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SUDS - THE CURRENT US PERSPECTIVE: INTEGRATED STORM WATER MANAGEMENT IN NEW DEVELOPMENT AREAS

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ABSTRACT

There are many stormwater control practices available to address an expanding list of surface and groundwater protection objectives. There is an emerging trend to use combinations of individual stormwater devices and approaches to better reduce the wide variety of problems that occur with urbanization. These combinations use complementary unit processes in order to remove both particulate and dissolved forms of pollutants, and to manage the complex urban hydrological cycle. These combinations of unit processes, termed treatment trains, can be applied at individual controls and throughout a developed site. This paper describes two such treatment trains, one that can be used at a critical source area, and another example using different complementary controls throughout a newly developing industrial site.

INTRODUCTION

Many urban runoff control practices are available. These include infiltration devices (such as subsurface infiltration trenches, surface percolation areas, and porous pavements), sedimentation devices (such as wet detention ponds), public works practices (such as grass drainage swales, street cleaning, and catchbasin cleaning), critical source area controls (media filters, chemical treatment, etc.). Many of these devices can be located at source areas and/or at outfalls. In most situations, combinations are needed to meet the broad needs of a comprehensive stormwater management program and receiving water objectives (Burton and Pitt 2002).

There are therefore many stormwater control options, but all are not suitable for every situation. It is important to understand which controls are suitable for the specific site conditions and can also achieve the required goals. This will assist in the realistic evaluation for each practice considering the technical feasibility, implementation costs, long-term maintenance requirements, and life-cycle costs. The most promising and best understood stormwater control practices are wet detention ponds. Less reliable in terms of predicting performance, but showing promise, are stormwater filters, treatment wetlands, and biofiltration devices.

An interesting study examined 11 types of stormwater quality and quantity control practices that were used in Prince George’s County, Maryland (Shepp and Cole 1992). They concluded that several types of stormwater control practices had either commonly failed or were not performing as well as intended. Generally, wet ponds, treatment wetlands, sand filters, and infiltration trenches achieved moderate to high levels of removal for both particulate and soluble pollutants. However, only wet ponds and treatment wetlands demonstrated an ability to adequately function without frequent maintenance. Control practices which were found to perform poorly were infiltration basins, porous pavements, grass filters, small “pocket” wetlands, extended detention dry ponds, and oil/grit separators. Early designs of infiltration stormwater controls had high failure rates which could often be attributed to poor initial site selection and/or lack of proper maintenance. The poor performance of some of the controls was likely a function of poor design, improper installation, inadequate maintenance, and/or unsuitable placement of the control. Greater attention to these details would probably reduce the failure rate of these practices. The wet ponds and treatment wetlands were much more robust and functioned adequately under a wider range of marginal conditions. Other important design considerations include: safety for maintenance access and operations, hazards to the general public (e.g., drowning) or nuisance (e.g., mosquito breeding), acceptance by the public (e.g., enhance area aesthetics and property values).

The majority of the available stormwater treatment processes are more effective for the removal of particulates, especially the settleable solids fractions, than the dissolved pollutant fractions. Removal of dissolved, or colloidal, pollutants is minimal in most commonly used stormwater controls and therefore pollution prevention at the sources is usually a more effective way to control the dissolved pollutants. Fortunately, most toxic stormwater pollutants (heavy metals and organic compounds) are mostly association with stormwater particulates (Pitt, *et. al.* 1996). Therefore, the removal of the solids will also remove much of the pollutants of interest. Notable exceptions of potential concern include: nitrates, chlorides, zinc, pathogens, 1,3-dichlorobenzene, fluoranthene, and pyrene.

STORMWATER QUALITY

When local stormwater quality data is not available, the data collected as part of the US EPA's stormwater permit program, and summarized in the National Stormwater Quality Database (NSQD), can be used (Maestre and Pitt 2005). The NSQD project reviewed and statistically analyzed data collected by municipalities [municipal separate storm sewer systems or MS4s] at their stormwater outfalls under their National Pollutant Discharge Elimination System (NPDES) permits (summary data provided in Table 1; the full database, including tables showing concentrations for different land uses, is located at http://unix.eng.ua.edu/~rpitt/Research/ms4/mainms4.shtml, along with several published papers describing the database features and example evaluations). This database reflects outfall samples from throughout the United States. There were significant differences in concentrations associated with different land uses and geographical areas for most pollutants, while seasonal variations (excluding snowmelt) were much less. Higher concentrations were observed for some pollutants at the beginning of rains in some areas (the "first flush" effect), but only in land uses having large fractions of paved areas, and only for some pollutants. Prior summaries of source area data (Pitt, *et al.* 2005) indicated how some locations (critical source areas) were more contaminated than other areas. These more contaminated areas are mostly paved areas that are associated with high levels of automobile activity, storage of heavy equipment, or other material, etc. In most cases, special stormwater controls should be located at outfalls serving the most contaminated areas, and at critical source areas where the most contaminants originate.

Table 1. Summary of MS4 Stormwater Outfall Data from National Stormwater Quality Database.

Pollutant	Frequency of Detection, % (Filtered, %) - Overall	Median Unfiltered Concentration (Filtered Concentration) for Detected Values - Overall	Median Unfiltered Concentration (Filtered Concentration) for Detected Values - Residential Areas	Median Unfiltered Concentration (Filtered Concentration) for Detected Values - Commercial Areas	Median Unfiltered Concentration (Filtered Concentration) for Detected Values – Industrial Areas
TSS (mg/L)	98.8	59	49	43	81
COD (mg/L)	98.4	53	55	58	59
Fecal Coliforms (MPN/100mL)	91.2	5,090	7,000	4,600	2,400
Fecal Strep. (MPN/100 mL)	94.0	17,000	24,300	12,000	12,000
NO_2+NO_3 (mg/L)	97.3	0.60	0.60	0.60	0.69
Phosphorus (mg/L)	96.6 (85.1)	0.27 (0.13)	0.31 (0.18)	0.22 (0.11)	0.25 (0.10)
Cadmium (µg/L)	40.8	1.0	0.5	0.96 (0.30)	2.0 (0.6)
Chromium (µg/L)	70.2 (60.5)	7.0 (2.1)	4.5	6.0 (2.0)	12 (3.0)
Copper (µg/L)	87.4 (83)	16 (8.0)	12 (7.0)	17 (7.6)	21 (8.0)
Lead (µg/L)	77.7 (49.8)	17 (3.0)	12 (3.0)	18 (5.0)	25 (5.0)
Nickel (µg/L)	59.8 (64.2)	8.0 (4.0)	5.6 (2.0)	7.0 (3.0)	14 (5.0)
Zinc (µg/L)	96.6 (96.1)	116 (52)	73 (32)	150 (59)	200 (112)

CRITICAL SOURCE AREA CONTROLS

There are a number of controls that can be used at critical source areas within the drainage area. These include biofiltration, porous pavement, hydrodynamic devices, filtration devices, etc. The following briefly describes a newly developed device that incorporates several different unit processes in a unique combination that has been tested under EPA support at pilot and full-scale installations (Pitt and Khambhammettu 2006). The UpFlow Filter^{TM} was developed to overcome a number of problems of existing source area treatment devices to allow high treatment flow rates with good to excellent levels of control, and reasonable maintenance requirements.

Recent research on filtration examined alternative media and ways to reduce clogging that is prevalent with typical stormwater filtration. Upflow filtration was examined as a way to reduce clogging, at the same time as providing a much higher treatment flow rate. The UpFlow^{TM} Filter was conceived as a treatment device to allow many of the treatment train components of the multi-chambered treatment train (MCTT) (Pitt, *et al.* 1999) but that can be used in a smaller area by providing much faster unit area stormwater flow treatment rates. Pollutant removal mechanisms in the UpFlow^{TM} filter include several unit processes:

- Coarse solids and litter removal in the sump and by screens
- Capture of intermediate solids by sedimentation in sumps by controlled discharge rates
- Capture of fine solids in primary filtration media
- Sorption and ion-exchange capture of dissolved pollutants in primary and secondary media

The basic removal of solids is therefore dependent on physical sedimentation in the sump, and by filtration in the media. Figure 1 is a drawing of the full-sized commercial unit showing the water treatment path during normal operation. The UpFlow^{TM} Filter was designed to be placed in a standard 4 ft (1.2 m) diameter catchbasin inlet, having a sump. Up to six upflow filtration modules can be used in each UpFlow^{TM} Filter, and the media can be selected to target specific treatment flow rates and pollutants of interest. Figure 2 shows the performance of the UpFlow^{TM} Filter during controlled tests using finely graded silica particles representing typical stormwater particles, while Table 2 shows the results of the filter during actual rains. High removals of almost all particles were observed. The flow-weighted treatment level of the device was about 80% for particles.

Table 3 shows the needed treatment flow rates to treat specific levels of the annual runoff volume. The needed treatment flow rates are less than the corresponding flow rate distributions because portions of the largest events are treated, while the flows in excess of the treatment flow rate bypass the device. If an 80% control objective is desired (a relatively common objective for many U.S. locations), the device would need to have a flow-weighted pollutant removal rate of about 90% and the about 90% of the annual runoff volume would need to be treated at that level. With lower treatment objectives, there would be more combinations of removal rates and treatment volumes. The UpFlow^{TM} Filter can provide about 25 to 35 gpm (95 to 130 L/min) treatment flow rates per module. Therefore, only about one module would be needed per acre (0.4 ha) of paved area in Seattle in order to treat about 90% of the annual runoff volume, while about four modules would be needed per acre (0.4 ha) of paved area in Atlanta to treat the same percentage of the annual flow. With an 80% flow-weighted pollutant removal rate, this would correspond to an annual pollutant control level of about 70 to 75%. Other media can be used having higher pollutant removal rates, but they typically have lower treatment flow rates, requiring more modules for the same drainage area.

TREATMENT APPROACH FOR NEW INDUSTRIAL DEVELOPMENT

Treatment train approaches for stormwater management should also be applied at larger scales. The following is a recent example for a new industrial development in Huntsville, AL. Being a new development, there were no physical restrictions that would typically be associated with a retro-fitting project. This was an unusual project in that we worked with the site planners and engineers, and the site owners, from the early stages of site planning in order to optimize the conservation design aspects of the site development project. In most cases, the site engineers would address stormwater issues well after major aspects of the site layout had been completed, severely restricting available conservation design options. During retro-fitting projects, only selected source area options may be available, along with outfall controls, if space allows.

The stormwater elements proposed for the new 250 acre (100 ha) Huntsville industrial park will result in a conservation design that minimizes both runoff water volume discharges and stormwater pollutant discharges. The stormwater management elements of the conservation design are included at several levels at this site. Deed restrictions will require some simple on-site controls, as needed, the drainage system will be constructed to encourage grass filter treatment and biofiltration, and the main drainage subareas will contain large grass swale conveyances and wet detention ponds. Much of the upland areas of the site will also remain in open space. There area numerous sink holes on the site and these will be isolated from the drainage system by berms and buffers to restrict surface runoff entry.

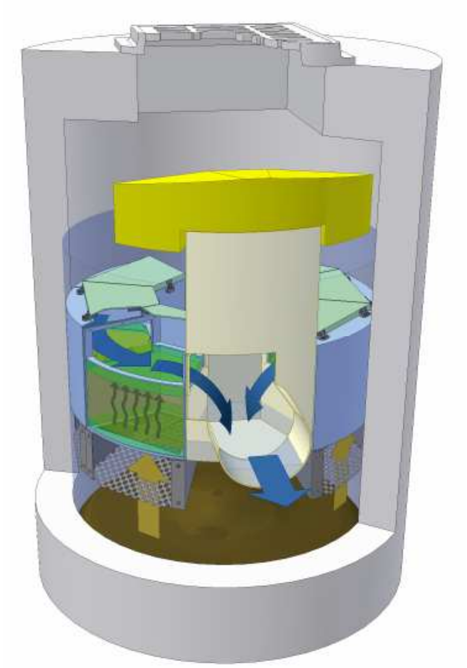

Figure 1. UpFlow™ filter drawing showing normal filtering operation (Hydro International, Ltd.).

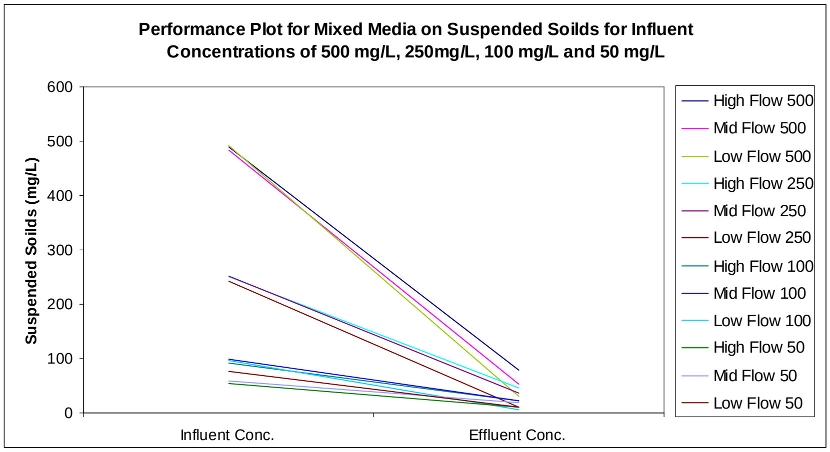

Figure 2. Performance plot for mixed media for suspended solids at influent concentrations of 500 mg/L, 250 mg/L, 100 mg/L and 50 mg/L.

Table 2. Calculated Mass Balance of Particulate Solids for Monitoring Period

particle size range (µm)	SS influent mass (kg)	SS effluent mass (kg)	SS removed (kg)	% reduction
0.45-3	9.3	2.8	6.6	70
3-12	18.7	6.4	12.3	66
12-30	22.4	7.7	14.7	66
30-60	26.7	6.8	19.9	74
60-120	4.6	1.8	2.9	61
120-250	19.8	4.3	15.5	78
250-425	11.5	0.0	11.5	100
425-850	17.1	0.0	17.1	100
850-2,000	10.5	0.0	10.5	100
2,000-4,750	4.8	0.0	4.8	100
>4,750	3.5	0.0	3.5	100
sum	148.9	29.8	119.2	80

Table 3. Treatment Flow Rates Needed for Different Treatment Objectives*

	Annual Flow Rate Distributions (gpm/acre pavement)			Treatment Flow Rates Needed for Different Levels of Annual Runoff Volume Treatment (gpm/acre pavement)		
Location	**50th Percentile**	**70th Percentile**	**90th Percentile**	**50%**	**70%**	**90%**
Seattle, WA	16	28	44	10	18	30
Portland, ME	31	52	80	18	30	53
Milwaukee, WI	35	60	83	20	35	65
Phoenix, AZ	38	60	150	20	35	90
Atlanta, GA	45	65	160	25	40	100

* multiply by 9.5 to obtain L/min/ha of pavement

These elements will work together to provide the most cost-effective set of stormwater controls for the site and provide high levels of control of both runoff volume and pollutant discharges. These site elements are all relatively common controls that have been applied at many locations throughout the U.S., and have been designed to take advantage of specific site characteristics and the desire to use this site as a demonstration of effective stormwater controls for the region.

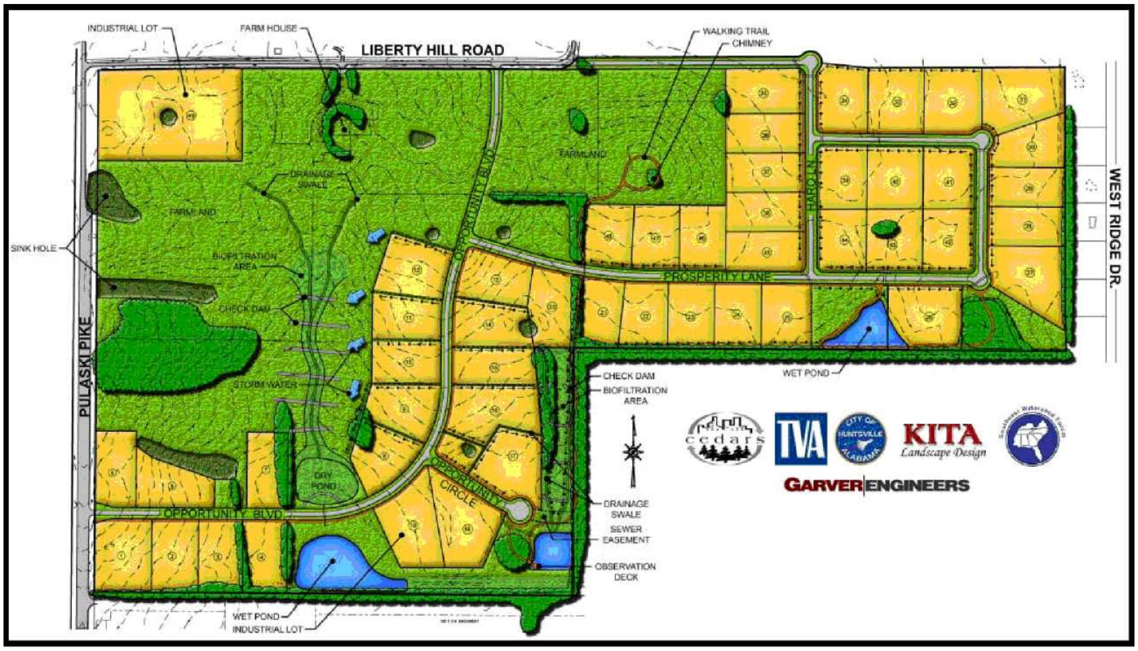

Figure 3. Layout of North Huntsville Industrial Park Showing Conservation Design Elements

The stormwater controls include three main elements:

1) Critical source areas will need special attention. Industrial stormwater permits usually specify specific activities needing control. At industrial sites, these areas usually include material storage areas and truck loading bays. Most bulk material storage areas subject to rainfall exposure should preferably be covered, or the storage areas need to be bermed and the runoff treated with specialized controls (such as the Multi-Chambered Treatment Train). Heavy equipment yards (and public works yards) also need similar attention. Loading bays also need to be hydraulically isolated with the runoff treated with specialized controls (such as the UpFlow™ Filter).

2) The building materials should be selected with pollution prevention in mind. The most serious problems normally associated with low and medium intensity industrial areas are the zinc concentrations in the runoff associated with the use of galvanized metal. In many areas, galvanized metal has been largely replaced by Zincalume or Galvalume (aluminum with zinc coatings), which still result in large zinc concentrations in the runoff. There has also been a shift from in-situ application of roofing paints to factory-painted paint to the metals. There have been considerable advances in coating technology, with increased durability and decreased breakdown of roof coatings and materials. The zinc concentrations from zinc-coated metal roofs is related to the degree of weathering and corrosion, with runoff from heavily weathered and corroded roofs having several times the zinc concentrations compared to runoff from roofs in good condition. Also, most of the zinc in runoff from metal roofs is in the dissolved state which is much harder to control and has more damaging environmental effects.

3) The building areas should have bioretention/grass swales for site runoff control. They will be located on the downslope side of the paved areas and roofs to direct the roof and lot runoff to the drainage systems. The bioretention/grass swales will be relatively small and mild sloped and can be easily maintained. They will be used in conjunction with other drainage way and pond stormwater controls as summarized below.

DRAINAGE WAY AND POND STORMWATER CONTROLS

The site was divided into four main drainage subareas, designated as subareas A, B, C, and D. The drainage way and pond stormwater elements, in conjunction with the lot-scale controls, will result in a conservation design that minimizes both runoff water volume discharges and stormwater pollutant discharges. The same stormwater elements are not recommended for each subarea due to different characteristics in each area. As an example, the industrial sites in subarea A are about evenly divided into an area that will be developed with conventional drainage having minimal on-site stormwater controls having conventional curbs and gutters, and an area with on-site stormwater controls. The conventionally developed area will discharge near the head of a wet pond with no regional swale treatment, while the other area will drain through a long natural grass drainage way before entering a wet pond. In addition, this area will incorporate on-site bioretention controls (site grass swales graded as linking rain gardens) to provide grass filtering pre-treatment and infiltration) to help compensate for the other area having minimal site controls.

Subarea B has extensive natural grass swales (two parallel swales) that will significantly reduce the runoff volume before another wet pond. Site bioretention controls can also be used to further reduce the volume, if desired. The pond will also be reduced in size to better fit the available area due to the reduced runoff volume. Site bioretention controls are not likely to be needed in this subarea due to the large amount of swales available. Subarea C is mostly developed with little open area, but with roadside grass swales that are suitable for runoff volume reductions. Site bioretention controls can also be used in this subarea. In this subarea, a relatively small pond (0.19 acres, or 0.08 ha) could be used due to the runoff volume reductions from use of grass swales. However, a full-sized pond (0.38 acres, or 0.15 ha, at normal pool elevation) is recommended to reduce the maintenance problems and make it more aesthetically pleasing. Subarea D will also utilize a roadside swale system along with on-site bioretention for runoff volume reductions. A wet pond will be located on adjacent city-owned land that may be developed in the future as a residential area. The large pond will also treat the runoff from that area.

These varying stormwater controls will provide an interesting and useful demonstration for the City of Huntsville. The drainage way and pond stormwater controls recommended for each subarea are listed in Table 4. The WinSLAMM model was used to predict reductions in runoff volume and particulate solids discharge vs. what would be expected with base conditions. These projections were based on 40 years of Huntsville rainfall data (1959-1999). Base conditions are defined as conventional development design with curb and gutter drainages and directly connected impervious surfaces. Other pollutants are expected to be reduced by similar percentages: those that are mostly associated with the dissolved fraction (nitrates and pesticides, for example) are expected to be reduced by about 50 percent and those mostly associated with particulates (phosphates and many heavy metals and PAHs, for example) are expected to be reduced by up to 90 percent. The percent reduction in runoff and sediment loss with the conservation design vs. base case increases as rain depth decreases. A 90 percent or greater reduction in sediment loss occurs with rain depths of approximately 2.5 inches or less. A 70 percent or greater reduction in runoff occurs with rain depths of approximately 1.5 inches or less.

Table 4. Summary of the conservation design stormwater components for each subarea and their projected reductions in runoff volume and particulate solids discharge[1]

Drainage Area	Drainage way and pond stormwater controls	Runoff Volume reduction[2]	Particulate solids reduction[2]
A	Pond, swale, and site bioretention	61	96
B	Small pond and swale	69	93
C	Pond and swale	68	94
D	Off-site pond, swale, and site bioremediation	50	92
Total Site Area		56	93

[1] Projections based on 40 years of rainfall data (1951-1999) using WinSLAMM model

[2] Base conditions are conventional development design with curb and gutter drainages and directly connected impervious surfaces.

COST OF STORMWATER CONSERVATION DESIGN

Garver Engineering of Huntsville provided a review and cost analysis of the conservation design for Phase 2 of the North Huntsville Industrial Park. This analysis established the base construction cost of the park using conventional engineering practices to which adjustments were made for the additional facilities required for conservation design. Credits were then applied for the value of practices replaced by the conservation design construction. The base bid to which these adjustments were made was $1,163,429. The net difference for this phase is approximately $33,750 in cost savings for the conservation design. Other intangible but nevertheless real advantages favor the conservation design plan. These include:

- Enhanced groundwater recharge through infiltration of treated stormwater through permeable soils, rather than the collection and conveyance of the runoff off the site.
- Reduction in offsite management costs of peak storm water volume. The discharge channel downstream from the wet ponds may have required concrete armoring if conventional stormwater facilities had been used. This cost savings alone could range from $400,000 to $500,000.
- Preservation of natural drainage areas by their incorporation into the master drainage system.

Significant improvements in post development groundwater and surface water quality.

Future cost savings are also anticipated through the use of conservation design practices in Phase 3. While this phase is more dense and conventional in layout, cost saving will accrue through the use of swales with curb outlet flumes in lieu of stormwater inlets with reinforced concrete piping. Phase 2 bid prices for inlets are $2,300 each while reinforced concrete pipe ranges from $34 to $53 per foot for 18-inch to 30-inch pipe. The unit costs for outlet flumes are $2,000 each while the grass swales cost approximately $15 per foot. Actual savings will depend on final engineering design and construction bids, but experience suggests that savings could range from $50,000 to $100,000.

CONCLUSIONS

This paper presented two case studies illustrating how treatment trains for stormwater management can be effectively used at different scales; one a critical source area treatment device, and the other a new industrial park. In both cases, different, but complementary, unit processes work together to result in an effective stormwater management process. This paper also briefly showed how using a continuous simulation model can be effectively used in sizing different types of controls, and how the different unit processes can function together. A recent paper (Pitt and Voorhees 2007) can be examined to illustrate how this type of information can be used in a decision analysis framework to guide in the selection of the most appropriate stormwater management program considering many conflicting objectives (costs, maintenance, pollutant control, runoff volume reduction, etc.).

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