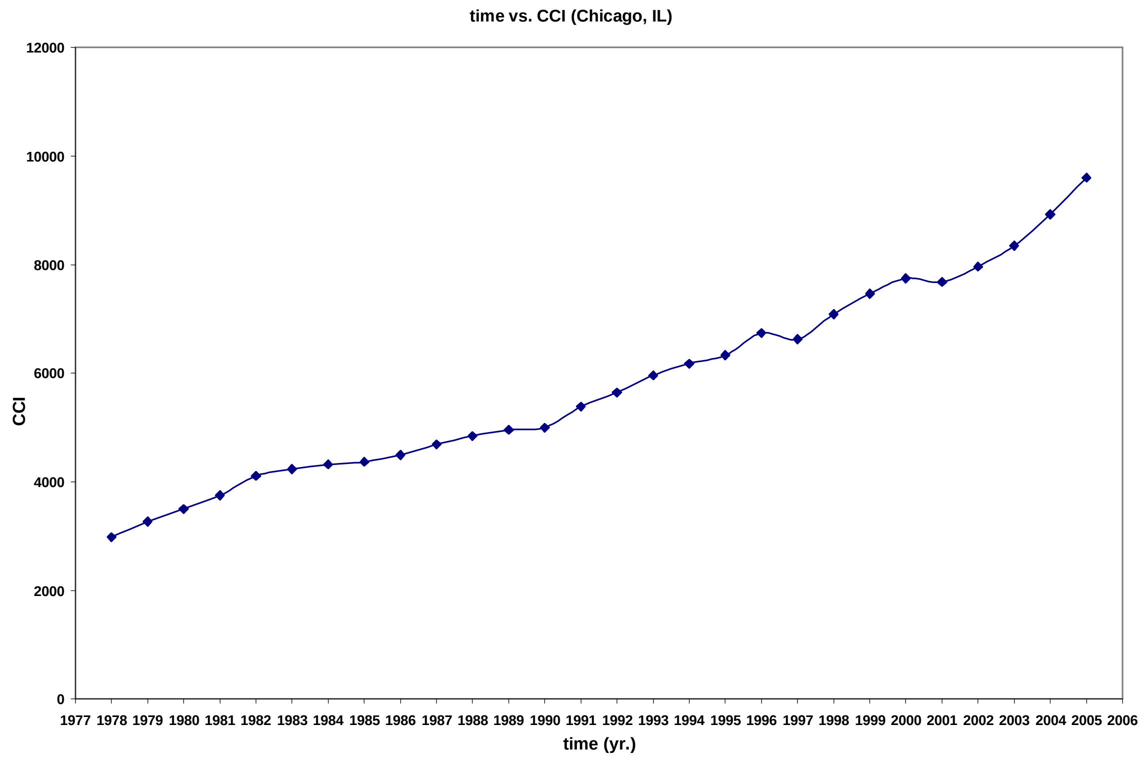

Figure A5. Variation in CCI from 1978 to 2005 for Chicago, IL

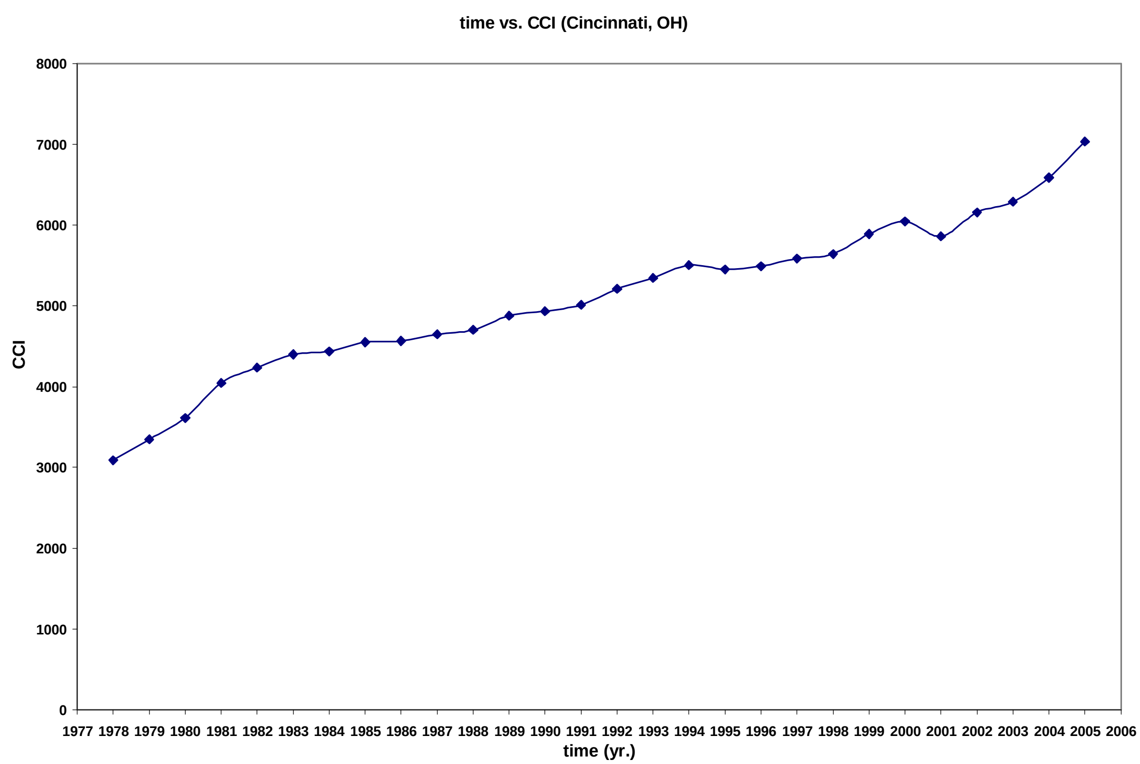

Figure A6. Variation in CCI from 1978 to 2005 for Cincinnati, OH

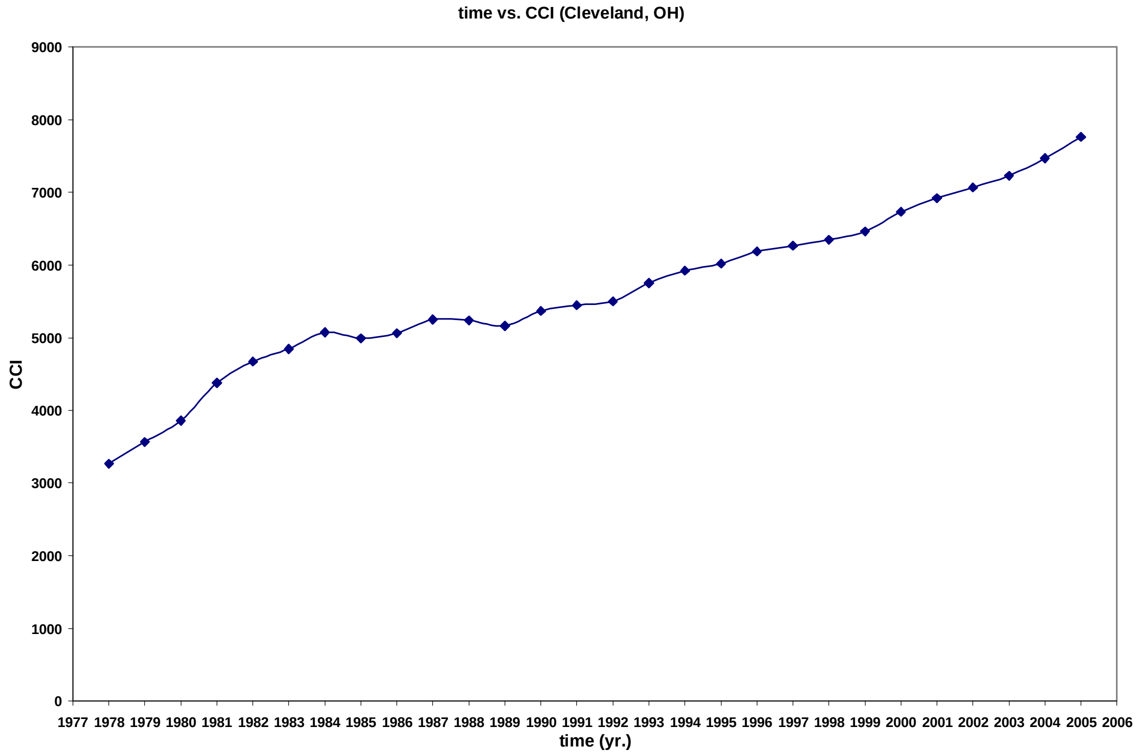

Figure A7. Variation in CCI from 1978 to 2005 for Cleveland, OH

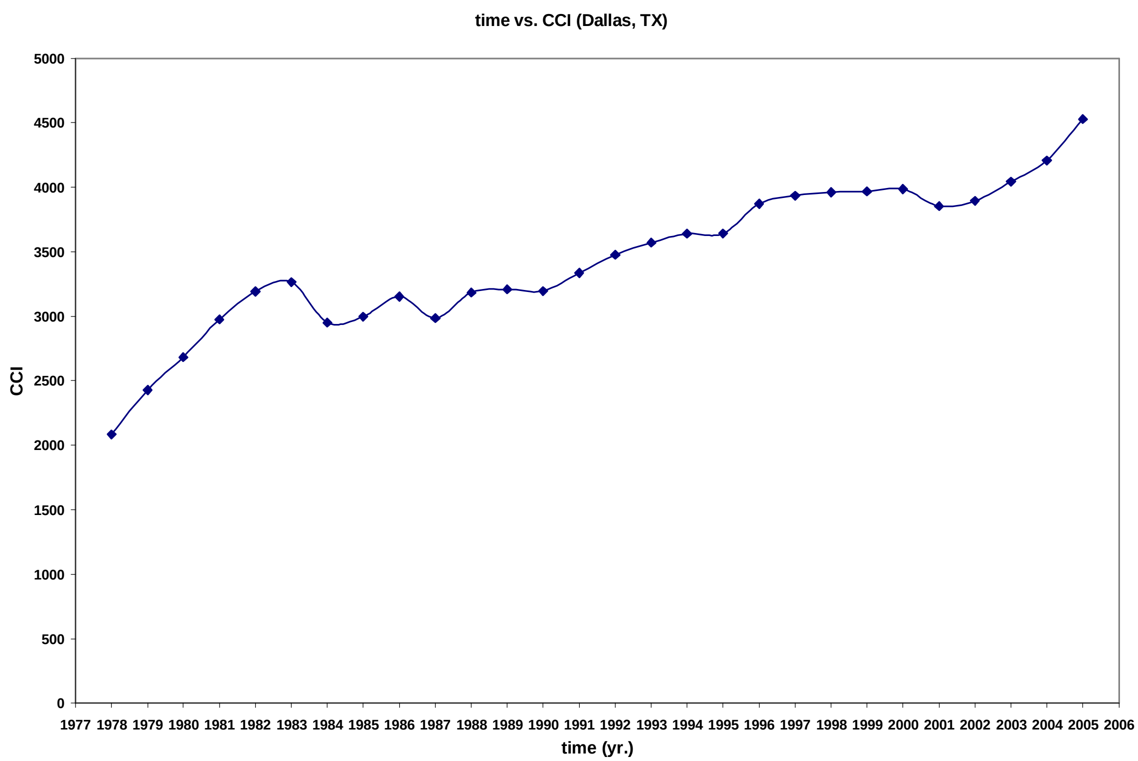

Figure A8. Variation in CCI from 1978 to 2005 for Dallas, TX

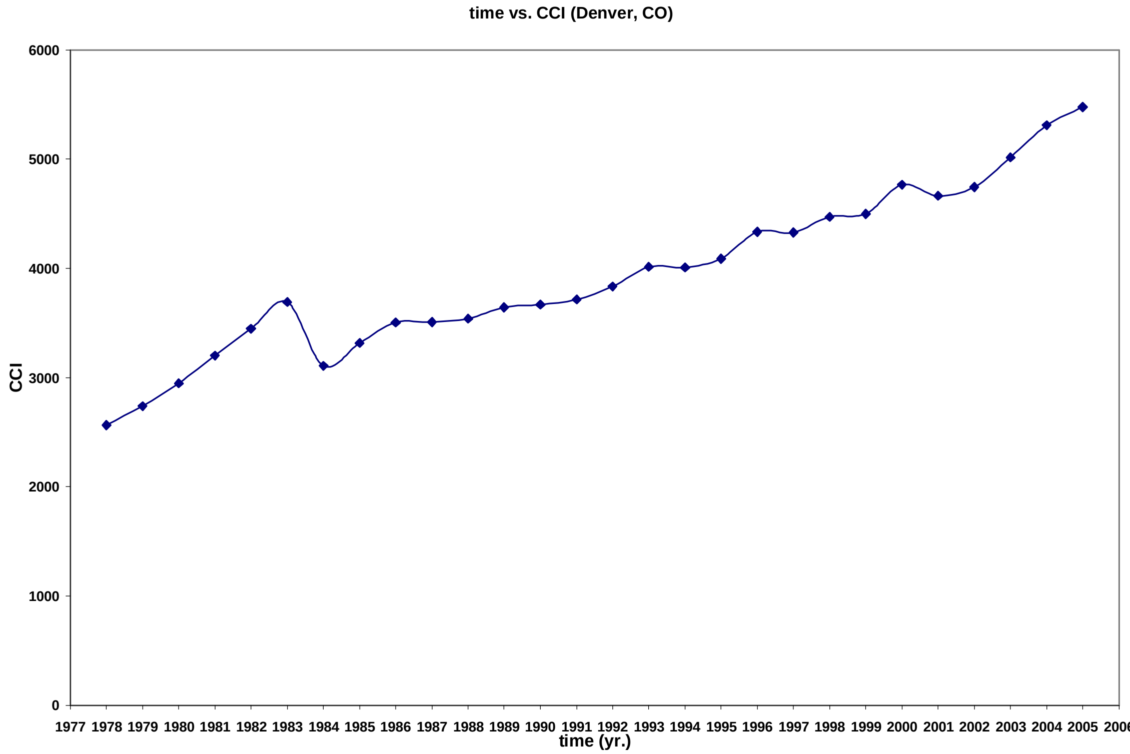

Figure A9. Variation in CCI from 1978 to 2005 for Denver, CO

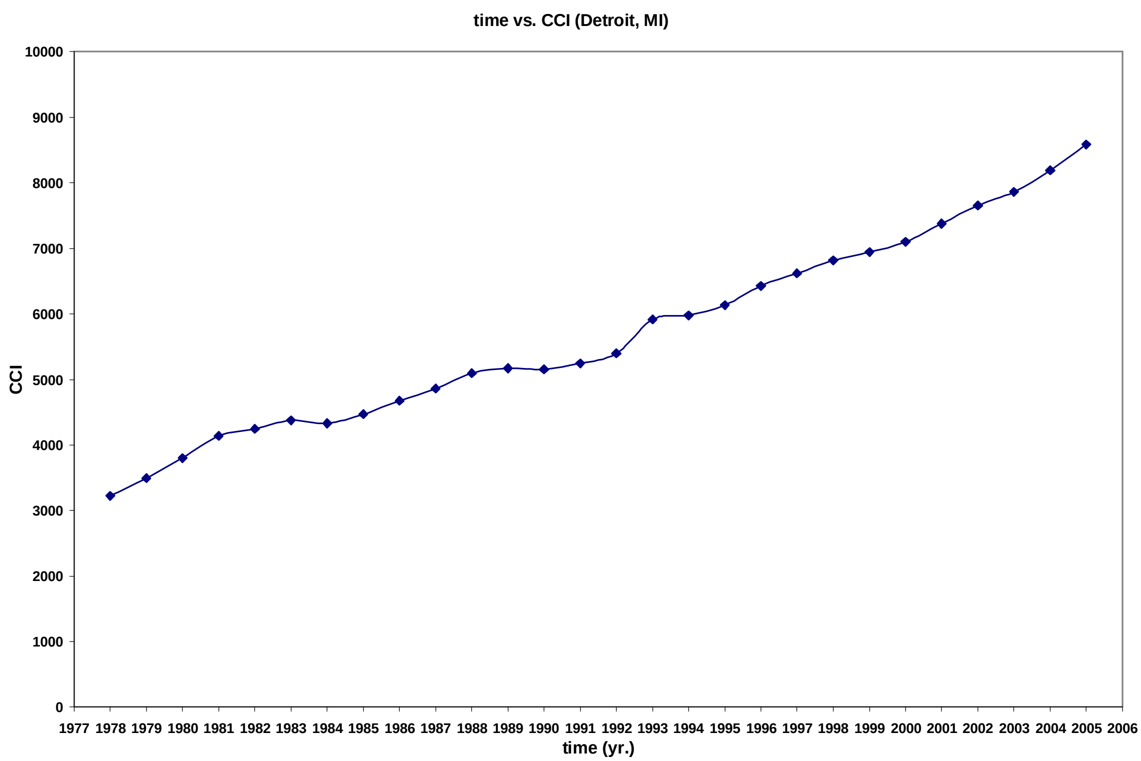

Figure A10. Variation in CCI from 1978 to 2005 for Detroit, MI

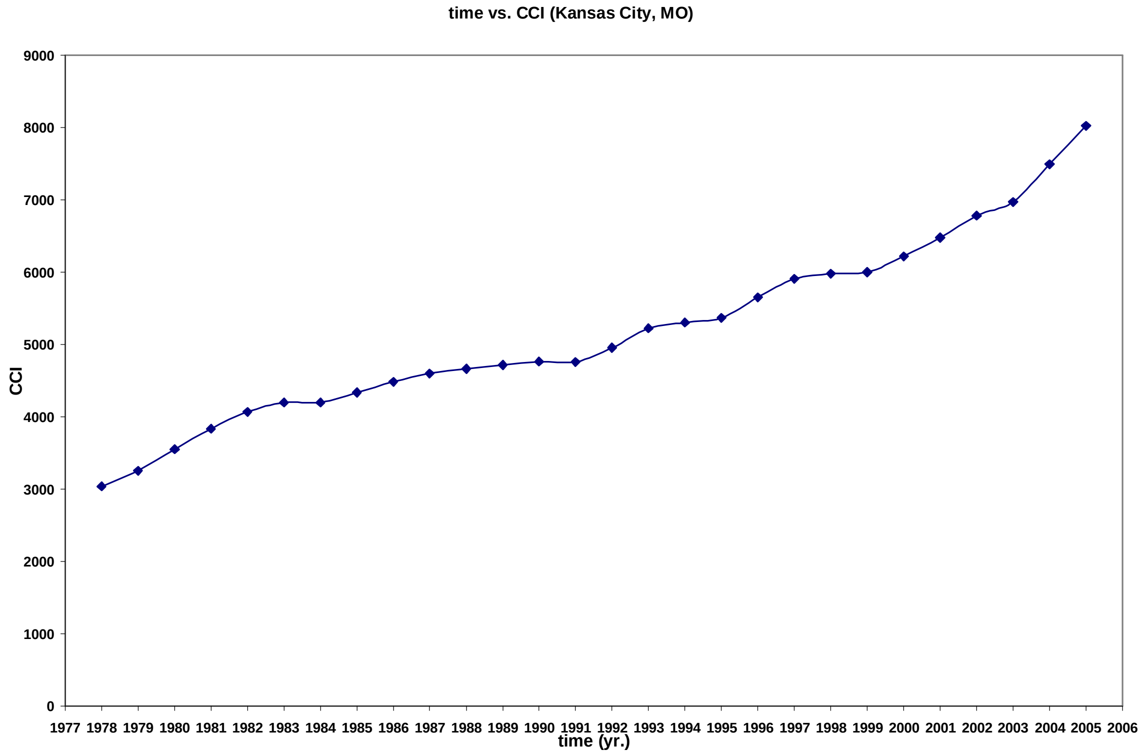

Figure A11. Variation in CCI from 1978 to 2005 for Kansas City, MO

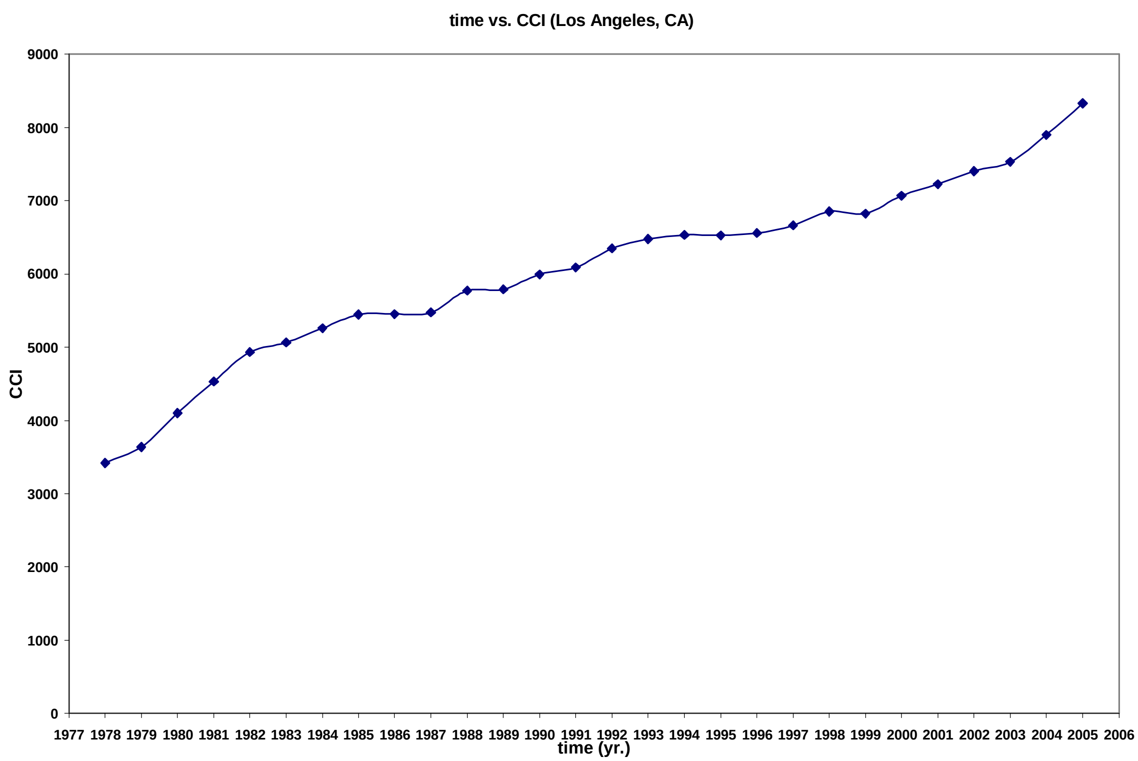

Figure A12. Variation in CCI from 1978 to 2005 for Los Angeles, CA

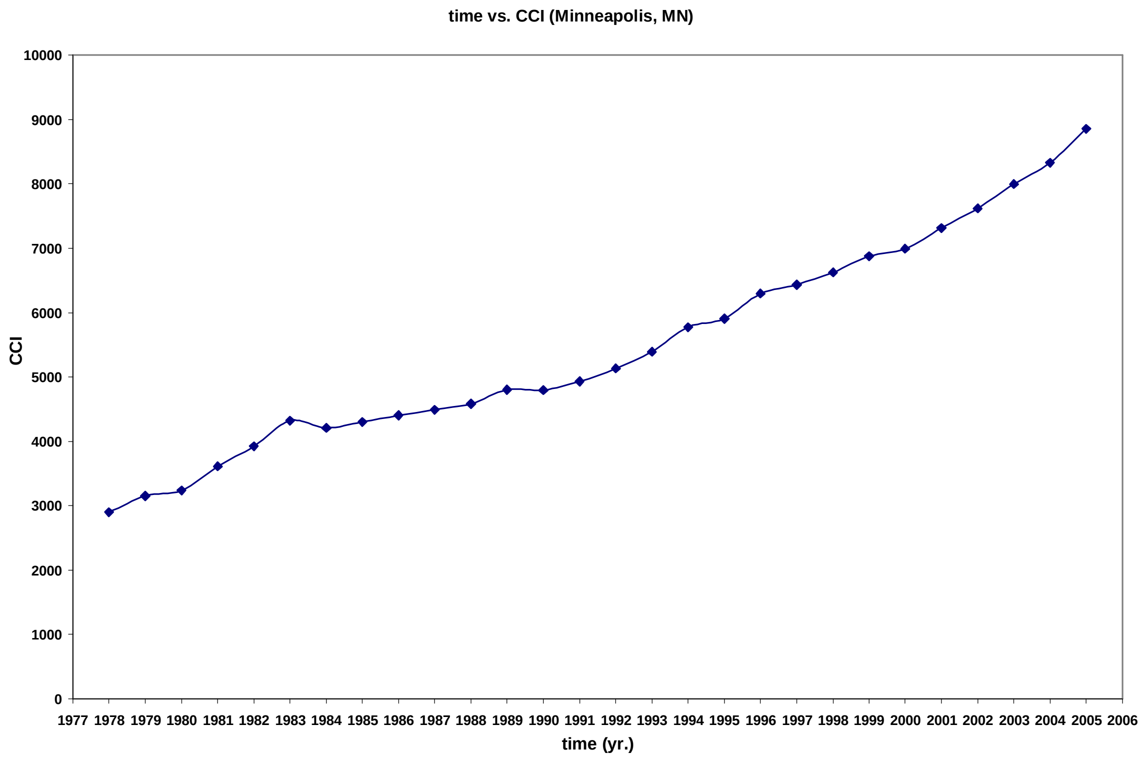

Figure A13. Variation in CCI from 1978 to 2005 for Minneapolis, MN

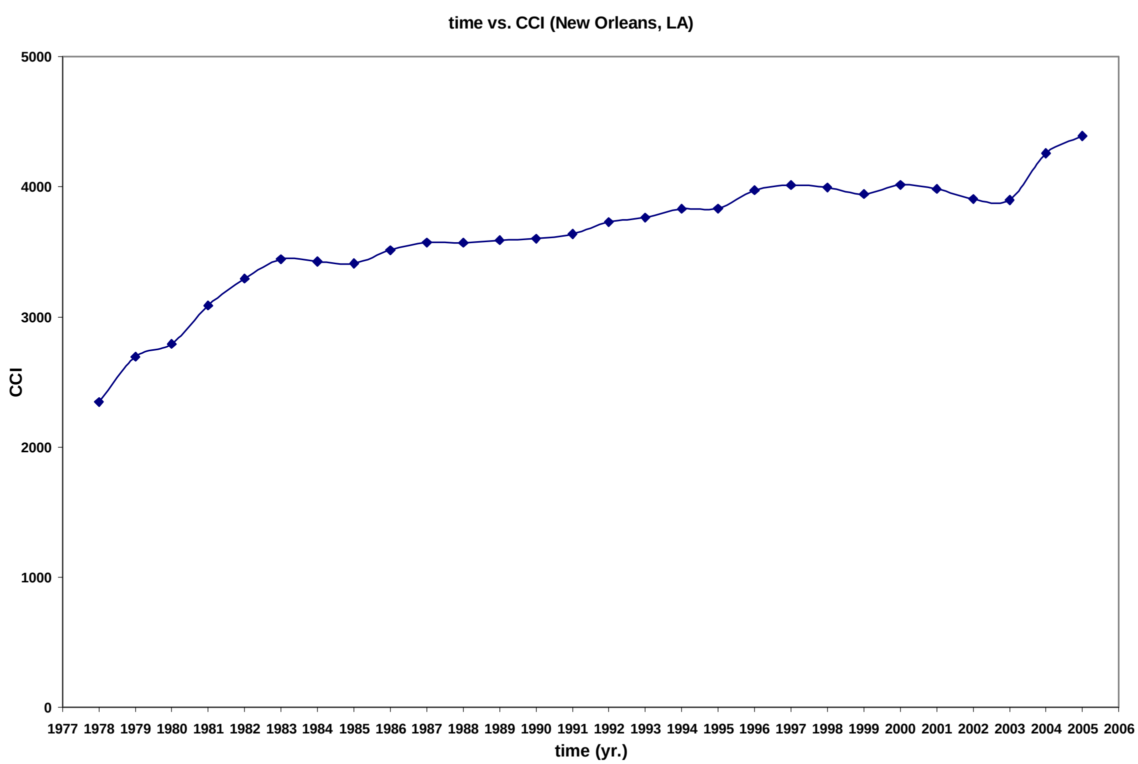

Figure A14. Variation in CCI from 1978 to 2005 for New Orleans, LA

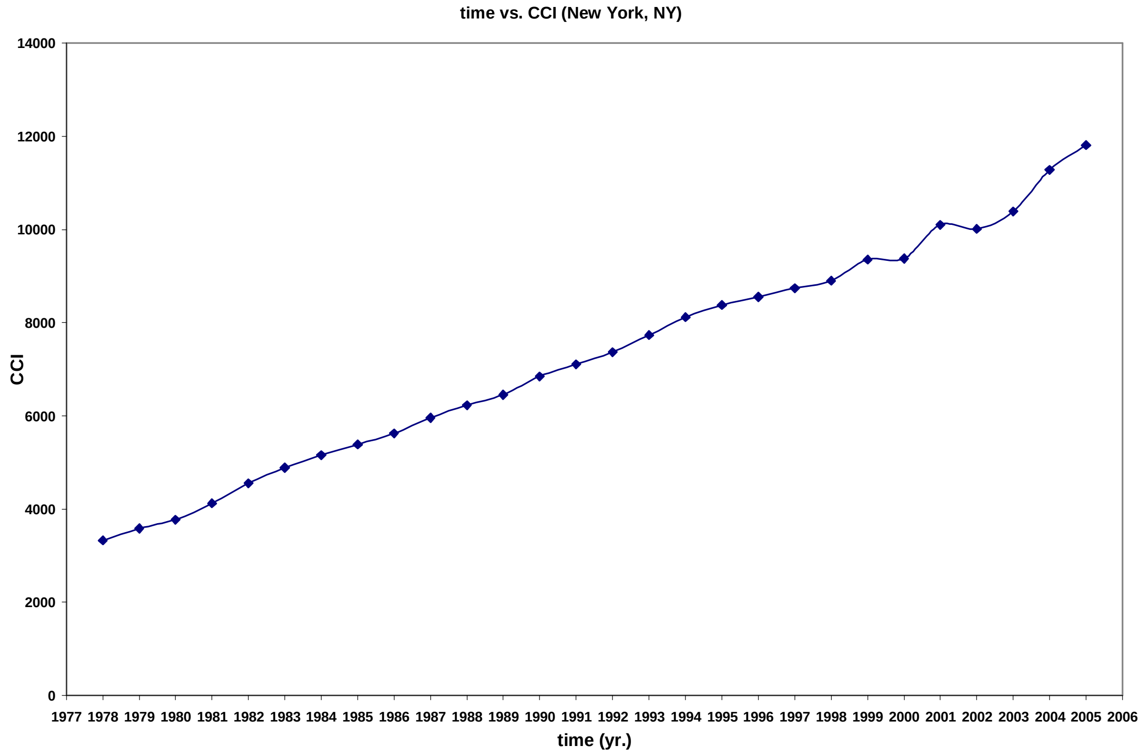

Figure A15. Variation in CCI from 1978 to 2005 for New York, NY

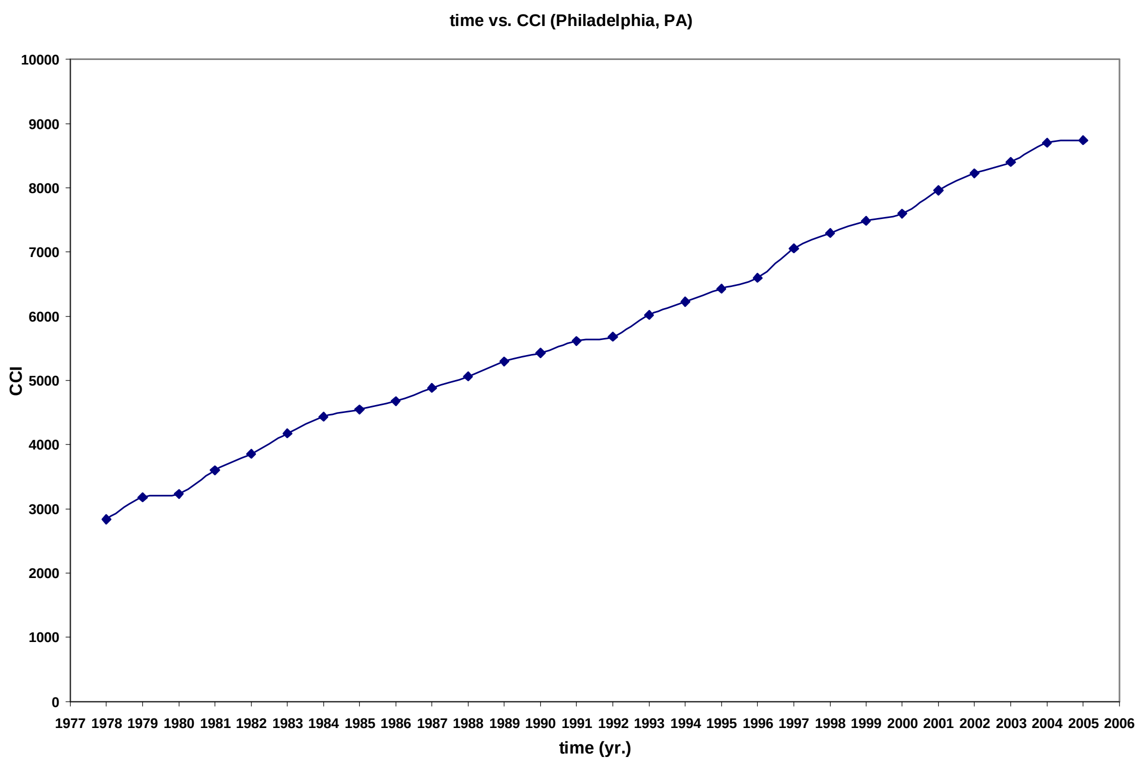

Figure A16. Variation in CCI from 1978 to 2005 for Philadelphia, PA

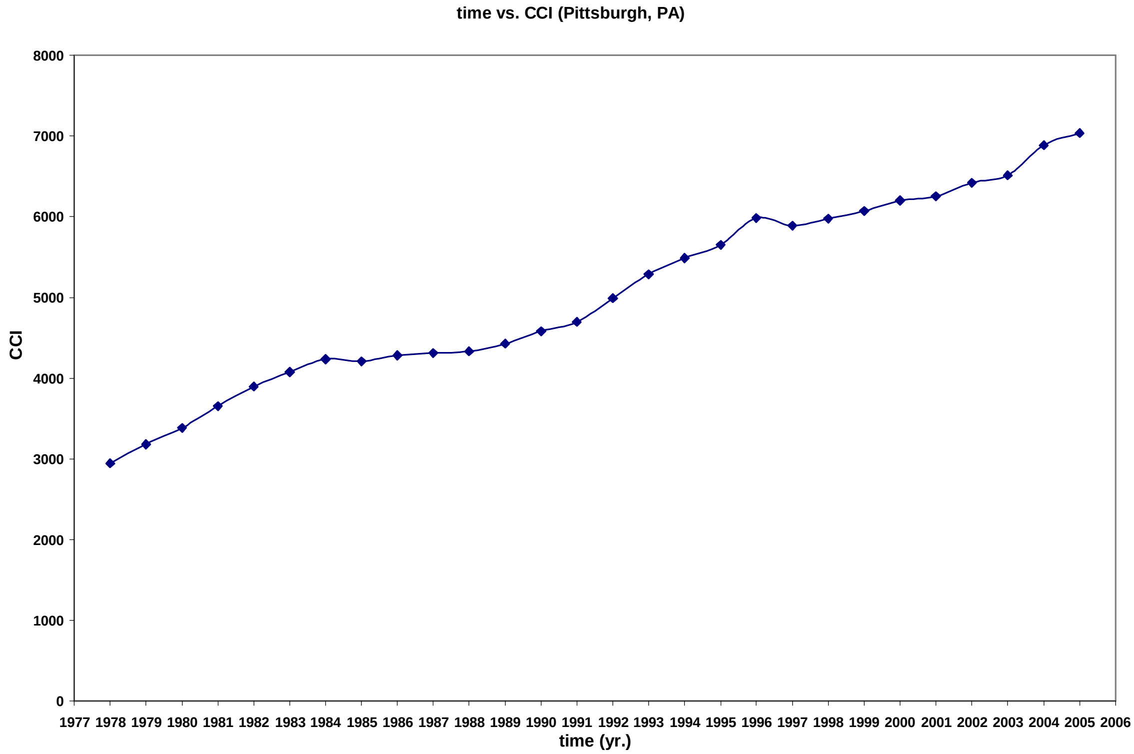

Figure A17. Variation in CCI from 1978 to 2005 for Pittsburgh, PA

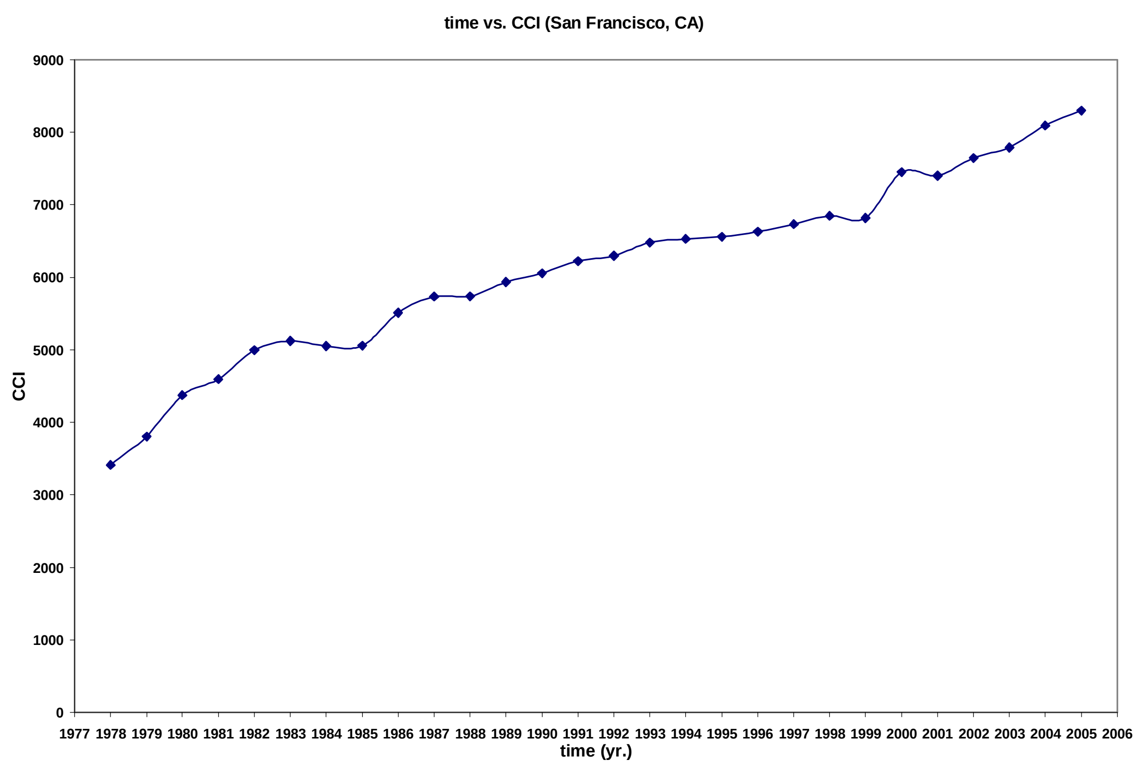

Figure A18. Variation in CCI from 1978 to 2005 for San Francisco, CA

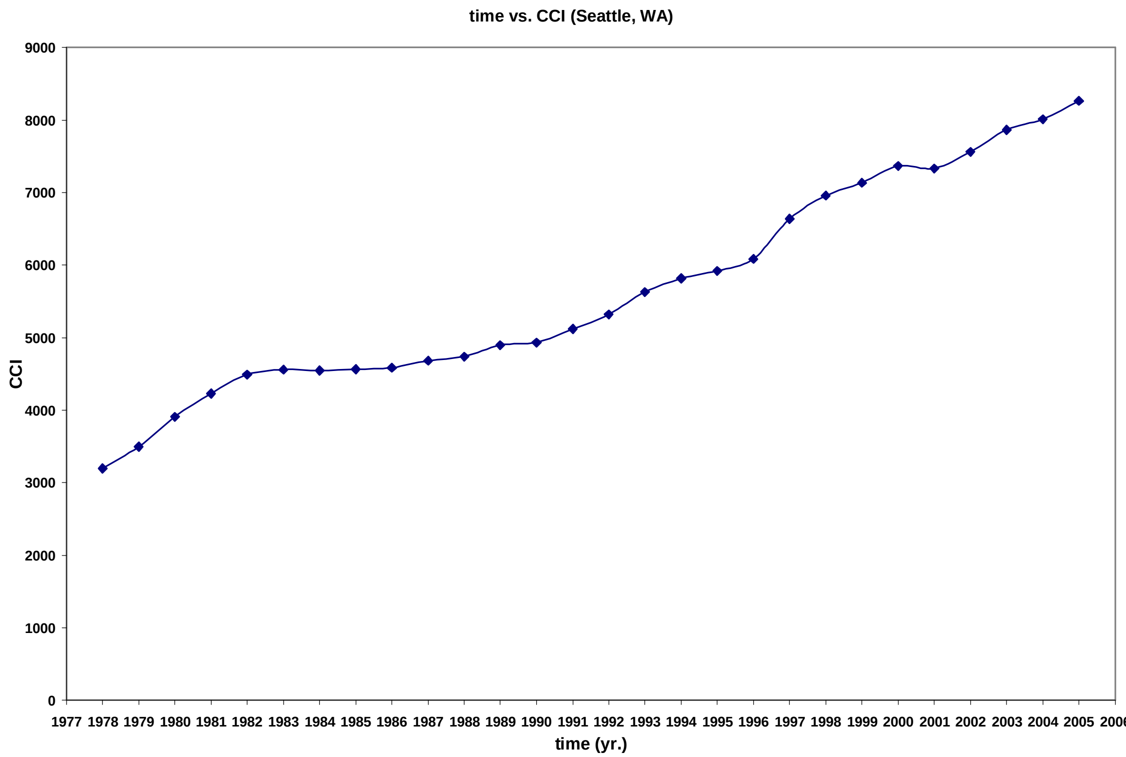

Figure A19. Variation in CCI from 1978 to 2005 for Seattle, WA

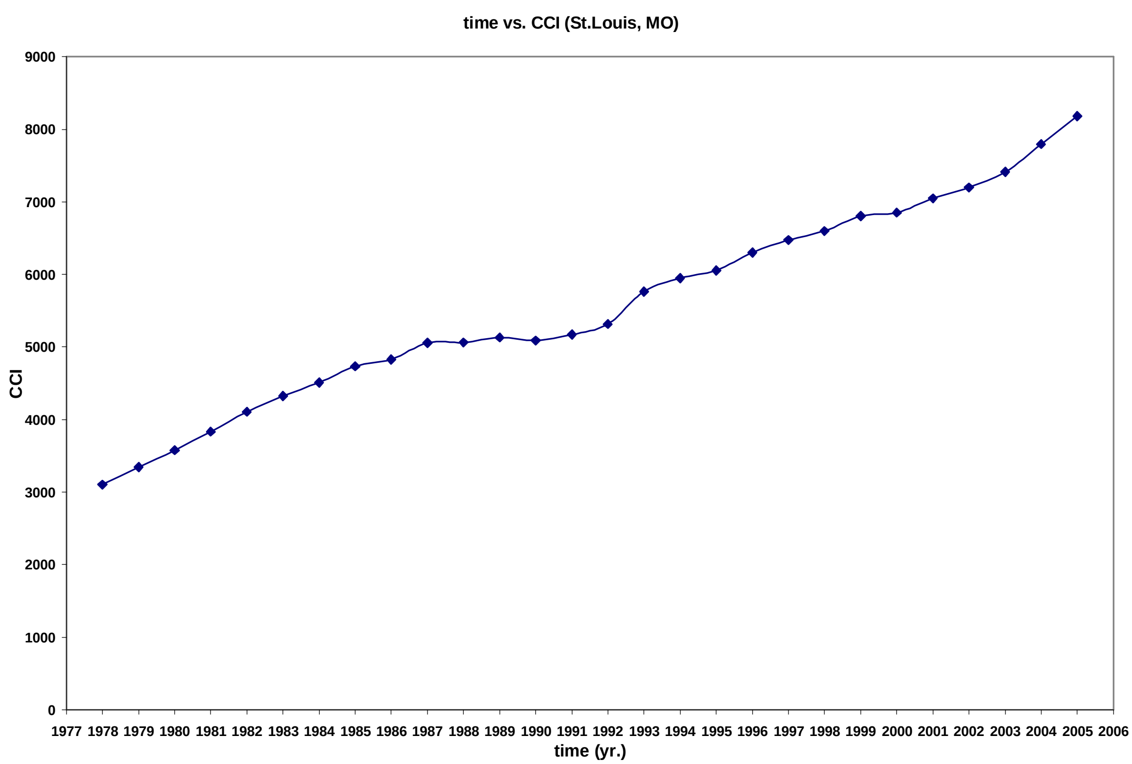

Figure A20. Variation in CCI from 1978 to 2005 for St.Louis, MO

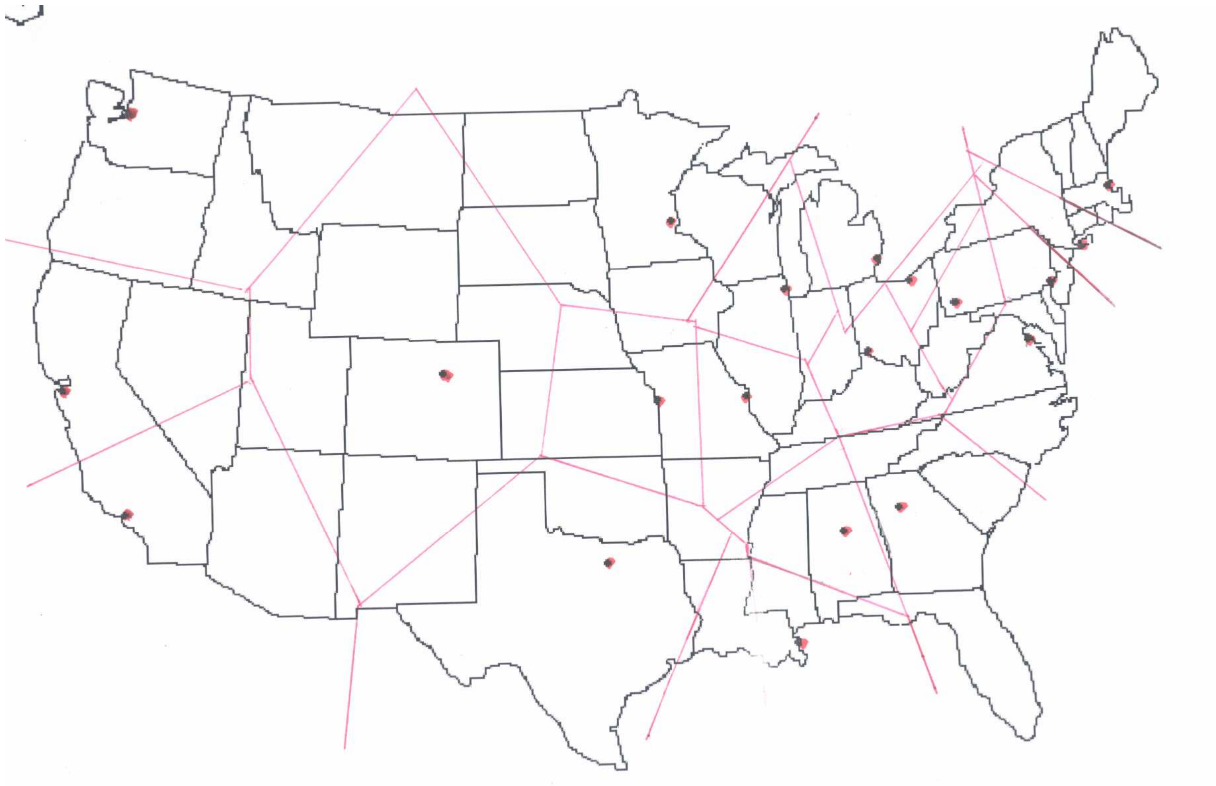

Figure A21. Thiessen Polygon for 20 Cities Listed in ENR