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16. Abstract
This project will identify best management practices (BMPs) suitable for retrofitting stormwater conveyance structures on highway rights-of-way. This information will be used to prepare two guidance documents. The first guidance document will assist in selecting appropriate retrofit BMPs for a wide range of locations and regional circumstances and provide detailed information about design, installation and maintenance. The second guidance document will provide a process for prioritizing the installation of stormwater quality BMPs as required in the National Pollutant Discharge Elimination System (NPDES), Phase II rules.

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RETROFITTING TxDOT DRAINAGE STRUCTURES TO IMPROVE STORMWATER QUALITY

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DISCLAIMER

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EXECUTIVE SUMMARY

The need to investigate options for retrofitting existing highway drainage systems for water quality can be attributed to three changes in environmental rules. These are changes in the Phase II stormwater program to include smaller communities, the increased focus on the utilization of permanent water quality structures and the implementation of Total Maximum Daily Load (TMDLs) standards for 303 (d) listed water bodies. The requirement to retrofit the drainage infrastructure of the state's highway system will continue to escalate over the next decade. The capital requirement to install new structures in urban areas represents a significant allocation of resources. More importantly it will require a significant new commitment of resources for maintenance. Depending on the kind of structure and the area served maintenance costs, including the replacement of filter media, cleaning and servicing after every storm event will run from $2,300 per year for an extended detention basin to around $23,000 per year for a large sand filter structure.

By themselves they are not necessarily large numbers but in the context of an urban district the costs are significant. For example, Ft. Worth has identified some 460 outfalls in its joint permits with the cities of Ft. Worth and Arlington. If only one third of these outfalls (152) required the installation of permanent treatment structures, a budgetary commitment of around 1.8 million dollars annually for maintenance alone would be needed. This fact underscores the need to provide information about available stormwater technologies appropriate for retrofit, guidance for selecting the most cost effective BMPs and a means for prioritizing the allocation of resources for stormwater retrofitting.

Available Technologies to Improve Stormwater Quality

Numerous BMPs have been developed to improve stormwater quality, both generic and proprietary. This project looked at a full range of options based on the available current literature with respect to water quality performance, space required, and overall cost for installation and maintenance. This review suggests that the variety and performance of non-proprietary technologies is sufficient so that proprietary technologies need only be used in unique or very unusual circumstances.

One of the current disadvantages of using all non-proprietary BMPs is that each one has to be designed for site-specific conditions. This is generally only a handicap when space and time are limited. It is recommend that TxDOT address this deficiency by developing standard details for non-proprietary modular stormwater BMPs. This is essentially the selling point of most commercially marketed devices.

Potential Land Resources for Retrofitting

In intensively developed urban centers the cost of retrofitting for water quality will be extremely high if structures must be installed underground. In all likelihood some underground structures will be required. However, a very limited review of the Houston IH 610 and IH 10 corridors, suggests that interchanges represent a significant land resource that could be employed to develop permanent stormwater quality structures. These resources need to be inventoried, preserved and prioritized for development.

Many of Texas' major cities are built on very flat terrain. This situation can be further complicated if there is a high water table. In these situations the only economical way to treat storm water is in surface based structures, because of the lack of head to move the water through the structure. Most proprietary technologies, particularly those that operate on centrifugal principles will not operate effectively. In these cases the only retrofit option is to use pumps to move the water out of the treatment chamber and on to the release point. For this reason cities and districts in the coastal regions of the state should begin planning immediately to conserve and or acquire ROW that can be used for surface treatment of stormwater.

Lack of Documented Performance Values

The most troubling finding is the lack of hydraulic performance data that allows the evaluation of in-line impacts of stormwater BMPs. This is a critical consideration when retrofitting an existing drainage system. Even when a BMP is installed off line, that is the stormwater is diverted into the BMP out of the direct line of flow, there is some loss of energy that must be taken into account. Without this information the installation of any stormwater BMP could result in flooding and driving hazards.

Recommendations

Implementation

This project includes guidance for selecting an appropriate structural retrofit strategy for improving stormwater quality and for prioritizing the allocation of resources for retrofitting. These procedures should be included in the appropriate on-line design manual. This will complement the recommended procedures for estimating pollutant loadings and structure sizing provided in report 0-1837.

Performance of Stormwater Quality BMPs

The major gap in the information has been in the documentation of the performance of proprietary BMPs. However, this past year a study was initiated by the Washington Department of Transportation, with the Environmental Technology Evaluation Center, of Washington D.C. to perform side by side testing of these technologies. This study will fill the gap in water quality performance information for this group of BMPs.

There has also been some question about the need for further monitoring and testing of BMPs for water quality performance. Based on extensive review of the literature it appears that there is a need to better understand the causes of the considerable difference in event-to-event performance. This is particularly true since TNRCC has yet to accept a full range of BMP technology in the Texas Pollutant Discharge Elimination System (TPDES), which will replace the national NPDES program when EPA releases regulatory control to the state.

Develop Modular Details for Generic Stormwater Quality BMPs

The primary deterrent to the use of the non-proprietary technologies is the lack of modular design standards based on pollutant loadings and stormwater volume. Many of the small footprint generic BMP technologies can be developed around precast concrete units. Applications include technologies for trapping floatables and hydrocarbons as well as sediments, metals and nutrients. It is recommended that TxDOT consider developing a series of standardized, modular details for small footprint generic BMPs that can be used when surface basins and ponds will not fit the site.

Study of Hydraulic Properties of Key Technologies

TxDOT should consider an effort to evaluate the hydraulic performance of selected BMP technologies so designers can be assured that the addition of stormwater quality treatment will not reduce the performance of the existing drainage systems.

Development of Field Based Cost Data

Cost information on construction and maintenance is very limited. Manufacturers of proprietary BMPs appear very reluctant to address the issue of cost. While there have been some efforts to develop cost related to construction, maintenance costs are virtually undocumented. This is a matter of considerable concern. An effort to look at TxDOT and City of Austin expenditures on BMP maintenance was helpful, but most of the information was related to hazardous materials traps and large filter structures in the Austin District. This allowed the projection of maintenance costs for maintaining surface structures but it has not been possible to develop cost information on proprietary technologies or other underground, small footprint technologies. This is important because long-term maintenance of any underground installation will likely be significantly higher, which raises long-term sustainability questions. For this reason it is recommended that TxDOT consider an effort to document the long-term costs associated with the various BMPs.

Prioritization Process

The prioritization process outlined in this report has not been applied to Texas. While the process follows the process developed by the Washington State Department of Transportation closely it needs to be calibrated to meet regional differences in Texas, probably on a district-by-district basis. The original project proposal has included an option for a second year in which this type of calibration could be done. Since TNRCC will likely begin developing TMDLs that will impact TxDOT and there will be a need to allocate resources for stormwater quality retrofit activities TxDOT should consider a pilot project to calibrate this system to meet their needs.

About Reference Sections of the Report

The report is put together in sections and intended as a pull-apart reference piece. That is, the parts that provide selection, prioritization, and design recommendations are designed to stand-alone as reference or supplemental educational materials. Therefore, there may appear to be repetition of some text materials.

INTRODUCTION

RULES AND AUTHORITY FOR STORMWATER RETROFITTING

The Clean Water Act (CWA) of 1977 (PL92-500) as amended in 33 U.S.C. 1251 et. seq. Section 251 (a) (7) provides the authority to implement rules intended to control nonpoint source pollution.

The rules governing the quality and management of nonpoint source pollution are promulgated in response to requirements of Section 402 of the CWA that creates the National Pollutant Discharge Elimination System (NPDES) (33 U.S.C Section 1342). Subsequent rules governing stormwater quality are contained in Code of Federal Regulations, 40 CFR Parts 122, 123, 124, and 125.

The most recent rules are those governing the Municipal Separate Stormwater Systems (MS4) Phase II Permits, which are contained in 40 CFR Parts 9, 122, 123, and 124. In part 122.26 (iv)(A)(4), entities are required, as part of the stormwater management plan, to evaluate the potential for retrofitting existing flood control structures.

CONCEPT OF RETROFITTING FOR WATER QUALITY

The previously described rules, which govern the quality and management of nonpoint source pollution, focus on existing water quantity structures as the targets of retrofitting to improve water quality. However, the Texas Department of Transportation has a limited number of existing stormwater quantity structures. In 1998, the Environmental Protection Agency (EPA) sponsored a conference entitled: Retrofit Opportunities for Water Resource Protection in Urban Environments. This forum considered a much wider range of options from stream restoration and retrofitting of flood control structures, to retrofitting the urban landscape. While some of the options explored at the conference are not well suited to transportation facilities, the variety does emphasize the need to look beyond retrofitting of water quantity structures to ensure that all existing resources are utilized in order to best minimize the cost of meeting stormwater quality mandates. This becomes increasingly important in dense, urban areas where limited land resources make conventional stormwater quality technologies cost prohibitive.

ECONOMICS OF RETROFITTING

While the rules require consideration of retrofitting water quantity structures to improve stormwater quality, there are some very basic economic reasons that make this an important exercise in developing a long-range stormwater quality strategy. Most of the expenditure on highway development in the foreseeable future will be concentrated in our urban centers. In urban areas, additional right-of-way is very expensive or not available. At the same time, the most effective and least expensive stormwater quality technologies are land intensive, meaning they require large land areas to store and treat water before it is discharged into a receiving water body.

Small footprint and underground technologies are available, but costs for installation and maintenance of these options are significantly higher than land-based structures. Therefore, it is important to explore how existing structures, drainage ways, and open portions of the existing right-of-way might be retrofit to help meet stormwater quality goals while maintaining the safety and capacity of the transportation system.

EXISTING FACILITIES ON TxDOT ROW

At this time, only one TxDOT district has been identified that has purpose-built water quantity structures on state maintained right-of-way (ROW). However, there are miles of grass-lined channels, numerous interchanges with large land areas, and other drainage structures that should be examined as a potential resource for water quality improvement. The existing grass-lined channels and shoulders already have some water quality benefit. However, there are enhancements that could further increase their water quality function. Channels lined with concrete riprap also represent resources that could be retrofit when it is necessary to replace or remove the existing rigid lining. Each of these possibilities represents an opportunity that should be explored.

Finally, there are large areas of right-of-way in urban interchanges that are not currently used for either water quality or quantity control. Other sites may exist as the result of fee-simple purchases of borrows pits or remnants of larger properties acquired as part of other right-of-way acquisitions. These properties should be explored to determine if they could be used as part of a stormwater quality retrofit plan.

RETROFIT OPTIONS FOR STORMWATER QUALITY IMPROVEMENT

There are several groups of technology that have application for retrofitting of existing drainage structures. Each of these has application depending on the site conditions and the target pollutant.

Outlet Control Devices

Outlet control devices trap floatables and extend the detention time in existing stormwater quantity structures.

Inlet Control Devices

Inlet controls include traps, filters, and inserts placed in drainage inlets to prevent pollutants or floatables from entering the stormwater stream.

Volume/Capacity Increase of Water Quantity Structures

Where water quality or quantity structures exist, it is often possible to increase the water quality volume of the structure by increasing the area or depth of the structure.

Offline Technologies

These structures divert a portion of the stormwater stream for treatment. This technology bypasses the remaining flow directly to the downstream water body.

Proprietary Technologies

There are numerous proprietary technologies that are being marketed to meet stormwater quality needs. These technologies may be inlet control, outlet control, or offline devices that utilize proprietary designs to accomplish pollutant removal. A large cross-section of these technologies will be discussed in the section on proprietary technologies for retrofitting.

Reuse or Redesign

Reuse or redesign is a category that is being introduced in this report but is not commonly found in the literature. It explores the potential for the use of interchange sites and other specialized, open areas of the right-of-way as potential sites that can be utilized for stormwater quality improvement.

RETROFIT ISSUES

Water Quality Performance

The structures used for stormwater quality improvement are, for the most part, passive processes that rely on gravity and other naturally occurring biologic processes to provide treatment. Depending on the specific technology, they will have varying effectiveness in removing certain kinds of pollutants. The most common technologies will be effective in removing suspended solids and will have some limited effectiveness in removing nitrogen, lead, zinc, copper, oil, and grease. They are generally ineffective in removing biological compounds, pathogens, and hydrocarbons.

Because the quality and volume of stormwater influent fluctuates radically over time, the performance of a stormwater quality structure varies on an event-to-event basis. This wide variability in event performance results in a significant variation in the range of performance reported for available stormwater quality technologies. The rigorous sources of performance data on generic technologies for stormwater quality treatment are the National Pollutant Removal Performance Database (Winer 2000) and the National Stormwater BMP Database (EPA 2001).

Maintenance Requirements

Clearly, maintenance is critical to ensuring that anticipated pollutant removal levels are maintained in a permanent water quality structure. However, in a transportation setting, particularly highway transportation, the means of accessing and maintaining a water quality structure must also be considered. In some cases, the equipment or access requirements may limit the applicability of a technology if it poses a safety hazard to the maintenance personnel or the highway users.

Hydraulic Performance

Hydraulic performance refers to the impact a retrofit technology will have on an existing structure or drainage system. Most all drainage structures and conveyance channels have been designed to store and/or convey a given volume. If changes are made in the structure or channel, there will be accompanying effects on the hydraulic performance of the entire drainage train, which could lead to flooding. For example, drainage inlet inserts will decrease the flow rate of a drainage inlet, which can result in some flooding of the paved area being drained. While some flooding may be acceptable in low use areas or on residential streets, this poses significant safety hazards on higher-speed thoroughfares. In addition to the potential flood hazard that must be considered, many of the proprietary technologies are dynamic separators. This requires several feet of head to ensure proper operation. For this reason, these technologies will have limited application in areas of very flat terrain.

Costs

The cost of developing water quality structures fluctuates radically depending on site conditions, land cost, and construction materials (Landphair et al. 2000). If the construction materials palette is held constant, the cost of a water quality control structure can be reasonably estimated. However, site conditions and land cost, both unpredictable variables, impact the overall cost. As land costs escalate, water quality technologies that have small surface footprints or are fully underground become more cost-effective.

Targeted Pollutants

There are a variety of pollutants that may be targeted in a stormwater quality retrofit program. These range from surface litter, waste, paper, plastics, bottles, leaves and other vegetation, which are grouped as "floatables," to pesticides, pathogens, heavy metals, and nutrients. The most common pollutants found in highway runoff are solids, metals, and floatables, along with a group of other organic and chemical compounds.

Table 1 shows data for solids, metals, and other compounds for four Austin, Texas, sites compared to a range of national observations. The national values were taken from Young, (Young et al. 1995) and the values for Austin were taken from work by Barrett et al., (1996) and Landphair et al. (2000). The mean constituent loadings experienced at any given location may vary significantly, and there will be even greater variation from event to event. However, these values do serve as a guide to the types of pollutants that will be encountered and the range of concentrations.

Floatables

Floatables consist of mostly garden waste such as leaves, sticks, grass clippings, and wood mulch, as well as litter, paper, and plastic products. The water surface transports these floatables, which tend to collect at low places and stormwater outlets.

Dissolved Pollutants

Dissolved pollutants include a wide range of elements and compounds. The most common dissolved pollutants found in highway runoff are solids, volatile solids, and nutrients.

Table 1. Concentration of Selected Stormwater Constituents: National and Austin Sites.

Constituent	National[1] Concentration mg/L	Austin, TX[2] Concentration mg/L	Austin, TX[3] Concentration mg/L	Austin, TX[4] Concentration mg/L	Austin, TX[5] Concentration mg/L
			Solids		
TSS	45-798	131	304	167	208
VSS	4.3-79	36			
Total Volatile	57-242				
			Metals		
Zn (d)	0.056-0.929	0.208	0.141	0.184	0.108
Cu (d)	0.022-7.033	0.034			
Pb (d)	0.073-1.78	0.050	.023	.024	.018
			Nutrients		
Ammonia Nitrogen	0.07-0.22				
NO_3-N	0.15-1.636	1.03[6]			
TKN	0.335-55.0		14.33	12.88	15
TP	0.113-0.998		0.38	0.34	0.14
			Other		
COD	14.7-272	126			
Oil and Grease	2.7-27		89.28	37.36	234.7

[1]Young et al., 1996
[2]Barrett et al. 1996, MoPac at 35th Street
[3]Landphair et al., 2000, MoPac at Barton Creek
[4]Landphair et al., 2000, 290 at MoPac
[5]Landphair et al., 2000, Ben White at Lamar South
[6]NO_3-only

Suspended Pollutants

Particulate and solid materials are generally considered the most important pollutants in highway runoff. This is because the solids will readily adsorb other pollutants such as zinc, copper, lead and other metals, as well as phosphorous. While the actual amount of material adsorbed is linked to the particle size distribution of the sediment, suspended solids are one of the easiest pollutants to screen for and therefore, are often used as the primary index pollutant for highway runoff.

Pathogens

The primary pathogens found in highway runoff are Coliform bacteria. While these bacteria are often present, most researchers attribute their presence to livestock and wildlife populations adjacent to the right-of-way.

Additional Pollutants

Buckler, Young, Driscoll, Barrett, and many others have compiled literature reviews that list a much broader range of pollutants than those shown in Table 1. These include a wider range of solids, many more metals, and broader ranges of organics and compounds like calcium magnesium acetate (CMA), polycyclic aromatic hydrocarbons (PAHs), and mono-aromatic compounds. While many of these other constituents may occur in highway runoff, researchers do not usually monitor them because they tend to be regionally specific. In addition, monitoring for all potential pollutants would be cost prohibitive.

Shoemaker's study (2000) of best management practices (BMPs) for ultra-urban settings observed a very high correlation between the following:

- total suspended solids (TSS) and volatile suspended solids (VSS),
- total Kjeldahl nitrogen (TKN) and nitrate (NO_3-), and
- total phosphorous (TP) and orthophosphate (OP).

EPA also notes that a significant amount of the metals carried in stormwater adsorbed to the suspended solids (Strassler et al. 1999). Therefore, monitoring of TSS, TKN, and TP gives a good indication of nutrients and solids and some indication of metals. However, specific metals do have to be monitored if there is a need to know concentrations in the influent stream. For example, there are several water bodies on the Texas 303(d) list that have been listed for copper impairment.

TECHNOLOGIES AVAILABLE FOR STORMWATER QUALITY RETROFIT

OUTLET CONTROL DEVICES

Outlet control devices refer to technologies that are used to trap pollutants in an outfall or a storage area that precedes the outfall. Their primary purpose is to trap floatable materials that must be removed regularly to ensure proper operation. The following outlet devices can be employed as retrofits to existing drainage structures.

Reverse Slope Pipe

A reverse slope pipe accomplishes essentially the same task as a baffle tank or a catch basin. The pipe inlet is submerged before actual discharge begins. Therefore, floatable materials are above the entrance to the outfall line and will not be transmitted downstream. However, if cleaning is not conducted on a regular basis, some materials will enter the outfall and be transported downstream before the pipe inlet is covered.

Outfall Screens and Grates

Screens and grates can also be fitted to the outfall line. These can be effective for very small drainage areas. However, they must be cleaned frequently to avoid flooding.

INLET CONTROL DEVICES

Inlet control devices are placed in stormwater drainage structures to trap or filter pollutants. Because they are placed in an inlet, they must be carefully maintained. Floating debris such as paper, leaves, and grass can quickly gather at an inlet and effectively block it. This can lead to flooding of the adjacent driving lanes.

Catch Basins

A catch basin, sometimes called a skimmer or turndown inlet, resembles a simple hood over the end of the outfall line. As the water rises in the reservoir or drainage structure, the outfall is covered with water; the lighter material floats and is prevented from passing downstream. Heavy solids also settle out of the stormwater stream and are caught in the trap area below the pipe entrance.

Baffle Tank, Water Quality Inlets

Baffle tanks are boxes with a set of offset baffles. The lighter materials float to the top surface of the first two chambers. Water exits the third chamber, and the solids and floatables are prevented from moving downstream.

Floatables Boom

A floatables boom is a floating dam, originally developed to contain oil spills. These but have since been adapted for stormwater management applications. Floating booms have been used successfully to control floatables in West Bouldin Creek and Shoal Creek in Austin, Texas.

Floating Outfalls

Floating outfalls are essentially flexible pipes attached to a float. As the water rises in a basin, the outlet floats and continues to rise until the reservoir fills completely. This action traps a predetermined stormwater volume, which is held until it infiltrates, evaporates, or is displaced by another storm event.

Drain Inlet Inserts

Drain inlet inserts are basket-like devices placed in the grate of a drain inlet to trap floatables or filter other target pollutants.

Inlet Dams

Inlet dams are flap-like devices placed at the entrance of a drain inlet that block floatables and other debris from entering the storm system.

Drain Filters and Separators

Drain filters and separators are similar to the drain inlet inserts except that they utilize some gravity or filter device to trap target pollutants. Separators generally target oil, grease, and some sediment. Other filter type materials target single pollutants, such as oil and grease.

Grates and Screens

Grates and screens can be placed at inlets. Simple grate inlets can be very effective in limiting the floatable materials entering a drainage channel. However, they require frequent cleaning.

VOLUME/CAPACITY INCREASE OF WATER QUANTITY STRUCTURES

Where existing water quantity structures are already in place, there is usually a potential for increasing the water quality capacity by deepening the structure or increasing the area. Some detention basins can be converted to water quality structures by adding a permanent water pool with a surface elevation set at the same elevation as the bottom of an existing detention basin. Floating outfalls can also be used to increase the detention time of the basin.

CHECK DAMS

Check dams are a retrofit option for shallow, grassed swales. Small check dams will reduce the velocity of flow and increase the time that water is in contact with vegetation. This technique has been shown to significantly increase the performance of grass channels (Strassler et al.1999) (Young et al.1995).

ENHANCE VEGETATION

The health, type, and density of vegetation is strongly correlated to the amount of sediment lost from a slope (Landphair et al. 2001). A significant source of suspended solids in highway runoff can be attributed to embankment erosion, shoulder, and roadside channel erosion (Young et al.1995) (Strassler et al. 1999). Therefore, programs to improve the density and health of the vegetative cover can make a significant contribution to stormwater quality.

INFILTRATION TRENCHES

Often, infiltration trenches or swales can be used to further increase the treatment capacity of a drainage swale or roadside channel. However, the potential hazard to groundwater limits the application of any infiltration technology.

OFFLINE TECHNOLOGIES

Offline technologies divert a predetermined volume of stormwater into an offline device for treatment. Once full, any remaining flow will be conveyed downstream, bypassing the offline treatment device. The most common technologies used for offline applications are storage tanks, filters, and detention/infiltration devices. Many of the proprietary technologies can be employed offline as well. The primary reason for using an offline technology is to avoid adverse impacts to the hydraulic operation of the existing drainage system. This will often be the most desirable approach in retrofit situations.

Storage Technologies

Storage devices are usually tanks that receive a predetermined volume of stormwater, which is held for later release. These storage devices are often used as pretreatment (sedimentation), which precedes other types of treatment downstream. Stored stormwater may be removed by gravity or by pumps.

Filter Technologies

Filters, such as the Austin Sand Filter or the Delaware Sand Filter, can be employed offline. Proprietary filtration systems can also be employed offline.

Detention/Infiltration

Detention or infiltration devices can be used offline as well as on line. When size is a limiting factor, they will usually be placed offline.

PROPRIETARY TECHNOLOGIES

Most of the proprietary technologies being marketed for stormwater treatment fall into four broad categories. The most common technology is probably centrifugal separation, followed by filters and biofiltration.

Vortex/Centrifugal

A number of devices use a vortex or centrifugal force as the principal means of separating solids from the incoming stormwater stream. These are the Storm King, V2B1, Vortechs, StormCeptor, and continuous deflective separation (CDS) units. The main chamber of the device traps solids, and the water is passed downstream. Most of the technologies can be used on line or offline. At design capacity (full bypass), the StormCeptor and Downstream Defender units require 21 to 28 inches of hydraulic head to operate. The CDS unit, however, requires from 0.6 feet to 4.3 feet of hydraulic head, depending on design flow capacity.

Gravity Separators

Several of the proprietary technologies use the standard water quality settling approach of allowing gravity to drag suspended particles to the bottom of the device. These units are Hydrasep (oil only) and BaySaver. These devices are used on line or offline, depending on site requirements. Typically, they obtain best treatment of low flows. Flow rates approaching the design flow rate are generally bypassed to prevent resuspension of trapped solids. The BaySaver unit requires 12 inches of hydraulic head at design capacity.

Filters

Filter technologies are usually an adaptation of technologies used to filter potable water or polish wastewater discharges. Filters may use cartridges or proprietary media for filtration. The filter devices are generally scalable and can be used to treat relatively large flows. These units are Gullywasher, Aquashield, and StormFilter. Because of the energy loss associated with the filter media, these structures may require more hydraulic energy to operate. No hydraulic performance data were available.

Other Approaches

One proprietary unit, the StormTreat, marketed as a biofiltration device, combines plants with a filtration media in a segmented tank. The combination of vegetation with filtration media is supposed to give better removal of nutrients and some organics than simple filtration. No hydraulic performance data were available.

The Infiltrator Chamber is another proprietary unit that uses underground infiltration to achieve treatment. This particular unit is targeted at improving infiltration for septic tank leach fields. Flow capacity of the infiltration technology is limited.

WATER QUALITY PERFORMANCE OF AVAILABLE TECHNOLOGIES FOR RETROFITTING

INTRODUCTION

Numerous studies in the literature provide performance numbers for various generic stormwater quality structures. Likewise, most manufacturers of proprietary technologies publish performance data for their product. However, it is very difficult to compare performance properties because the measurement, sampling, and reporting techniques are not consistent. On the other hand, the reported numbers can be used as a beginning point for evaluation.

This section presents compiled pollutant removal performance for a variety of technologies available for retrofitting existing drainage structures. This includes drainage inlets and outlets, detention and retention structures, existing drainage swales, and roadside shoulders. Performance information for each group of retrofit BMPs is presented in tabular format. The information in the tables has been compiled from a wide range of sources, as noted in each table.

POLLUTANT REMOVAL PROCESSES

Prior to presentation of pollutant removal efficiency information for the various BMPs suitable for retrofit applications, it is important to introduce the means by which the various BMPs remove the various constituents. Some BMPs perform well in removing certain constituents and poorly in removing others. For example, wet ponds are far more efficient than filtration BMPs at removing dissolved nutrients. For the most part, BMPs use natural processes to remove waterborne pollutants. Each BMP takes advantage of one or more of these processes depending on the design (Strassler et al. 1999) (Young et al. 1995). The processes are as follows.

Sedimentation

The primary process for pollutant removal from the water column is by gravity settling. The rate of settling or sedimentation depends on particle size, fluid density, and viscosity. Sedimentation will be a factor in any still water body regardless of other design features incorporated to enhance pollutant removal. Since many other constituents, such as metals, hydrocarbons, nutrients, and oxygen demanding contaminants can be adsorbed to solid materials, they are also removed from the water column as the solids are removed.

The time required for solids to settle depends on the particle size distribution. Sand size particles will settle rapidly while clays may stay suspended for several days. Schueler found that detention times greater than 48 hours would remove over 90 percent of the suspended solids. Urbonas and others have suggested that sedimentation can be expected to remove solids to a threshold of about 10 mg/L, after which no significant sedimentation will occur (Schueler 1987, Yu et al.1992, Urbonas 1996).

Filtration

Filtration is often employed where space is limited or in conjunction with sedimentation structures. Filters remove pollutants by passing water through a porous medium such as soil, sand, gravel, peat, compost, or composite materials that have an affinity for oil or some other material.

Infiltration

Infiltration is the natural process of moving water from the surface into the soil profile. The soil acts as a natural filter and removes nutrients and solids by natural filtration. Soil organisms also breakdown organic materials. Infiltration also can remove a considerable volume of water from the runoff stream, which helps minimize bank and surface erosion, major sources of solids in runoff. While infiltration is very efficient, it is not practical where the surface layers have a direct connection to ground water resources.

Flotation

Flotation is one mechanism utilized to separate hydrocarbons, gas, and oil, from the water stream. Baffles or flotation booms are placed so that the lighter materials float on the surface and are trapped in a holding basin until they can be removed and transported for proper disposal. Other floatables removed include paper, yard waste, and plastics.

Adsorption

Van der Waals forces and electrostatic attraction between soil particles mainly cause adsorption. Many soil particles, particularly clays, have high adsorptive qualities and will attract metals. Solids carried in stormwater also act as an adsorbent and, therefore, carry a significant portion of other pollutants.

Biological Utilization

Plants, algae, and other microorganisms growing in water or in stormwater channels will remove nutrients and trace elements and use them for life support. If vegetation is harvested, the nutrients fixed in the plant are permanently removed. However, if vegetation is simply cut or allowed to die and cycle naturally, the nutrients will be made available for release into the stormwater stream again. The most common use of biological utilization is for wastewater treatment (Wolverton and McDonald 1977).

Biological Conversion

Organic contaminants include a large group of chemicals and compounds such as chlordane and PCBs, DDT, and hydrocarbons. The most efficient means of removing this group of pollutants from soil and water is by bioremediation. Stormwater BMPs that utilize permanent water pools, soil, or organic filter materials will support colonies of microorganisms that will convert these organic materials to less complex materials that are less toxic (Young et al. 1995, Strassler et al. 1999, Schueler 1987).

Degradation

BMPs that utilize open water bodies can provide the environment and conditions necessary for volatilization, hydrolysis, and photolysis of organic compounds. Hydrolysis is a natural process that involves breaking down more complex compounds into intermediate compounds in water.

REPORTING OF BMP CONSTITUENT REMOVAL EFFICIENCIES

The reporting of constituent removal is most often given as the mass of constituent removed, expressed as a percent of the total amount present in a sample. However, studies are not always clear about the volume of water, the pollutant level of the influent water, the number of data points represented, and the data combination used to achieve the final performance number. This makes the interpretation and comparison of performance data very difficult. The EPA and American Society of Civil Engineers (ASCE) effort to develop a National Pollutant Removal Performance Database is a national effort aimed at reconciling these deficiencies in reporting stormwater performance data. This effort was initiated in 1999 and is continuing. When this effort matures, it will be a valuable information resource. However, it is early in the development stage, and standardized performance data for BMPs are limited. Where performance data are available from the national database for retrofit BMPs, they will be highlighted in the respective tables included in this report.

Performance tables have been developed from recognized sources for as many types of BMPs as possible. The performance tables show a wide range of stormwater pollution constituents, but not all of the studies and reports reviewed reported values for all of the constituents listed. In some cases, no performance monitoring data were found, so it was not possible to develop a table.

There is no consensus in the literature regarding which constituents should be monitored. The Texas Natural Resource Conservation Commission (TNRCC) and other regulatory bodies have adopted TSS as the primary constituent to be controlled since it does have a positive correlation with other constituents that readily adsorb to the solids. On the other hand, as total maximum daily loads (TMDLs) redevelop for 303(d) listed water bodies, TxDOT may be required to monitor and reduce other common constituents such as nutrients, oil and grease, and metals. The constituents shown in the tables are those that are common in highway runoff (Young et al. 1995). If the table is blank, the reference cited reported no value for that constituent.

Given the range of values reported for various constituents that are related to the various BMPs, it is inappropriate to suggest a single value for design purposes. In cases where TNRCC has an adopted standard for a particular BMP, it will be noted in the table along with other reported values. In other cases, design methods are suggested that will allow an estimation of performance. Designers must be aware that the performance results for any single event may vary significantly from an assumed or calculated design performance value. Therefore, until more and better quality data are available on performance, designers will have to rely on their best professional judgment and site-specific information.

Performance of Extended Detention BMPs

Retrofit Application

Existing water quantity control structures can sometimes be increased to provide additional water quality volume, and the outfall structures can sometimes be modified to increase the detention time in the basin, providing additional water quality benefits. While only two TxDOT districts appear to have water quantity structures, large urban interchanges often represent a land resource that could be used to develop extended detention water quality structures.

Extended detention has been demonstrated to be one of the most effective means of removing pollutants from stormwater. Schueler and Young reported removal rates as high as 90 percent for TSS when detention times were greater than 36 hours (Schueler 1987, Young et al. 1995). Table 2 summarizes efficiencies for removal of selected constituents.

Table 2. Water Quality Performance of Extended Detention Basins.

CONSTITUENT	EPA Strassler (Percent)	EPA/CWP Winer (Percent)	FHWA Young (24 hr) (Percent)	FHWA Young (48 hr) (Percent)	TNRCC** (Percent)
TSS	70	61	75	90	75
Ammonia	23				
Nitrate	23	-2*			
Organic Nitrogen	23	31*			
Total Nitrogen	30		32	40	
Soluble Phosphorous	34	-11	45		
Total Phosphorous	46	20		50	
Bacteria	74				
Organic Carbon	35				
Cadmium	47				
Chromium	49				
Copper	55	29*	45	50	
Lead	67		75	90	
Zinc	51	29*	45	50	
COD	nr		45	50	

** Fewer than 5 data points*
*** "Complying with the Edwards Aquifer Rules: Technical Guidance on Best Management Practices," June 1999, RG-348.*

The negative values for nitrates and soluble phosphorous are probably due to resuspension of pollutants. Intermittent negative values are not uncommon, particularly for grass-lined detention basins with no pretreatment sediment chamber (Winer 2000). Clearly, detention structures will remove a greater portion of the solids, the longer the detention. However, the removal of other constituents is not similarly enhanced after 24 hours (Young et al.1995, Schueler 1987).

Performance of Inlet Control Technologies

Inlet control technologies include a variety of techniques used between the end of an outfall and the receiving water body. These technologies may be employed to collect oil and grease, as a sediment trap upstream of another type of BMP, or to collect floatables (see figures 1 and 2).

Catch Basins

Retrofit Application. Standard, side, box, grate inlets can be converted to catch basins by adding a sump. The cost of making this adjustment must be weighed against the limited benefit of the improvement and the potential mosquito problem.

A single catch basin can serve only a limited drainage area of up to two acres, depending on the amount of impervious area. Catchment volume should be designed so that water has a residence time of at least 10 minutes or more to provide water quality benefits.

For design purposes Young suggests the following relationship, which can be used as design guideline (Young et al.1995):

$$R=41.5t_d^{0.2}$$

Where:

R= the TSS removal efficiency as a percent

t_d = the detention time in hours

Given this relationship, a detention time of 10 minutes should provide a TSS removal efficiency of approximately 28 percent. No other performance data for other highway or urban stormwater constituents were found for catch basins, so no performance table is provided.

Baffle Tanks, Water Quality Inlets, Oil and Grit Separators

Retrofit Application. Underground tank-type BMPs like baffle tanks, water quality inlets, and oil and grit separators, are most effective when used to replace or install in line with grate inlets or side inlets.

These three water quality BMPs have subtle design differences but perform very similar functions. They are essentially tanks divided into a series of chambers. The chambers are connected by submerged or protected openings to separate sediments, trash, and oil and grease. Figure 1 shows a water quality inlet, oil and grit separator with this configuration.

The baffle box in Figure 2 is a variation of the oil and grit separator, or stormwater quality inlet. It usually consists of a baffle at the inlet side of the box to slow the flow, and a weir at the outlet to trap sediment in the middle chamber. The first chamber allows floatables to rise to the surface and traps them there, as well as some sediment. The second chamber traps only sediment. As the water spreads into the middle chamber, sediment settles to the bottom and is held there.

There is one proprietary baffle tank that also incorporates screens to separate floating vegetation, which is supposed to reduce the release of nutrients into the water. No data were available to substantiate this claim, and this feature was not found in any of the other descriptions of generic baffle boxes. Several authors note that a significant amount of trash will be passed through these devices during high flows if they are not cleaned on a regular schedule.

Floatables, Booms, and Oil-Absorbing Materials

Permanent booms are usually made of polypropylene and simply float on the surface of the water, where they contain lighter materials floating on the surface. In a report for the Houston District, Pechacek and Van Sickle of Turner Collie and & Braden, Inc. (TC&B), recommended the testing of a floatables control boom (2000). This report cited successful use of containment booms for floatables control in New York City, New Rochelle, New York, and in Austin, Texas. Harris County Flood Control District (HCFD) tested a floatables boom to trap floatables near the intersection of Barker Cypress Road and I-10. The structure serves a large watershed of approximately 186 acres and has a permanent water quality pool. The material collected in this installation during the trial period consisted of 1 percent paper, 12 percent plastics, and 85 percent yard waste, i.e. leaves, grass clippings, and woody vegetation.

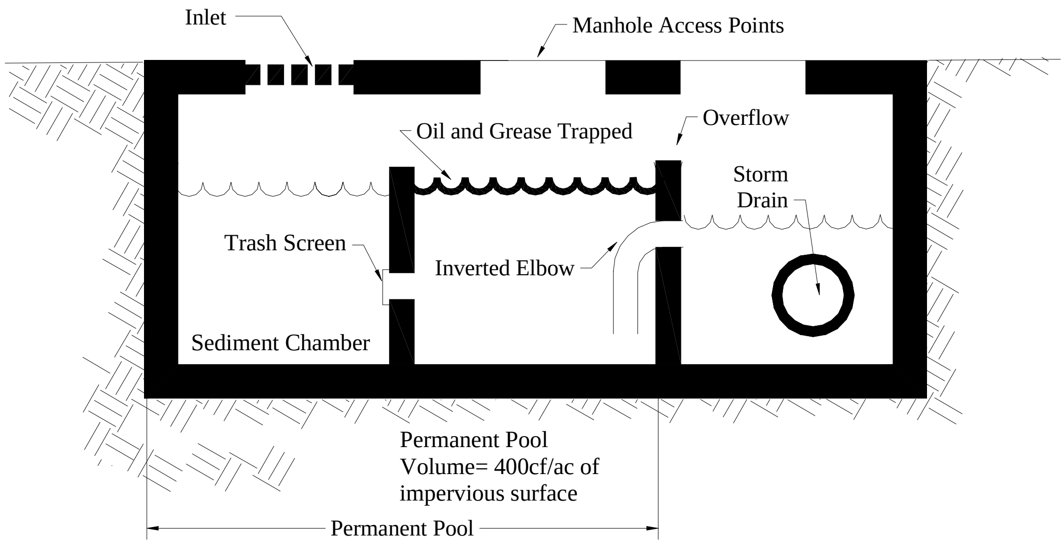


Figure 1. Water Quality Inlet or Oil and Grit Separator.

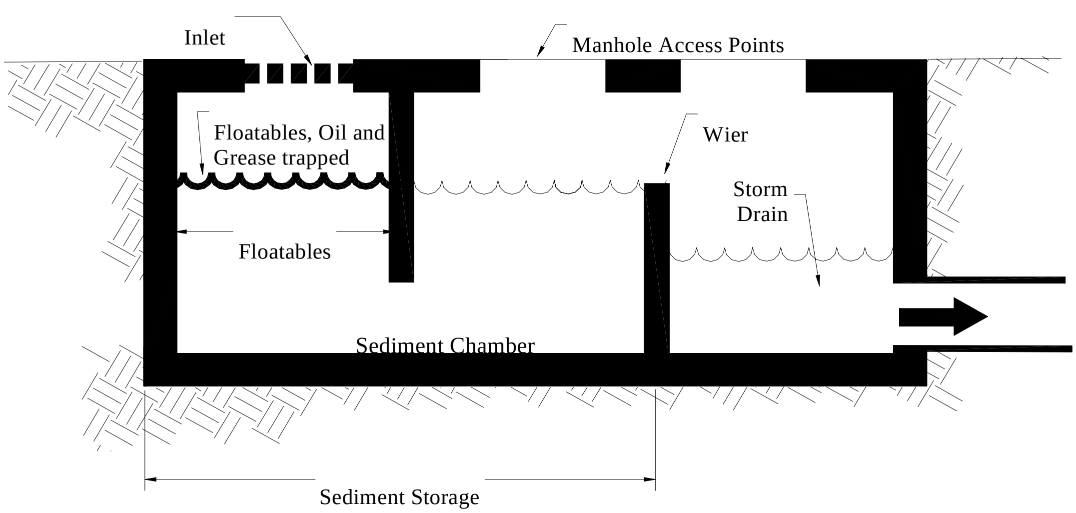


Figure 2. Baffle Box, Floatables Trap.

The booms used for this application are typical of those used for oil spill containment. Booms are also available to collect and absorb hydrocarbon materials. These materials trap the oil in the boom, which can then be safely disposed of as a solid waste. Because these devices do not absorb water and float, they could be very useful as a retrofit in areas where oil and grease contaminants pose a high risk to adjacent water bodies. Figures 3 and 4 show an oil-absorbing boom and a containment boom.

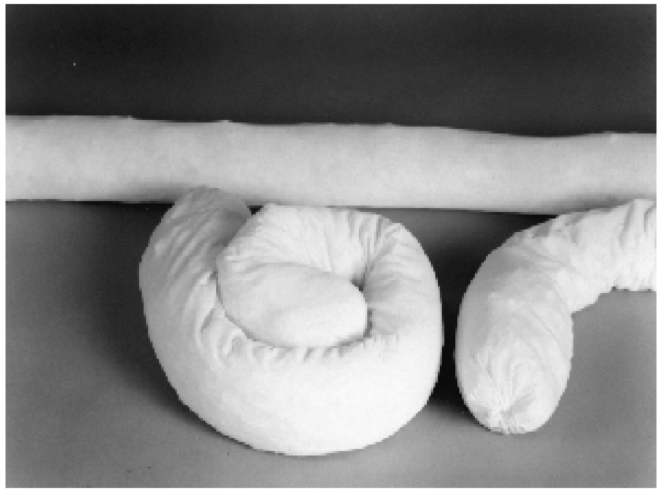


Figure 3. Oil-Absorbing Boom, AbTech Industries.

Inlet Inserts and Baskets

Figure 4. Containment Boom, Advanced Environmental Systems, Inc.

There is a wide assortment of drain insert filters, baskets, and screens. Most of these devices are designed to drop into a standard side or grate inlet. There are principally three variations of the insert: floatables removal, sediment collection, and/or hydrocarbons trapping. To service them, the grate is removed, and the filter is taken out and cleaned or disposed of. There are numerous variations of this basic idea. Figure 5 shows several drain insert examples. Table 3 shows performance data for the Ultra Urban Filter. The appendix materials provide web page addresses for manufacturers.

Flows through these devices are on the order of 0.25 CFS to 0.89 CFS. Some manufacturers suggest that there is no flow impedance, while others give flow rates for new media and average flow rates in use.

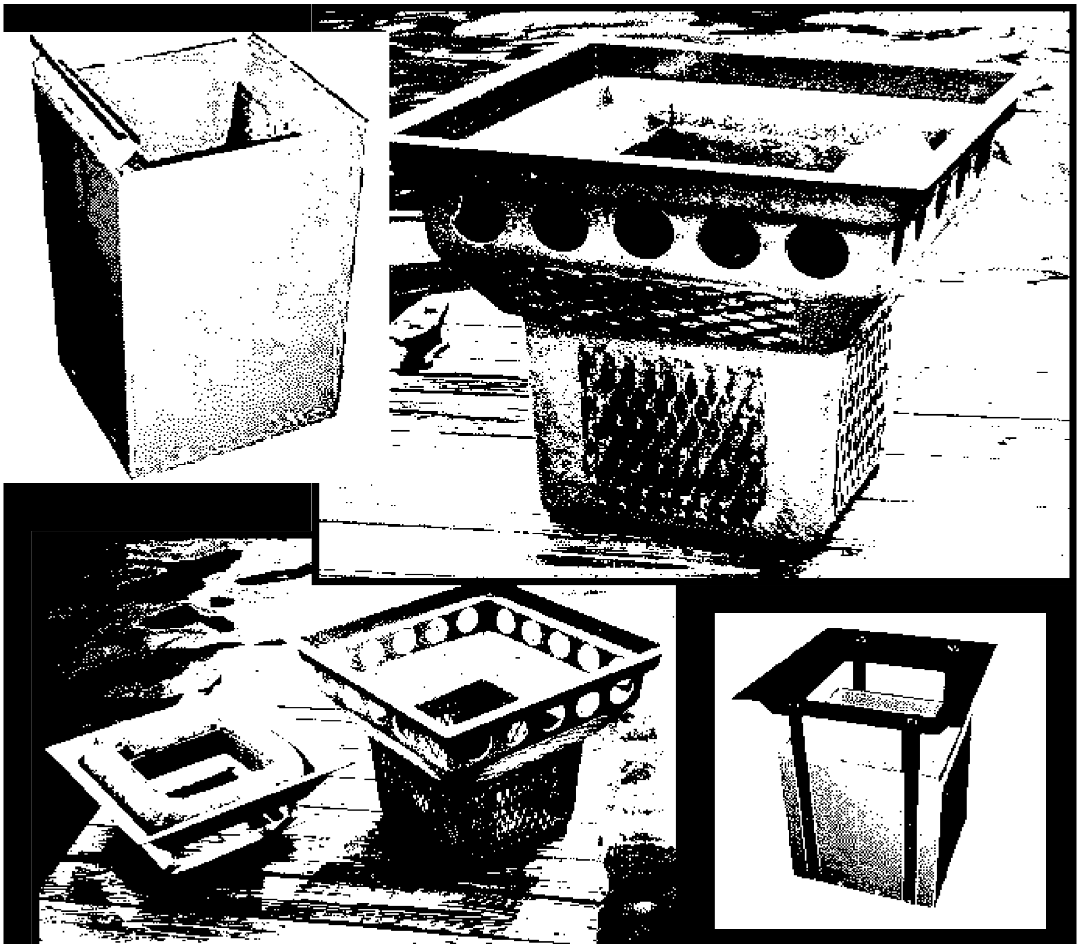


Figure 5. Drain Inserts.

Table 3. Performance of AbTech Technologies, Inc. Ultra Urban Filter.

Constituent	Performance
Solids and Debris	10 – 70 lbs
Total Petroleum Hydrocarbons (THP)	89% - 99%
Oil and Grease	85% - 99%
Metals (Pb, Zn, Cu)	99%

No independent studies of hydraulic performance of these devices were found. Designers should examine the technical specifications for these products and visit with manufacturers to be sure that the hydraulic performance will meet the hydraulic requirements of their site. Shoemaker et al. and others suggest that inlet inserts are only good for removal of coarse particulate matter, large floatable material, and hydrocarbons. The focus of the performance tests found in the literature was on hydrocarbon removal and floatables (Shoemaker et al. 2000).

The research was reasonably controlled, but the data for metals removal were apparently from a single unit, and the performance appears to be overstated when compared to the performance of other BMP types. There are also questions about maintenance frequency and cost that cannot be answered without further information. Table 3 shows performance data for the Ultra Urban Filter, one example of an inlet insert.

Using inlet inserts or drain baskets can significantly increase the residence time of water, and the treatment values should reach the highest values shown for extended detention basins in Table 2. This is a very simple, inexpensive, retrofit device that can be fabricated on site.

The drawdown time for a floating outlet depends on the configuration of the inlet. Most inlets appear to follow the rules of sharp crested weir flow or orifice flow. Since many different inlet variations are possible, each device will have to be calibrated.

If a floating outlet is being considered for an existing detention basin, the design hydraulics and hydrology should be reviewed, particularly with regard to the water volume and emergency spillway design and condition.

Floating Outlets and Skimmers

The use of floating outlets and skimmers is a retrofit technique designed to increase, simply but effectively, the residence time of an existing water quantity basin. Figure 6 shows a floating outlet for retrofitting detention structures. A flexible pipe is attached to the existing outlet, and a perforated or screened inlet is placed on the upstream end of the flexible pipe. The inlet is attached to some type of float. As the drainage basin fills, the restricted outlet floats and only allows the high quality water near the surface to pass through the outlet.

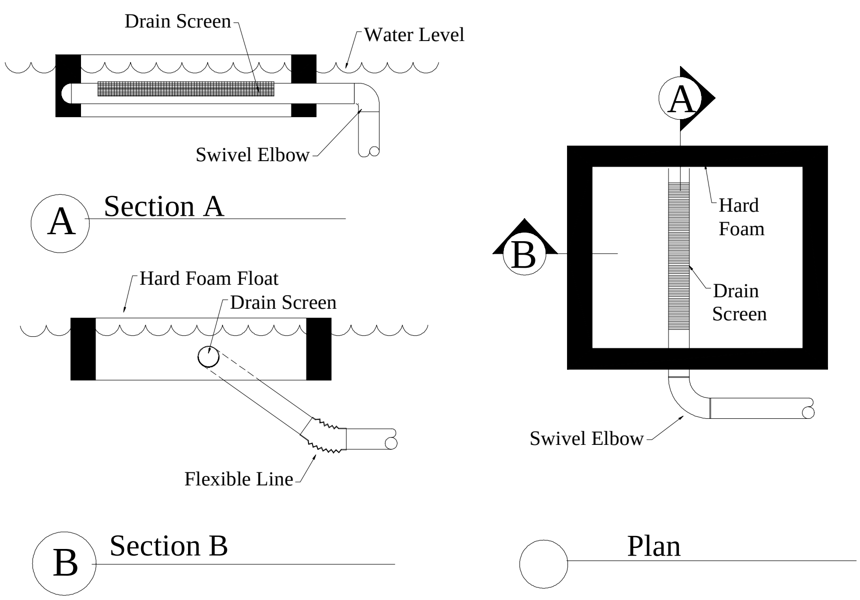


Figure 6. Floating Outlet for Retrofitting Detention Structures.

Depending on the region of the state, one or more storm event may occur prior to the basin being fully drained, and the spillway will have to be able to pass any excess flow without damage to the basin. Likewise, the likelihood of another storm event occurring before the basin has emptied must be taken into account. However, acknowledging potential disadvantages, the floating outlet represents one of the most economical and effective water quality retrofit devices available.

Surface Wet Ponds and Constructed Wetlands

Surface wet ponds and constructed wetlands have potential to be developed in the open land areas of large highway interchanges to increase water quality.

Retrofit Application. Wet ponds and constructed wetlands are considered one of the more effective and least expensive practices for nutrient removal and for the breakdown of some complex hydrocarbon and chemical compounds. Tables 4 and 5 present the pollutant removal efficiencies reported in the literature. The big drawback is that these structures require significant land areas.

Most discussions on retrofitting for water quality in urban areas tend to focus on the existing water quantity ponds and drainage structures because of the cost and availability of land. However, limited access highway interchanges represent a significant land resource in large urban areas. The land area in some of the largest direct-connect interchanges ranges upwards of 80 acres.

Earthen structures located on the surface are the most cost effective in terms of life-cycle cost-per-pound of pollutant removed. For example, an earthen wet pond with a contributing watershed of 50 acres has a cost-per-pound of TSS removed of approximately $0.57. In contrast, a sand filter to serve the same 50-acre watershed would have a cost-per-pound of TSS removed of about $1.20 (Landphair et al. 2000). The sand filter would have a smaller footprint than the earthen wet pond with very similar performance characteristics. Therefore, the cost for a 20-year lifecycle period based on 50,000 pounds of TSS per year removed, would be $570,000 for the wet pond compared to $1,200,000 for the sand filter. This is a difference of $630,000. Multiply this total by several structures and the difference is clearly significant.

The adaptability of the open space in urban interchanges for stormwater quality depends on the topography and drainage basin upstream, but many urban interchanges have significant land areas that could be developed for water quality purposes. Numerous opportunities may exist for the installation of wet ponds, particularly in the large interchanges of urban freeways.

The primary difference between the performance of the wet pond and the detention basin is the removal of soluble nutrients. Continued research indicates that extending detention times to 48 hours or greater may offer similar benefits.

Table 4. Pollutant Removal Efficiency for Wet Ponds.

Constituent	New Jersey DOT Hayes et al. (Percent)	EPA/CWP Winer (Percent)	FHWA Young (Percent)	MWCG Schueler (Percent)	TNRCC* (Percent)
TSS	60	80	74	54	93
Ammonia					
Nitrate		63		60	
Organic Nitrogen				20	
Total Nitrogen	35	35	34		
Soluble Phosphorous		67		80	
Total Phosphorous	45	55	49	20	
Bacteria					
Organic Carbon					
Cadmium					
Chromium					
Copper		44			
Lead	75		69	65	
Zinc	60	69	59	51	
COD	40		45	30	

** "Complying with the Edwards Aquifer Rules: Technical Guidance on Best Management Practices," June 1999, RG-348.*

Table 5. Effectiveness of Constructed Wetlands.

Constituent	EPA** Strassler (Percent)	EPA/CWP Winer (Percent)
TSS	76	71
Ammonia	33	
Nitrate	46	
Organic Nitrogen	7	40
Total Nitrogen	24	19
Soluble Phosphorous	23	43
Total Phosphorous	46	56
Bacteria	78	
Organic Carbon	28	
Cadmium	69	
Chromium	73	
Copper	39	58
Lead	63	
Zinc	54	56
COD		

*** Compiled by Strassler from Strecker and Schueler.*

Some authors and agencies are recommending the use of very small onsite wetlands and ponds for water quality improvement. The Maryland State Highway Administration and the Maryland Department of the Environment encourage the use of very small wetlands and ponds as part of their water quality strategy. However, most of these installations are on private property and are privately maintained. Since cost related to maintenance and operation of structures serving small drainage basins increases rapidly for these methods, small wetlands or wet ponds do not appear to be a feasible retrofit option (Landphair et al. 2000).

Large Filters

Austin Filter, Delaware Sand Filter, Alexandria Dry Vault Underground Sand Filter, and D.C. Underground Sand Filter

Filters are large tanks or basins that may be situated at the surface or below grade. They can be fitted to the site in a variety of ways depending on the topography and the land available. The most common filters used in highway practice are sand filters, which include the Austin Filter, the Delaware Sand Filter, Alexandria Dry Vault Underground Sand Filter, and the D. C. Underground Sand Filter. Schematically, these filters are very similar. Each one employs a pretreatment sediment chamber—a weir to distribute the stormwater uniformly to the filter medium. The chief differences are in how emergency overflows are handled and the separation between chambers.

Retrofit Application. The Delaware filter, seen in Figure 7, uses a downstream weir to pass excess flow. Therefore, if the chamber overfills, excess flow simply bypasses the filter. This has some disadvantage in that higher velocity flows over the filter can damage the filter bed and resuspend material trapped in the filter medium.

The Austin, Alexandria, and DC filters (Figures 8, 9, and 10) use a flow splitter to meter the appropriate water quality volume into the filter changer. Excess flow bypasses the structure completely, which prevents any damage to the filter or resuspension of material trapped in the filter chamber.

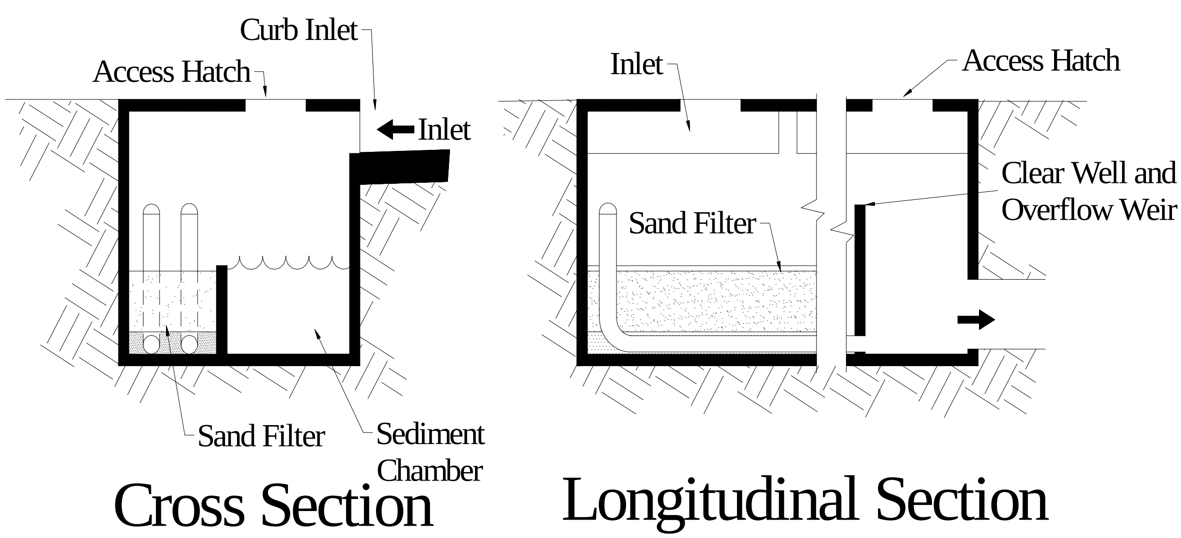


Figure 7. Delaware Sand Filter.

The Alexandria Dry Vault Filter uses a gabion as the separation between the sediment trap and the filter chamber. This acts as an energy dissipater but may not spread the water to the filter media as uniformly as a weir or spreader box.

The DC Underground Sand Filter uses a baffle in the sediment chamber to dissipate energy, separate oil and grit, and trap some floatables. This is a good option where oil and grease or other hydrocarbon materials pose a significant problem.

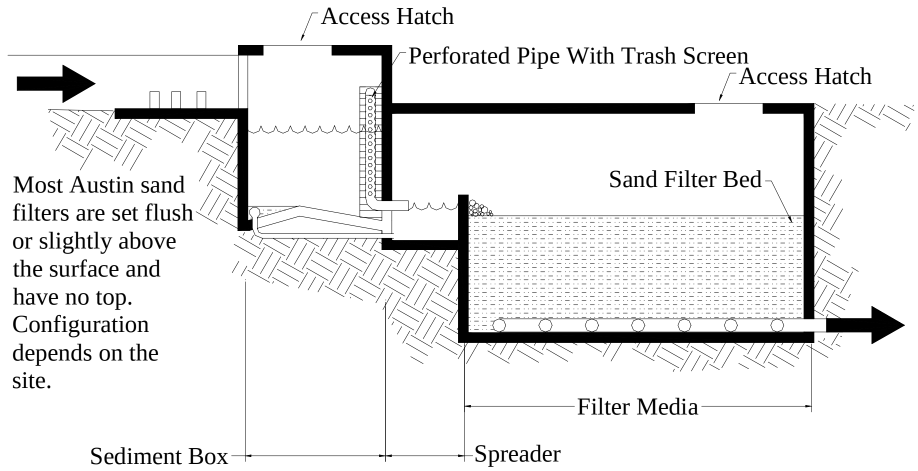


Figure 8. Austin Sand Filter.

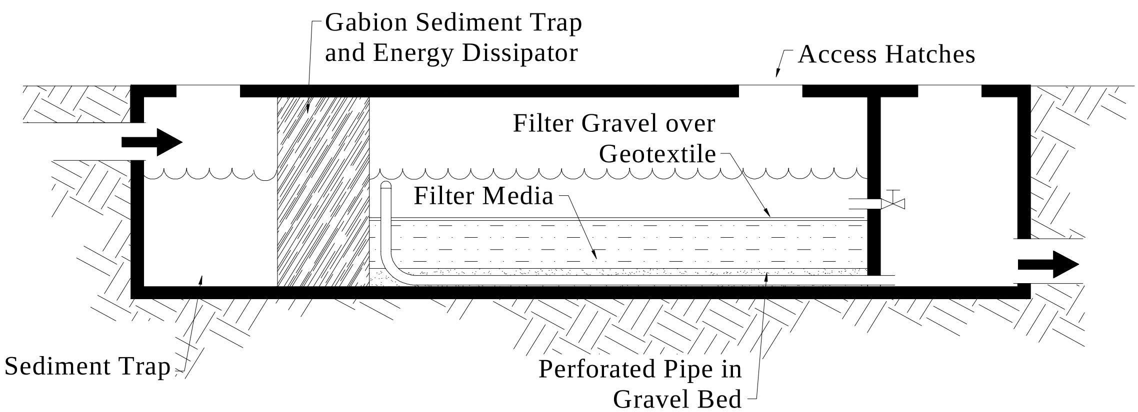


Figure 9. Alexandria Dry Vault Sand Filter.

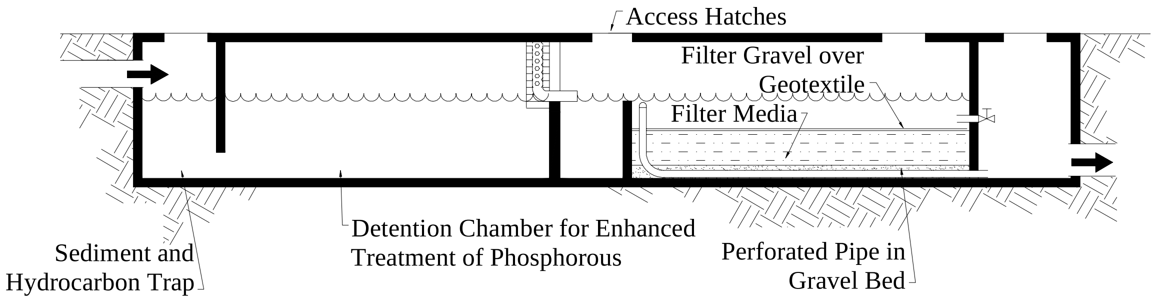


Figure 10. DC Underground Sand Filter.

A major consideration with these applications when fully covered is providing access for maintenance and replacement of the filter media. Many of the installations in Texas and California leave the sediment and filter chamber open, providing easy access for heavy equipment.

This can significantly decrease the long-term maintenance costs. Covers are not recommended unless there are safety hazards or aesthetic reasons that justify full cover.

Sand filters are flexible in their design and can be fitted to almost any site condition. The most limiting factor is usually elevation. Very flat sites will limit the depth of the filter material and may prohibit their use altogether.

Sand filters are one of the most consistent stormwater quality treatment performers. Numerous studies have been completed so that performance is better documented for these structures, as shown in Table 6. Their primary deficiency is the ability to handle nitrate and nitrite (NO_2 and NO_3). Effective removal of these nutrients is dependent almost completely on plants. This is the primary advantage of the constructed wetland and wet pond for stormwater treatment.

In Channel Improvements

Improving grass channels and shoulders is an inexpensive, high reward retrofit. Grass shoulders and channels make up a great portion of the standard rural highway cross-section. Grass channels can be improved by adding flow splitters, check dams, and by simply improving the health of the vegetative stands.

Table 6. Pollutant Removal Efficiency of Sand Filters.

Constituent	EPA Strassler (Percent)	EPA/CWP Winer (Percent)	FHWA Young (Alexandria) (Percent)	FHWA Young (Austin) (Percent)	TNRCC (Percent)
TSS	81	87	78	86	89
Ammonia	68		39	89	
Nitrate	-13	-13	-62.7	-38	
Organic Nitrogen	28		70.6	81	
Total Nitrogen	32	32	47.2	47	
Soluble Phosphorous	-31	-17	68		
Total Phosphorous	45	59	63	65	
Bacteria	37				
Organic Carbon	57		65.9	87	
Cadmium	26				
Chromium	54				
Copper	34	49		71	
Lead	71			79	
Zinc	69	80	90.7	84	
COD					

Brodie Oaks Basin, after Chang, et al.

Grass Channels and Filter Belts

Grass channels and filter belts have been demonstrated to be effective in removing sediment and other adsorbed pollutants from stormwater.

> **Retrofit application.** Where possible, it will benefit the overall stormwater quality system to make improvements to vegetated areas of the roadside since it will reduce the load and need for other, more expensive types of structures.
>
> It is recognized that in many urban areas, the demand for more capacity is forcing full utilization of the existing right-of-way. Therefore, there may be no opportunity to use these retrofit techniques. On the other hand, where vegetated areas such as medians, embankments, and vegetated borrow ditches are present, they should be considered for retrofit as part of a plan to meet water quality requirements.

The literature is not consistent in the assessment of water quality benefits derived from unimproved grass channels and shoulders. This inconsistency may be attributed to differences in soils and the condition and type of vegetation cover. Schueler initially indicated that benefits afforded by vegetated swales and shoulders were very small. However, controlled laboratory and field studies conducted by Malina et al., in Austin, Texas, suggest better performance than reported by other researchers (1997). Young indicates that some of Barrett and Malina's work was incorporated into the FHWA publication, but it is not clear how the values were compiled (see Table 7).

The TxDOT study by Malina et al. was conducted at two Austin sites along MoPac. The values in the third column of Table 7 show the mean reduction for each constituent at each site. The differences in removal of zinc, lead, and nitrates can probably be attributed to significantly higher concentrations in the influent. All other values seem to be reasonably close. It should be noted that the vegetation on MoPac at 183 site was mostly buffalograss. The performance of the vegetated channels remained reasonably consistent, even during the dormant season.

Buffalograss is a bunch grass that requires full sun and has limited resistance to abuse, such as driving on it or high velocity drainage flows. The standard TxDOT seed mix uses a variety of species that over time, have demonstrated better erosion and sediment control properties than monocultures or other pure native mixes (Landphair et al. 2001).

Schueler (1987) , Young et al. (1995), and others, particularly in the agriculture literature, have demonstrated that vegetated filter belts, belts of vegetation perpendicular to normal sheet flow, have significant water quality benefits. To be effective, filter belts should have reasonably flat slopes, 5 percent or less, and be at least 60 ft long (Yu and Kaighn 1992).

Table 7. Performance of Grass Channels (Swales).

Constituent	EPA Strassler (Percent)	TxDOT Malina (Percent)	FHWA Young (W=20ft.) (Percent)	FHWA Young (W+100ft.) (Percent)	TNRCC (Percent)	EPA/ASCE Winer
TSS	66	85-87	20-40	60-80	85	
Ammonia	3					
Nitrate	11	50-23				
Organic Nitrogen	39					
Total Nitrogen	11	33-44	>20	40-60		
Soluble Phosphorous	11					
Total Phosphorous	15	34-44	>20	40-60		
Bacteria	-25					
Organic Carbon	23	51-53				
Cadmium	49					
Chromium	47					
Copper	41		20-40	>80		
Lead	50	41-17	20-40	>80		
Zinc	49	75-91	20-40	>80		
COD		61-63	>20			

Brodie Oaks Basin, after Chang, et al.

The example shown in Figure 11 is a typical bridge approach embankment retrofitted to use the flatter portions of the interchange as a filter belt. Water sheet flows over the embankment, which provides some initial benefit. The shallow gravel trench at the toe of the slope is set level and spreads the water uniformly over the filter belt portion of the interchange. This particular application has not been tested and favorable conditions will not be present in all such interchanges. On the other hand, the application should work so long as the width of the filter belt portion is 60 ft or more with a slope of 5 percent or less.

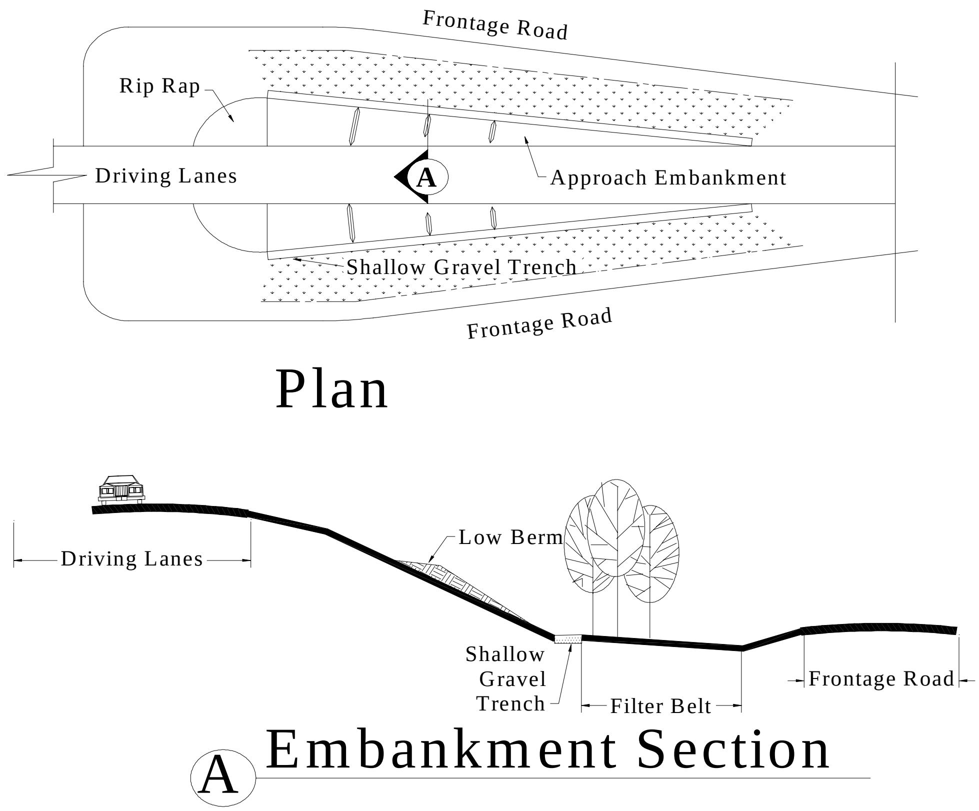


Figure 11. Bridge Embankment with Filter Belt.

Water Quality Swales

The water quality swale shown in Figure 12 can be applied to existing roadside channels to further improve water quality. The incorporation of 4 inches of compost into the bottom and sides of the channel helps improve moisture infiltration and will support and encourage a more vigorous vegetation cover. The low divider berm is needed only if the channel bottom width is greater than 10 ft. The berm should be permanent and 4 to 6 inches high. Since the effective water quality depth is between 3 to 4 inches (Malina et al 1997), a 4 inch divider is considered optimum so as not to interfere with mowing and maintenance activities.

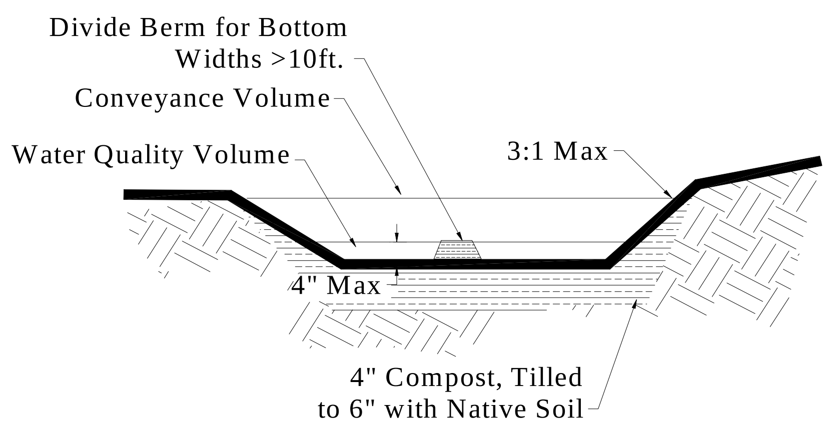


Figure 12. Water Quality Retrofit to Drainage Channel.

Water Quality Berms

The performance of existing grass swales and channels can be significantly enhanced by the addition of low check berms inserted perpendicular to the direction of flow (see Figure 13). Addition of the berms reduces low flow velocity and increases the residence time of the water in the channel. This improvement is effective to flow depths of about 4 inches; after that, water quality improvement is minimal. Therefore, the major benefit is pretreatment and to help minimize the size and increase the effective life of downstream structures.

Channels with slopes of 3 percent or less are the best candidates for this enhancement. Berm spacing is further apart, and tractive forces on the bottom of the channel are less than channels with steeper slopes. Berms should be 6 inches or less in height to avoid interference with mowing operations and should be made of rock or geosynthetic-reinforced soil to ensure longevity. The performance of grass swales will approach the highest values shown in Table 7 (Young et al. 1995).

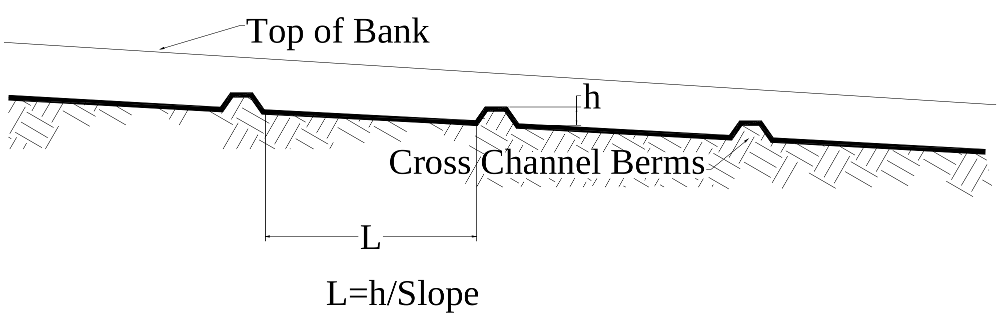


Figure 13. Swale with Water Quality Berms.

Biofiltration/Bioretention

Biofiltration/bioretention combines the basics of filtration, infiltration, and biologic uptake to remove pollutants from stormwater. Biofiltration/bioretention often appears in the literature mixed with discussions of constructed wetlands. However, as described by Washington State Department of Transportation, Schueler, and the Center for Watershed Protection, these are essentially landscapes with enhanced soils and vegetation enhanced to provide water quality benefits.

Although key reference publications, Winer, Young et al., Schueler, etc., describe biofiltration/bioretention, they do not cite performance characteristics for this type of BMP. However, Maryland has been using bioretention for several years. The lack of reported data is probably because performance studies have only been completed and published in recent years. Two very recent studies have been found for biofiltration/bioretention in Maryland and Florida (EPA 2000). The effectiveness values are shown in Table 8.

Table 8. Pollutant Removal Efficiency of Biofiltration/Bioretention Structures.

Constituent	Maryland SHA (Percent)	EPA Largo Maryland (Percent)	EPA [1] Tampa Florida (Percent)	EPA [2] Tampa Florida (Percent)	EPA[3] Tampa Florida (Percent)
TSS			46	78	91
Ammonia	92				
Nitrate	16	15	44	41	66
Organic Nitrogen					
Total Nitrogen	52	67	9	16	42
Soluble Phosphorous					
Total Phosphorous	65	87	-94	-62	3
Bacteria					
Organic Carbon					
Cadmium		27			
Chromium					
Copper	97	43	23	72	81
Lead	95	70	59	78	85
Zinc	95	78	46	62	75
COD					

[1] Asphalt surface to bioretention swale.
[2] Concrete surface to bioretention swale.
[3] Porous pavement to bioretention swale.

Research on these BMPs focuses on their ability to remove metals and nutrients. The values from recent studies suggest that this method is one of the most effective means of removing these particular constituents. The Tampa, Florida, project cited was a retrofit situation where water from a large parking lot was collected and channeled into very small bioretention islands and then into bioretention swales.

The construction details or improvements to the swales that conveyed the water to the detention structure were not described. It is assumed that they were similar to the detail shown in Figure 14.

Based on the data from the studies reported in the literature, it appears that bioretention can be very effective in removing metals and possibly nutrients. The fact that phosphorous removal seemed very positive in the Maryland studies, but was reported negative in Florida, seems to suggest there are some soil and water chemistry variables affecting performance. However, no detailed information was available to substantiate this point of view.

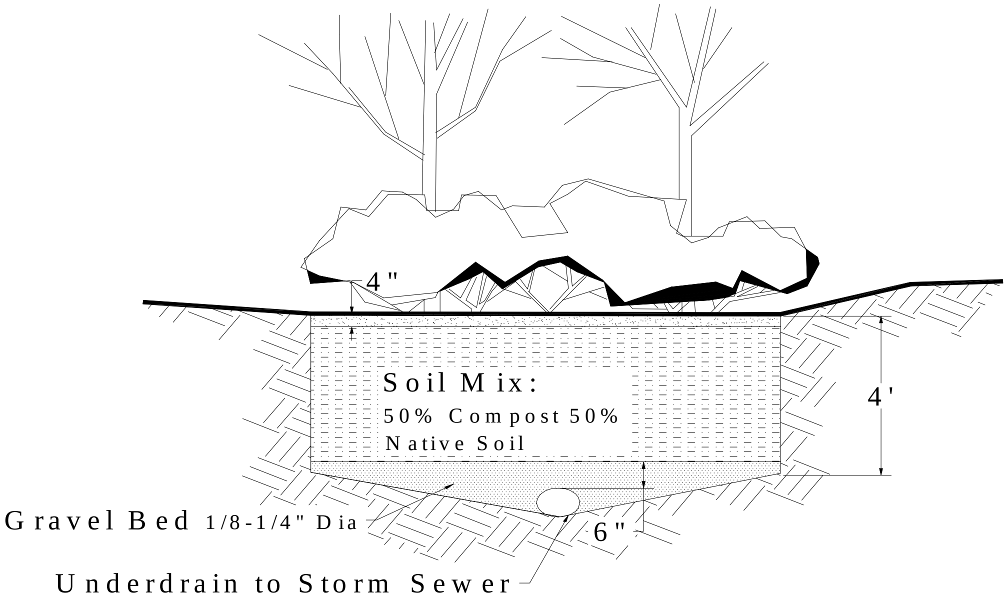


Figure 14. Bioretention Area.

Proprietary Technologies

As part of the review of available technology, researchers contacted companies dealing in proprietary stormwater treatment technologies. Representatives of these companies provided information on the use and expected performance of their products. Little documentation exists on the performance of proprietary technologies. Most documentation reported reductions in at least TSS. Some had additional performance data. These values are summarized below.

Vortex/Centrifugal

The dynamic separation technologies report reduction in TSS ranging from 50 percent to 80 percent, depending on site-specific characteristics. Factors that influence treatment efficiency include particle size distribution of the incoming sediments and flow rate. Some manufacturers report TSS removal on an annual basis and others on an event basis. Most of these devices trap floatables to some degree. Oil and grease removal is said to be from 80 percent to 90 percent or better. Although removal of nutrients is less efficient, some reduction in nutrients is achieved. Table 9 summarizes some manufacturer-provided test results for the StormCeptor.

Table 9. Percent Reduction in Constituents for StormCeptor Applications.

Site	TSS	TN	TKN	TP	TPH	Oil and Grease	Cu
Santec, WA	87	43	--	11	99	--	28
Westwood, MA	93	--	--	--	82	--	--
Como Park, MI	76	--	65	32	--	--	--
Edmonton, AB	53	--	--	--	--	43	22

Gravity Separators

Fewer of the available proprietary systems use gravity separation. The gravity separators are also relatively efficient at removing TSS. Manufacturer literature reports TSS removal rates of 80 percent. These units are also effective at removing oil and grease and hydrocarbons. The Hydrasep is specifically targeted (and only targeted) at hydrocarbons and is reported to remove 99.9 percent of hydrocarbons from the incoming stream.

Filters

Fewer data are available for the filtration systems. However, these systems appear capable of reducing TSS by about 80 percent to more than 95 percent from limited manufacturer testing. They are also effective at removing oil and grease, with one manufacturer reporting a removal rate of 90 percent to 95 percent from incoming flows. For example, Table 10 shows test results reported for the StormFilter. In addition, removal rates for the AquaFilter are reported by the manufacturer to be 84 percent TSS, 98 percent oil and grease, 81 percent TKN, and 51 percent phosphates.

Table 10. Percentage Reductions in Constituents Reported in StormFilter Literature.

Site	TSS	Oil and Grease	TPH
Laboratory Cartridge Test	74	--	--
Average of Field Test Sites	--	53	77

Other Approaches

No data are available for the infiltration system. This is not surprising given the target application.

The biofiltration device is capable of achieving significant reductions in TSS and nutrients because of the action of plants in combination with the filtration media. The StormTreat (biofiltration) manufacturer reports removal of TSS as nearly 100 percent, COD removal of 80 percent, dissolved nitrogen removal of 80 percent, TP removal of 90 percent, and metals removal from 80 percent to 90 percent of incoming concentration.

EVALUATING DRAINAGE STRUCTURES FOR RETROFIT

TYPE OF TREATMENT NEEDED

Stormwater treatment structures are capable of removing a wide range of pollutants from stormwater. However, no single structure is capable of satisfying all water quality parameters. The primary pollutants found in urban and highway runoff are sediments like sand silt, clay minerals, and other granular materials; metals, such as copper, lead, zinc, cadmium, and chromium; nutrients, primarily nitrogen and phosphorous; bacteria; organic compounds; hydrocarbons; floatables, like plastic and paper; and other chemical compounds. The processes that remove these pollutants include: sedimentation, adsorption, flotation, filtration, infiltration, biological uptake, biological conversion, and degradation.

This section provides a discussion of the processes that remove pollutants, links this with the available technologies, and outlines a process for selecting the appropriate technology for a given situation.

STORMWATER QUALITY TECHNOLOGIES

Wet Ponds

Wet ponds combine sedimentation, vegetative filtration, and biologic uptake as the primary pollutant removal processes. Wet ponds can often be added to existing water quantity basins, which provide water quality benefits without the need for additional land. This assumes that the water quantity volume remains constant and the water quality volume in the permanent pool is replaced by each successive storm event.

Biofiltration/Bioretention

Biofiltration/bioretention areas are landscaped areas specially constructed to provide water quality benefits. They generally serve small drainage areas of up to 1 acre. Continuing research has demonstrated that areas as small as the islands in a parking lot can provide significant water quality benefits (EPA 2000). These areas use vegetation in conjunction with modified soil profile and shallow flow depths to treat stormwater. The combined effects of surface filtration, infiltration through the soil profile, adsorption, and plant uptake provide treatment.

Sedimentation Basins

Sedimentation basins, or chambers, are used to dissipate flow and settle out larger suspended solids. Stormwater is then passed on to a second treatment structure such as a sand filter, or infiltration basin. Figure 15 illustrates this process. To maximize the life and ensure proper function, sediment basins should be the first step in all permanent stormwater structures.

Oil and Water Separators

Oil and water can be separated by dividing the lighter oils from the water surface with a baffle or by using an oil-absorbing material, such as a boom or an insert in an existing drainage structure.

In large, vault-type structures, adding a baffle to the sediment chamber in order to trap floating oil combines the sediment pretreatment with the oil and water separation function.

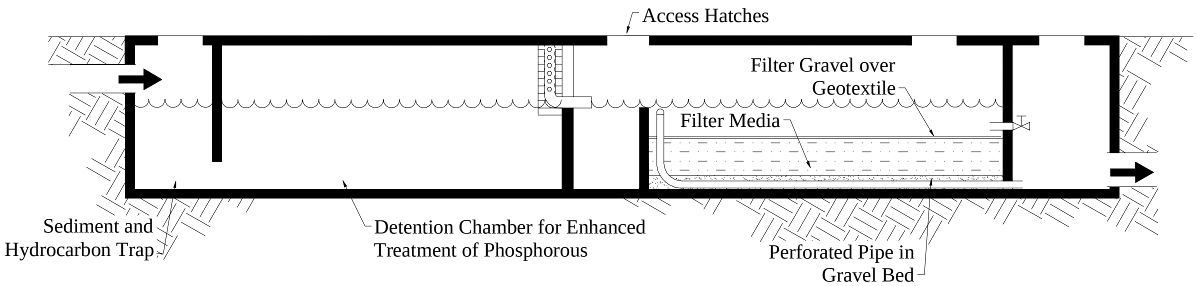


Figure 15. Detention Chamber Added to Sand Filter for Phosphorous Removal.

Infiltration

Infiltration takes advantage of the filtration properties of the existing soil profile. With the appropriate soil and geologic structural conditions, infiltration basins can be developed that use the filtration, adsorption, and biological breakdown properties of soils to remove targeted pollutants. Infiltration has the added benefits of maintaining groundwater recharge and reducing runoff peaks. However, it requires deep, permeable soils and a profile of sufficient depth to avoid any hazard to groundwater.

Filtration

Filters that utilize sand, compost perlite, zeolite, or other media are increasingly employed in urban areas, where land cost and availability make surface-based, earthen structures cost prohibitive. Filters do a good job of removing hydrocarbons, soluble metals, and solids.

SELECTION PROCESS

Several issues must be considered in selecting a BMP, from site considerations to the size of the drainage area and type of pollutant to be removed. The issues influencing the selection process are as follows.

Size and Character of the Site

Extended detention ponds, or wet ponds, require large, relatively flat surface areas for installation. Vaults, filters, and similar BMPs can be fitted to sites with steeper terrain since they can have greater depth to minimize the area of the footprint.

Site Access

Safe access to the site to perform maintenance and cleaning activities is essential. Sites should not be selected that could be hazardous to maintenance personnel or to highway users.

Drainage Area

The drainage area served by the BMP should be considered carefully. Studies of the long-term cost of building and maintaining BMPs shows BMPs that serve drainage areas of 20 or more acres in size are the most cost-effective regardless of type (Landphair et al. 2000). Furthermore, maximizing the area served minimizes the overall number of BMPs required. Minimizing the number of BMPs that must be maintained is critical to long-term sustainability.

Type of Technology

The literature suggests that there are numerous generic BMP options that will satisfy practically every site and water quality situation. For this reason, proprietary technologies should be used only when it is essential to meet specific requirements of a regulator or other jurisdiction.

Table 11 provides guidance for selecting an appropriate BMP for retrofitting an existing outfall. In addition, the diagram in Figure 16 outlines a process for selecting the group or type of BMP needed to address specific problems.

Table 11. Retrofit Options for Stormwater Quality.

Facility Type	Constituents	Recommended Retrofit	Optional Retrofit	Phosphorous Retrofit
Limited Access and Urban Highways	High O&G TSS, Cu, Zn, Pb	Appropriate sand filter[1] O& G Separator with Filter	O&G Separator with a water quality inlet and sand filter.	Requires the addition of a detention structure/vault, (See Figure 13).
Rural Highways	O&G, TSS, Cu, Zn, Pb	Extended Detention Pond, Constructed Wetlands[2]	Wet Pond or appropriate sand filter[3]	Constructed Wetlands, Bioretention or Wet Ponds[4]
Residential and Farm to Market Roads	Low O&G TSS, Cu, Zn, Pb, N, and P	Extended Detention Ponds, Constructed Wetlands[2]	Bioretention, appropriate sand filters	Constructed Wetlands, Bioretention and Wet Ponds

[1] Sand filters should be selected based on the site configuration. The Delaware filter is for long, narrow applications; the Austin filter is more flexible. The DC filter incorporates the O&G trap in the basic design.
[2] A constructed wetland requires that the site have appropriate hydrologic properties to sustain vegetation.
[3] In rural and suburban situations, acquisition of additional ROW should be considered in locations that will service watersheds of 20 or more acres. This will maximize the cost-effectiveness of the BMP used. Sand filters should be used only if limited footprint structures are possible.
[4] For drainage areas of less than 10 acres, bioretention is suggested; for greater than 10 acres constructed wetlands should be used.

Nutrients

Nitrogen and phosphorous are the primary nutrients and are largely responsible for oxygen deficiencies in water bodies. When nutrients are a problem, vegetated swales will not provide needed treatment. In fact, they can serve to exacerbate the problem. Extended detention structures, vaults, and sand filters will do a reasonable job of reducing nitrogen but, as a rule, will have little impact on phosphorous. In order to reduce phosphorous, constructed wetlands would be the preferred method for large drainage areas. Bioretention would probably be the most economic for drainage areas less than 10 acres. Wet ponds should be considered only if the site hydrology would not permit the maintenance of a viable wetland.

Metals

Metals can be removed with vegetated BMPs and with extended detention structures. Sand filters, although expensive, are also effective. As a rule, the sand filter should be used only when space or site conditions prevent the use of an extended detention facility.

Suspended Solids

Solids are best managed with detention and sedimentation. All BMPs should provide a pretreatment sedimentation basin or chamber to remove solids and prevent the clogging of downstream treatment elements.

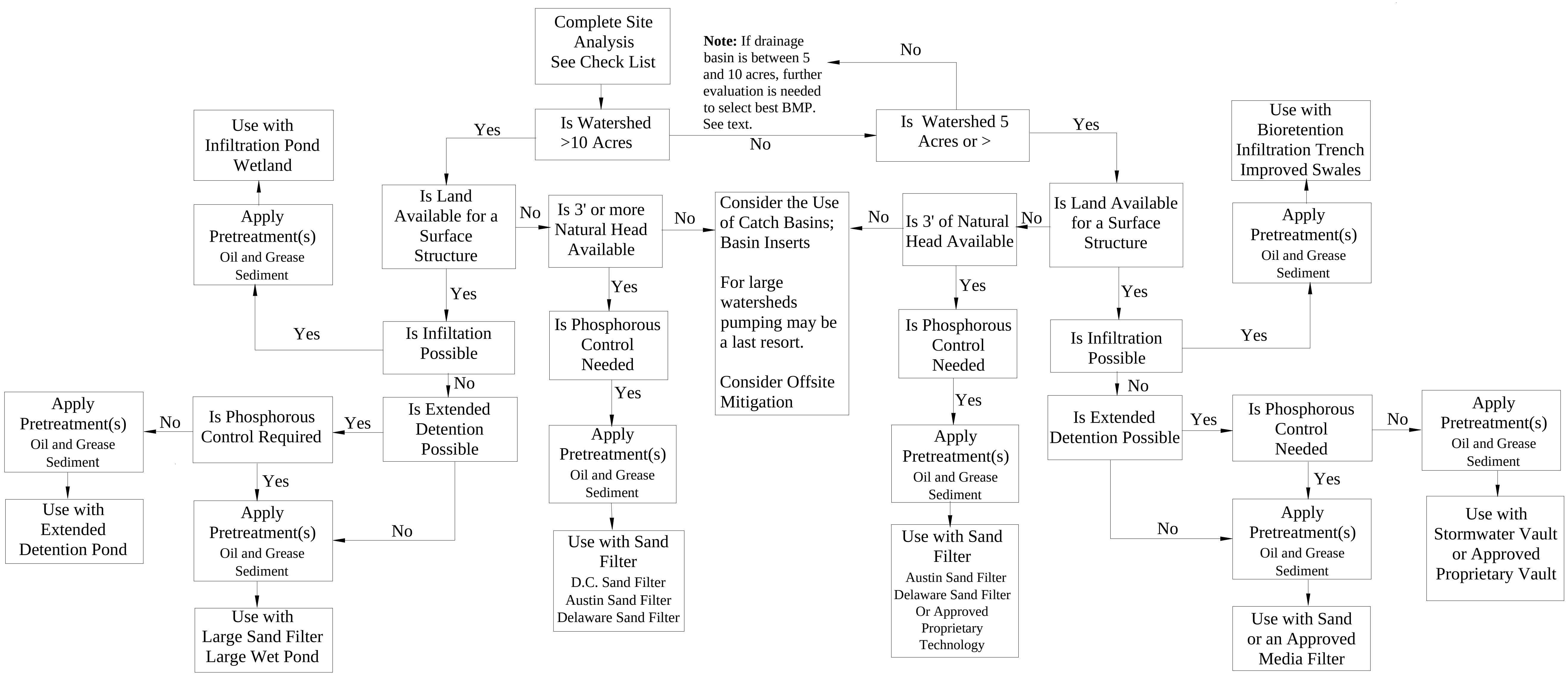


Figure 16. Retrofit BMP Selection Process

PRIORITIZATION FOR RETROFIT

INTRODUCTION

The two primary means being employed to establish stormwater retrofit priorities are the benefit-cost analysis developed by California Department of Transportation (CalTrans) and weighted scoring systems used by Washington State Department of Transportation (WSDOT).

California Prioritization System

The benefit-cost methodology developed by California is particularly interesting because it systematically deals with easily assessed variables, such as the cost of treating water, along with more abstract qualitative variables. Kalman et al. did a benefit-cost evaluation of the Ballona Creek watershed in the Los Angeles basin. The benefit-cost analysis was limited to those portions of Ballona Creek that had some impairment to the EPA beneficial uses, such as drinking, contact recreation, habitat, etc.

A scoring system based on pollutant concentration thresholds was used to estimate the degree of impairment for a specific range from no impairment 0 to fully impaired 1. Costs were estimated for three levels of BMPs. Level 1 included floatable and TSS control; Level 2 provided filtration and disinfection; and Level 3 was advanced treatment that would treat stormwater to a level that would meet all beneficial use standards.

Benefits were based on the economic benefits of improvement in beneficial use, that is the economic value of the restored beneficial use. These benefits were then compared to providing the different levels of treatment, Level 1 though Level 3.

With respect to Ballona Creek, the calculated benefit-cost ratios were 0.0089 for Level 1 treatment, 0.0062 for Level 2, and 0.0040 for Level 3. It should not be concluded from this that there is no benefit or need for stormwater quality management. It does underscore the need for making carefully considered tradeoffs to maximize limited resources.

Washington Prioritization System

The Washington State prioritization system is a weighted scoring process (Schaftllein 1996, Tetra Tech, Inc. 2001). System development began in 1995 and was revised in May of 2001. This system uses a multi-variable scoring system to establish priorities for the allocation of resources to the retrofitting program. The variables used are:

- Water Body Type (A),
- Beneficial Use of Water Body (B),
- Pollutant Loading (C),
- Percentage contribution of highway runoff to the watershed (D),
- Cost to Pollution Benefit (E), and
- Trade off Values (F).

After using the system for 5 years it was reevaluated and the variables were revised to account for weaknesses identified in early application.

The factors used in the revised prioritization system are:

- Type and Size of the receiving water body (***A***),
- Modified Beneficial use of the water body (***B***),
- Pollutant loading (***C***),
- Modified Percentage contribution of highway runoff to watershed (***D***),
- Cost/Pollution benefit (***E***),
- Values of trade-off (***F***), and
- Added Other factors considered by best professional judgment (***BPJ***).

The necessary revision addressed cost issue concerns raised by the Endangered Species Act (ESA) and the highway runoff contribution. The valuation of categories for beneficial use had been based on the basic EPA guidelines for drinking water supply, contact recreation, fisheries, non-contact recreation, etc. In the revised system, these categories have been adjusted to account for the influences of the Endangered Species Act. This significantly expands the number of categories in this variable.

The variable that measured the percent of contribution of runoff to the watershed outfall was also revised. In the original system the contribution was based on the percentage of the watershed represented by the right-of-way. The magnitude of the pollutant loading was then based on the ADT for that area. This method of valuation did not take into consideration the fact that not all of the right-of-way is impervious. The revised method considers the impervious area represented by the paved portions of the highway.

Finally, a category for "Best Professional Judgment" (BPJ) was added. This category provides a means to factor in intangible or cultural considerations that are not necessarily related to the more objective variables.

When initial review was completed, the distribution was 29 percent high priority, 16 percent medium priority, and 55 percent low priority. Additional detailed information was then developed for the high priority group including recommended retrofit measures. Retrofit measures could be new BMPs or improvements, such as replacing paved swales with grass channels. Finally, the prioritization scoring system was applied to achieve a final ranking. Under the revised system, many rankings were significantly increased due primarily to Endangered Species Act considerations incorporated into the beneficial use category.

Other Prioritization Approaches

Other examples were found of benefit-cost analysis, fault-tree analysis, and scoring systems used for prioritization by other planning and resource management agencies. For example, the U.S. Military has some well documented guidelines of scoring and benefit-cost analysis that are used to evaluate a variety of military projects. While each of these different systems has merit, they all require subjective judgments with respect to costs, benefits, and valuation.

The cost-benefit method of analysis reduces data to values in dollars, which is used to calculate a ratio of benefits to cost. If the value is greater than 1, the benefits are said to out weigh the cost. In the case of water quality retrofitting, this type of analysis tends to produce negative values. This is clearly illustrated by the California benefit-cost study where the benefit-cost ratios suggest that retrofitting is not cost-effective. Applied in the same way to other watersheds, the results would probably be the same. Therefore, the researchers question the value of using this type of system.

Negative values occur with the benefit-cost approach because the technology available to treat stormwater quality, in many cases, is very expensive and may still fail to produce a water quality to meet a standard of beneficial use. In other words, if a receiving water body had a beneficial use classification of drinking water, and a BMP was not available that would restore the beneficial use, this leads to the benefits of the BMP scoring zero. This score implies that there is no value, which can be misleading.

The scoring method of analysis can also be criticized for using subjective values. That is the scores applied to any given variable in the scoring system can be weighted so as to produce a different outcome. However, in the case of environmental decisions, these will often be influenced by conscious tradeoffs between options. That is, resource allocations must often be made based on the greatest perceived benefit given available resources and knowledge.

In the allocation of limited resources for the management of stormwater quality, the scoring system is preferred over other types of prioritization methods because it maintains the focus on specific defined issues. That is, it allows decision makers to decide whether beneficial use classification should be valued higher than cost, or whether percent of basin pollutant loading is more important than ADT in estimating ultimate pollutant load.

The TNRCC has also adopted guidance for prioritization of TMDL development related to 303(d) listed water bodies. The primary parameters used in assigning priorities in the TNRCC system are:

- designated use is not supported,
- Texas State Water Quality Standards (TSWQS) criteria are exceeded, and
- threatened (designated uses supported and TSWQS criteria met, but values of the maximum contaminant level (MCL) in excess of 50 percent and adjacent activities suggest that water quality could be impaired prior to the four-year cycle of consideration).

STORMWATER QUALITY RETROFIT PRIORITIZATION FOR TxDOT

Because TxDOT is dealing with environmental issues, which embrace environmental and cultural variables that may or may not be present in every case, and because environmental regulations and enforcement continues to change, a rule-based scoring system, patterned after the Washington State Department of Transportation model, seems to offer the greatest utility. Such a system has the greatest potential for satisfying regulators while maintaining a clear picture of the issues involved in the decision process.   The following section proposes and illustrates the application of a scoring system patterned after the one developed by Tetra Tech Inc. for Washington State.

RECOMMENDED PRIORITIZATION PROCESS FOR STORMWATER RETROFITTING

The need for retrofitting of the existing stormwater system will be related to construction and maintenance projects requiring permits and existing highway segments within drainage areas that contribute to a 303(d) listed water body. The large urban districts covered under NPDES Phase I, already have inventories of stormwater outfalls. Depending on the detail included in these inventories, some additional information may be needed in order to implement the retrofit prioritization system outlined here.

In the smaller TxDOT districts, impacted by NPDES Phase II requirements, the necessary data can be collected as a part of the initial inventory. The scoring system being recommended is patterned after the Washington State Department of Transportation System. The reason for suggesting that Texas follow this system closely is that Washington has been using the system since 1995, and it was reviewed and updated in 2001. The fact that the system has been successful enough to be in continuous use and has only required minor adjustments suggests that the system represents a sound conceptual framework that can be calibrated for use in meeting TxDOT's needs. Because of differences in regulatory frameworks, the initial scoring values may have to be adjusted on a district-by-district basis in order to properly recognize regional differences across the state.

Stormwater Outfall Retrofit Prioritization Spreadsheet

A compact disk containing two Microsoft Excel spreadsheets and one Microsoft Word document has been packaged with this report. The "Master Stormwater Outfall Retrofit Prioritization Spreadsheet" contains the necessary data entry categories and scoring application for prioritizing stormwater retrofit projects. The "Example Stormwater Outfall Retrofit Prioritization Spreadsheet" offers a hypothetical application of the Master spreadsheet with mock data used for the model. The Word document titled: "Stormwater Outfall Retrofit Prioritization Spreadsheet User Guide" describes the structure of the worksheets, as well as the data entry requirements for proper application. All documents have been included in two MS Word and Excel versions, 1997 and 2000, to ensure proper operation.

Steps in the Prioritization Process

The discussion of the prioritization procedure is presented as a stepwise process. This process is illustrated by a hypothetical application example contained on the compact disk (CD) included with this report. The CD also contains a master spreadsheet that has been developed to facilitate the scoring.

Step 1. Conduct an Inventory of Stormwater Outfalls on TxDOT ROW as Needed

The inventory of stormwater outfalls should include the following information to facilitate the use of the prioritization process. For urban districts that had Phase I MS4 permit(s) the inventory may already exist with sufficient detail. These inventories should be checked to be sure that all of the data required is included. If data are missing, additional data will have to be developed.

The outfall data that must be collected are:

1. Pipes and culverts with a cross sectional area of 36 inches or greater, unless in an industrial zoned land use. If in an industrial zone land use, pipes and culverts of 24 inches or greater. Required data are:

    - shape,
    - size,
    - material,
    - condition, and
    - available ROW.

    In coastal areas or where 303 (d) listed bodies are directly accessed by a culvert or receiving channel it would be advisable to inventory all pipes regardless of size.

2. Open channels with a cross sectional area greater than 7 sq ft, or 3 sq ft if it is in an industrial zone. Required data are:

    - material,
    - dimensions,
    - shape,
    - condition, and
    - available ROW.

    Any channel that directly discharges into a jurisdictional water body should be included in the inventory.

3. Water quantity or water quality structures shape. Required data are:

    - type of structure: wet pond, detention basin, catch basin, etc.,
    - material,
    - dimensions,
    - condition, and
    - available ROW.

A note should also be made if there is additional right-of-way available at or near the outfall discharge point. TxDOT districts do not generally consider this in Phase I inventories. However, this consideration is important in assessing the feasibility and priority for retrofitting. Researchers recommend districts consider this information routine and add it to their inventories.

Researchers also recommend data be stored in an electronic database that will allow easy query and extraction of data needed for prioritization for retrofitting. The Ft. Worth District has developed a prototype that could be adapted to meet individual district needs. The following considerations will be helpful in developing an outfall database:

- Develop a standardized form for field survey work. The Ft. Worth system, for example, did not include a field form to note the existence of additional ROW. However, because of the relational database format, a field form can be easily added to one of the tables.

- Consider the database update process. Over a period of several years construction and maintenance projects will result in changes to outfalls. The "Dry Weather Screening" process is a good vehicle for updating the database.
- Verify locations using global positioning system (GPS) data. Due to changes in the field, it is the best way to verify locations. Changes in appearance make if very difficult to do verification visually or by a numbering system.

When the initial inventory is complete an initial prioritization should be made based on several key variables:

- Is the receiving body 303(d) listed?
- Is there any water quality mandate or project delay due to stormwater quality?
- Is the receiving body a part of a drinking water supply?
- Does the stormwater discharge directly impact waters that support a threatened or endangered species?
- Are there local or regional concerns that warrant consideration for high priority?
- Are sensitive wetlands, or other environmental or cultural resources potentially or currently impacted by stormwater discharges?
- Is there planned construction that will be impacted by water quality requirements?

This list is intended as a guide for making the first cut evaluation for prioritization of outfalls for stormwater retrofitting. Each district should review this list and add concerns unique to their individual circumstances.

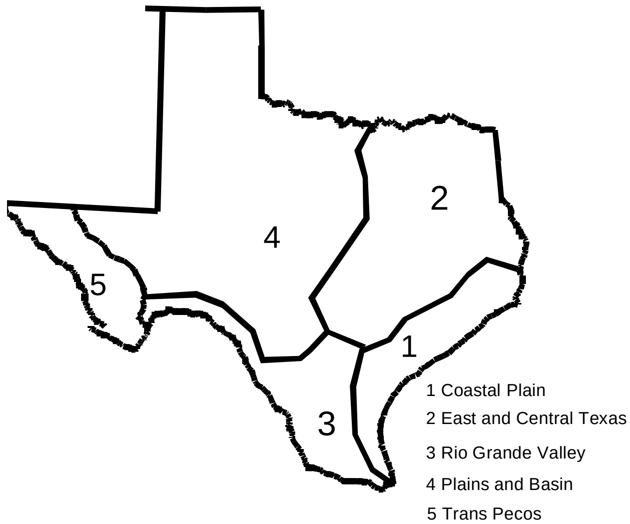
Step 2. Score the Type and Size of the Water Body (A)

The scoring system developed by WSDOT is based on the rationale that pollutants will have the greatest impact on water bodies with the least capacity to dilute the pollutant stream. This is a reasonable assumption, but should be used with caution since it does not account for natural background pollutant levels that may already exist. Several parts of Texas for example, have naturally high concentrations of salts, while others are high in metals. There are also regional landuse activities such as animal feeding operations that may result in unusually high background levels of nutrients related to elevated COD in streams lakes and rivers.

The scoring system in Washington State gave fairly high values to small streams, probably due to fisheries considerations. This was reduced somewhat for Texas to recognize regional differences in the water resources and climatic conditions in the state.

The low values given to the "other wetlands" category recognizes the value of wetlands in improving water quality and mitigating runoff volumes. The higher values for "sensitive wetlands" and "tidal wetlands" reflect the need to protect fisheries and associated habitats.

The recommended regions and scoring system for water body type are shown in Figure 17.



Type of Water Body	Coastal Plain Score *(A)*	East Central Texas Score *(A)*	Rio Grande Valley Score *(A)*	Plains and Basin Score *(A)*	Trans Pecos Score *(A)*
Groundwater Recharge	12	12	10	10	10
Large Perennial Stream	5	5	5	4	4
Small Perennial Stream	9	8	9	7	7
Large Ephemeral Stream	4	4	4	5	5
Small Ephemeral Stream	5	6	6	6	6
Large Lake/Reservoir	4	4	6	6	7
Small Lake/Reservoir	6	6	6	5	5
River	3	3	4	4	4
Sensitive Wetlands	8	8	8	8	8
Other Wetlands	3	3	3	3	3
Tidal Wetlands	8	-	8	-	-

Figure 17. Prioritization Scoring for Water Body Vulnerability.

Step 3. Beneficial Uses of the Receiving Water Body (B)

Ranking of beneficial use considers first whether or not the receiving water body meets the water quality standard for a specific beneficial use. If the water body is already in violation of that use, it receives the highest score. If there is no violation, the assumption is that any stormwater quality improvement would provide prevention rather than contribute to improvement. The assumption is that the existing system is equilibrium and that retrofitting should have a lower priority. Table 12 shows the recommended scoring for this variable.

Table 12. Priority Scoring for Beneficial Use.

Beneficial Use	Score
Impaired Drinking Water Supply	20
Safeguard Drinking Water Supply	18
Impaired Fisheries	16
Safeguard Fisheries	18
Impaired Contact Recreation	16
Safeguard Contact Recreation	14
Non-Contact Recreation (Aesthetics)	4
Flood Protection	4

In the Washington method they added several categories to this group to recognize the impact of the ESA. This makes this category somewhat confusing and unwieldy. For this reason it is recommended that a multiplier be used for each category to adjust for the impact of ESA.

Table 13 shows the multipliers recommended. These multipliers are applied in the example spreadsheet application.

Table 13. Multipliers for Endangered Species Impact Potentials

Proximity of Water Body to Potential ESA Impact	Multiplier
Connected to Water Body with Identified Endangered Species	1.8
Upstream of Water Body with Identified Endangered Species	1.5
Near (in the area of) Identified Endangered Species	1.3
Threatened species present in connected water body	1.2
No endangered species present	1

Step 4. Determine the Quality of the Stormwater (C)

The actual pollutant loading for a specific section of highway depends on the surroundings and numerous environmental variables. The literature has numerous studies that characterize the pollutants in urban and highway runoff, and it has been demonstrated that pollutant loads do have a direct correlation with Average Daily Traffic (ADT). Problematically, constituents will vary considerably due to environmental factors. For example, Bosque County experiences extremely high nutrient contents in some areas due to the presence of animal feeding operations. Solids will also increase in areas with surface aggregate mines.

The original Washington State system used ADT as the measure of pollutant loadings. This recognized the documented connection between ADT and increased pollutants but did not take into account other atmospheric and wind-borne pollutants and the offsite pollutants that enter highway drainage structures from the adjacent ROW. They have since revised the computation to include consideration of highway runoff as a percent of the total watershed, as well as the absolute impervious area contributing runoff. This recognizes that a right-of-way in urban areas may be almost fully paved, while in rural sections, pavement may cover less than half the right-of-way. They also adopted a modifier that recognizes pollutant sources from outside the ROW. The procedure recommended for TxDOT simplifies the Washington State method somewhat by including only one parameter for pollutant loading rather than the two-term calculation used by Washington State. The simplification is possible because the imperviousness factor is considered in the highway discharge computation explained in the next section.

Table 14 shows the recommended scoring to water quality based on ADT.

Table 14. Recommended Scoring to Water Quality Based on ADT.

ADT in Thousands	Score ***(C)***
Less than 10	1
10 to 50	2
50 to 100	3
Greater than 100	4

Step 5. Percent Contributed by Highway to Total Discharge (D)

This step accounts for the area of ROW in relation to the size of the watershed. The recommended calculation method is to take the area of entire state-maintained ROW and subtract the paved area to determine the percent impervious. This can vary significantly among deep urban sections, in large interchanges, or where grass shoulders are present.

To develop the percent contribution for a drainage area, first determine the average ROW width and the amount of pavement. For example, if the ROW has an average width of 300 ft with four main lanes each measuring 12 ft, a 4 ft inside shoulder, and an 8 ft outside shoulder, bounded by frontage roads with 12 ft driving lanes and no paved shoulder, the total pavement width is 120 ft, leaving 180 ft of vegetated area.

Using Table 15 to estimate the runoff coefficients, the composite runoff coefficient for the highway is:

120 ft ∗ 0.99 = 118

180 ft ∗ 0.30 = 54

172/300 = 0.57 composite runoff coefficient

Assuming a total length of 2500 ft and a total basin size of 1876 acres dominated by industrial land uses, the percent of runoff contributed by the highway to this basin would be:

1876 acres - Highway area in acres (2500 ∗ 300/43560) = 1859 acres industrial land use and 17.2 acres of highway.

Therefore:

1859 ∗ 0.70 = 1301

17.2 ∗ 0.57 = 9.80

Percent contribution by the highway ROW is:

9.80/1301 = 0.008 or 0.8%

Table 15. Runoff Coefficients for Use in Retrofit Prioritization Process.

Land Use	Runoff Coefficient
Natural Desert and Desert Shrub	.75
Commercial Districts	.80
Industrial Districts	.70
Subdivision ¼ acre lots	65
Subdivision 1 acre lots	.55
Highway Pavement	.99
Rural Subdivisions 2 acres and more	.30
Unpaved shoulders and medians	.30

The use of a composite runoff coefficient for the highway portion of the drainage basin is important because the coefficient can vary from the low 50s, where considerable vegetated ROW exists, to 0.99 in ultra-urban settings where no vegetation exists. In the example given if the ROW was completely paved, as in a major urban freeway, the drainage contribution would jump from 0.08 percent to 1.3 percent.

Based on the percent contribution to the total runoff for the watershed, the values assigned appear in Table 16. The scoring shown in Table 16 assumes drainage basins for third order streams and above. If smaller basins are used, the scoring should be adjusted to provide greater range. Further calibration may be needed to recognize regional differences in the characteristics of watersheds.

Table 16. Prioritization Scores for Percent of Runoff Contribution.

Runoff Contribution from Highway (percent)	**Score *(D)***
Less than 0.5	1
0.5-1	2
1-2	3
2-5	4
More than 5	5

Step 6. Pollution Benefit to Cost (E)

This scores the potential benefit to the receiving water body to the cost of building the BMP. The scoring system uses an adjustment coefficient to recognize the influence of water body size on the sensitivity to pollution. The type of existing conveyance structure is also considered as part of the cost score based on whether it is impermeable, vegetated, or bare soil. Bare soil and impermeable structures provide the least water quality benefit, and consequently, receive the higher score for retrofit consideration.

The variables considered are:

- land/right-of-way cost (L_c),
- design and construction cost (C_c),
- condition of receiving water body (W_Q),
- type of structure (*S*),
- site condition coefficient (*M*), and
- programmed improvements *(I)*.

The pollution benefit-to-cost score is developed with the following:

Benefit/Cost Score= $M\ (L_c+C+W+S)+I$

The scoring for these variables is as follows:

Land costs, shown in Table 17, are based on the probable cost for additional ROW given the adjacent existing land use. The site condition multiplier (*M*) is 0.5 for average conditions (marine, tidal and large, non-water supply reservoirs) and 1 for sensitive conditions (ground water, large connected wetlands, water supply reservoirs).

Table 17. Land Cost Scores (L_c).

Land Use Type	Score (L_c)
Unavailable	0
Urban	1
Suburban	2
Rural	3
TxDOT ROW	4

Construction costs, in Table 18, are based on data in the Austin district and from the City of Austin. The costs reflect only the annualized costs for design, construction, and maintenance.

Table 18. Scoring BMP Construction Cost (C_c).

BMP Cost	Score
$0-$50,000	5
$50,000-$100,000	4
$100,000-$150,000	3
$150,000-$250,000	2
>$250,000	1

Scoring for water bodies, Table 19, is based on placing the highest priority on cleaning up any impaired water bodies before providing protection to non-impaired waters.

Table 19. Condition of Receiving Water Body (W).

Condition of Receiving Water Body	Score (W)
303(d) or 305 (b) Listed	5
In Edwards Aquifer Recharge	5
Other Sensitive Ground Water	4
Marsh or Estuary	3
Other Water Body	2

The type of existing drainage structure, Table 20, considers the relative imperviousness and whether or not the channel is vegetated. The site condition multiplier (M) is 0.5 for average conditions and 1 for sensitive conditions.

Table 20. Type of Drainage Structure (S).

Type of Drainage Structure	Score (S)
Impervious	4
Unvegetated	3
Vegetated	1

The values for land cost (Lc), construction cost (C), water body condition (W), and drainage structure type (S) are adjusted using a multiplier for average or sensitive conditions. The multiplier (M) is shown in Table 21, Multiplier for Benefit Cost Components.

Table 21. Multiplier for Benefit Cost Components

Relative Sensitivity of Water Body	Multiplier (M)
Normal (no unusual or sensitive conditions)	0.5
Sensitive (environmental, cultural or stakeholder sensitivity)	1

Finally, the benefit cost portion of the prioritization score considers whether or not new construction is planned for the site being considered. The premise is that it will be more cost-effective to accomplish a retrofit project as part of a larger construction contract. This minimizes mobilization and other associated costs. The scoring for programmed improvements (I) is given in Table 22, Scoring for Programmed Improvements (I).

Table 22. Scoring for Programmed Improvements *(I)*.

Programmed Improvement	Score
Improvements are Programmed	3
No Programmed Improvement	0

Step 7. Score the Value of Trade Offs (Best Professional Judgment, BPJ)

The influences that relate to establishment of priorities are not all related to physical environmental variables. The final decision involves making trade offs to meet cultural and social demands on the project. The "Trade Offs" variable adds a scoring component to value these considerations. The means for scoring trade offs is shown in Table 23. This list is not exhaustive and may have to be revised to meet individual circumstances.

Table 23. Scoring Trade Offs for Setting Priorities.

Characteristic	Score No	Score Yes
Is the project in the boundaries of a watershed action plan (TMDL)?	0	4
A cost sharing opportunity exists with another agency.	0	4
Public relations and educational benefits would be accrued from the project.	0	2
There is a permit obligation or litigation requiring a retrofit.	0	4
Other financial support is available.	0	2

Step 8. Considerations of Site Specific Concern (SSC)

For any situation, unusual circumstances would merit consideration of higher priority. These would usually be intangible or site based considerations that are difficult to quantify in the other categories of the prioritization scoring system. For example, a site may be particularly scenic or have high public recognition as a landmark. In these instances additional points, up to 6, may be awarded. In the prioritization example problem that follows, several conditions are used to illustrate how these points may be applied.

Prioritization Example

The prioritization example is hypothetical in order to illustrate a range of scoring. There are 21 sites included in the example, which represent those sites that are considered the highest priority after the initial review of all outfalls in the inventory area. The sites are shown in Table 24, Prioritization Sites Example.

Each site was evaluated and scored for the prioritization variables described in the previous section.

The relationship between the variables is as follows:

$$\text{Priority} = A+B+(C_1 * D_1)+(C_1 * D_2)+ (M (L_c+C+W+S)+I)+F1+F2+F3+F4+F5+SSC$$

To facilitate the calculation of the prioritization score a spreadsheet was developed to do the calculations. This allows users to simply fill in the information from the outfall inventory and select the appropriate scoring categories from the tables provided. The spread sheet uses a series of look-up tables to establish the scoring values based on the categories input. The user applies any multipliers and calculates the scores as the data are entered.

Table 24. Prioritization Sites, Example.

Location	Priority Score	Watershed	Type of Water Body
Open Channels			
US 191 3	**42**	Harms Creek	Harms Creek is a small intermittent creek
US 191 7	**51**	Harms Creek	
US 191 11	**77**	Crystal Creek	Crystal Creek is a perennial, spring fed stream over a rock bed with clear water and direct recharge
US 22 2	**62**	Mud Creek	Mud creek is a nutrient impaired tributary of the Jordan River
US 22 9	**55**	Mud Creek	
IH 11 5	**51**	Jordan River	The Jordan River is a tributary of the Trinity River
IH 11 8	**42**	Jordan River	
IH 11 10	**94**	Crystal Creek	
FM 2	**39**	Teal Lake	Teal Lake is a reservoir fed by Nomad Creek
FM 2	**41**	Nomad Creek	
Pipes and Culverts			
US 191 1	**51**	Harms Creek	Harms Creek is a small intermittent creek
US 191 2	**51**	Harms Creek	
US 191 4	**77**	Crystal Creek	Crystal Creek is a perennial, spring fed stream over a rock bed with clear water and direct recharge
US 22 3	**62**	Mud Creek	Mud creek is a nutrient impaired tributary of the Jordan River
US 22 5	**55**	Mud Creek	
IH 11 4	**54**	Jordan River	The Jordan River is a tributary of the Trinity River
IH 11 7	**42**	Jordan River	
IH 11 9	**94**	Crystal Creek	
Existing Water Quality Structures			
US 191 2	**41**	Harms Creek	Harms Creek is a small intermittent creek
IH 11 6	**100**	Crystal Creek	Crystal Creek is a perennial, spring fed stream over a rock bed with clear water and direct recharge

TxDOT RESOURCES FOR RETROFITTING

The overview to this point has focused on the technologies available for retrofitting stormwater outfalls to improve water quality, the performance of these technologies, and how TxDOT might prioritize the allocation of resources for retrofitting. In reviewing the technologies available for improving stormwater quality, it is very clear that the most cost-effective technologies are extended detention basins or other surface-based technologies, such as wet ponds, wetlands, and bioretention. All of these require a significant amount of land surface, which is not usually available in heavily developed urban areas. On the other hand, the freeway systems of most urban centers include numerous diamond and direct connect interchanges, park and ride structures, and maintenance facilities. Many of these represent significant land areas that could be utilized for installing retrofit retention structures, wetlands, or bioretention areas.

The researchers inventoried along the Loop 610 Corridor and IH-10 corridor inside Loop 610 in the Houston District in order to see if utilizing these structures was indeed a potential. The purpose of the inventory was to determine:

1. If there were significant land areas in the major interchanges that could be utilized for constructing stormwater quality detention ponds or other stormwater quality structures.

2. If there was sufficient drainage area upstream of the interchange to warrant installation of a water quality structure.

Figures 18, 19, 20, and 21 show four sites identified as having areas of two or more surface acres that could be used to develop surface-based BMPs. The sites at US 59 and 610 West, downtown Houston IH 10 and US 59, the park and ride at IH 610 Southwest, and the IH 45 and IH 10 interchanges are significantly larger.

Finding the actual drainage area contributing water to each of these interchanges was not possible. Some of the newer work at IH 10 and IH 45 had available plan work, and some estimates were possible since drainage areas were found on the plans. The other sites were of an age that no plan work was readily available that would allow any determination of the drainage area contributing to each individual site. However, it was possible to determine that all of these sites lie within watersheds that may be impacted by a future TMDL; therefore, these land areas may prove to be a valuable resource in the future.

Figure 18. SH 59 at IH-10 Downtown Stockpile and Dump Area Close to Enron Field.
Approximately 0.2 of a mile of available space beneath elevated section of SH 59.

Figure 19. Loop 610 at SH 59 S.
Approximately 1 acre of available space currently under mowing contract.

Figure 20. SH 59N at Beltway 8.
Wet pond created simply to take area out of mowing. (Not in our survey area.)

Figure 21. Loop 610 at SH 59 S.
Additional open space available at interchange. Approximately 1 acre.

CONCLUSIONS

PROBLEM MAGNITUDE AND PLANNING NEED

The requirement to retrofit the drainage infrastructure of Texas' highway system to improve water quality will continue to escalate over the next decade. The capital requirement to install new structures in urban areas will represent a significant allocation of resources. More importantly, it will require a significant new commitment of resources for maintenance. Depending on the kind of structure and the area served, maintenance costs, including the replacement of filter media, cleaning, and servicing after every storm event will run from $2,300 per year for an extended detention basin, to around $23,000 per year for a large sand filter structure.

By themselves, these numbers are not necessarily unreasonable, but a district like Ft. Worth has identified some 460 outfalls in its joint permits with the Cities of Ft. Worth and Arlington. If only one third of these outfalls (152) required the installation of permanent treatment structures and assuming a mean annual maintenance of $12,000 per structure, this would represent a budgetary commitment of $1,836,000 annually for maintenance alone. This can become a significant burden on already limited resources. For this reason, it is vital that TxDOT adopt a planning strategy that will take the need for water quality structures into account early in the planning process so sufficient ROW can be acquired to minimize the need for more expensive small footprint type structures.

AVAILABLE TECHNOLOGIES TO IMPROVE STORMWATER QUALITY

There are numerous types of BMPs that have been developed to improve stormwater quality, both generic and proprietary. This study looked at a full range of options. Based on the information available in the literature with respect to water quality performance, space required, and overall cost for installation and maintenance, it appears that the variety and performance of non-proprietary technologies is sufficient. Therefore, proprietary devices as described in the preceding section, should only be used in unique or very unusual circumstances. The guidance section provides information on how to select the most appropriate type of BMP for various conditions.

One of the current disadvantages of using all non-proprietary BMPs is that each one has to be designed for site-specific conditions. This is generally only a handicap when space and time are limited. This could be addressed by developing standard details for non-proprietary modular stormwater BMPs. This is essentially the selling point of most commercially marketed devices.

TxDOT'S STRUCTURES WITH POTENTIAL FOR RETROFIT

In intensively developed urban centers, the cost of retrofitting for water quality will be extremely high if structures must be installed underground. In all likelihood, some underground structures will be required. However, as demonstrated in the very limited review of the Houston IH 610 and IH 10 corridors, many of these urban freeway systems have interchanges that represent significant land resources that could be employed to develop permanent stormwater quality structures. These resources need to be inventoried, preserved, and prioritized for development.

Retrofitting in Flat Terrain

Many of Texas' major cities are built on very flat terrain. This situation can be further complicated if there is a high water table. In these situations, the only economical way to treat stormwater is in surface-based structures because of the lack of head to move the water through the structure. Most proprietary technologies, particularly those that operate on centrifugal principles, will not operate effectively. The only retrofit option then will be to go underground, which will require the use of pumps to move the water out of the treatment chamber and on to the release point. For this reason, cities and districts in the coastal regions of the state should begin planning immediately to conserve and/or acquire ROW that can be used for surface treatment of stormwater.

Lack of Documented Operational and Maintenance Costs

Schueler (1987), Shoemaker et al. (2000), and Young et al. (1995) provided some cost information in their publications, but this was very general and did not include much information about the proprietary technologies. Researchers contacted by letter, phone, and e-mail, all manufacturers and marketers of proprietary technologies listed in this report and requested cost information about installation and maintenance. Not a single manufacturer replied. In addition, researchers tried contacting locations with installations, but this attempt was unsuccessful in obtaining cost data.

The California Stormwater study is being completed about the same time as this report. Our research team understands that this report has very detailed cost information on both construction and maintenance costs for a variety of BMPs, both generic and proprietary. This information should be available around the beginning of the new calendar year. However, our discussions with individuals involved in this work tend to support the overall conclusion that simple, non-proprietary technologies are the most cost-effective overall.

Lack of Documented Performance Values

The most troubling finding to this point is the lack of any significant data on the hydraulic performance or impact of the in-line stormwater BMPs. This is a critical consideration when retrofitting an existing drainage system. Even when a BMP is installed off-line where the stormwater is diverted into the BMP out of the direct line of flow, there is some loss of energy that must be taken into account. The absence of good hydraulic performance data creates a potential for unwanted outcomes, such as traffic hazards and property damage caused by flooding.

Water Quality Performance of Retrofit BMPs

Water quality performance is reasonably documented for most all of the generic and non-proprietary BMPs. In this regard, it is important to understand that performance is measured as the annual mean mass of a pollutant removed. The documentation of all the monitoring studies in the literature demonstrates that single event performance of BMPs varies significantly. This cannot be fully explained, but it appears to be related to variables such as total pollutant load of the event, period between precipitation events, ADT prior to and during an event, climatic variations, and the resident wildlife population.

There are national efforts underway to better understand the performance of the full range of BMPs used for stormwater quality improvement. However, there are sufficient data at this point to provide enough separation between types to make informed decisions about the most appropriate BMP for a particular situation. The guidance section of this report, Evaluating Drainage Structures for Retrofit, provides methods for making selections.

RECOMMENDATIONS

IMPLEMENTATION

This study includes guidance for selecting an appropriate structural retrofit strategy for improving stormwater quality and for prioritizing the allocation of resources for retrofitting. These procedures should be included in the appropriate on-line design manual. This will compliment the recommended procedures for estimating pollutant loadings and structure sizing provided in report 1837-1, Design Methods, Selection, and Cost-Effectiveness of Stormwater Quality Structures. It will also provide background information needed for training TxDOT staff.

Performance of Stormwater Quality BMPs

Volumes of research and monitoring have been directed to water quality performance of numerous types of BMPs. The major gap in the information has been in documentation of the performance of proprietary BMPs. However, this past year, the Washington Department of Transportation in cooperation with the Environmental Technology Evaluation Center of Washington D.C. initiated a study to perform side-by-side testing of these technologies. This study will fill the gap in water quality performance information for this group of BMPs.

The California Department of Transportation will also publish a report later this year that will be one of the most detailed evaluations of multiple stormwater quality technologies ever undertaken. This study will include not only water quality performance data but also detailed cost information on construction and maintenance.

To this extent, the researchers recommend TxDOT continue to follow this work and update the performance data provided in this report.

There has also been some question about the need for further monitoring and testing of BMPs for water quality performance. Based on extensive review of the literature and as evidenced by the data tables provided with the description of each BMP in this report, it appears that there is a need to understand the causes of the considerable difference in event-to-event performance. This is particularly true since the Texas Natural Resource Conservation Commission has yet to accept a full range of BMP technologies in the Texas Pollutant Discharge Elimination System, which will replace the NPDES program when EPA releases regulatory control to the state.

Because the issue of BMP water quality performance has national significance, TTI researchers recommend TxDOT consider the development of a pooled-fund study aimed at developing a better understanding of performance properties of various BMPs. This study could build on the experiences of California and Washington and provide much needed baseline information to get a wider range of BMPs approved by TNRCC.

Develop Modular Details for Generic Stormwater Quality BMPs

As noted in the discussion of generic versus proprietary BMPs, the primary deterrent to the use of non-proprietary technologies is the lack of modular design standards based on pollutant loadings and stormwater volume. Many of the small footprint generic BMP technologies can be developed around precast concrete units; this includes generic technologies for trapping floatables and hydrocarbons. Researchers recommend TxDOT consider developing a series of standardized, modular details for small footprint generic BMPs that can be used when surface basins and ponds will not fit the site. For example, a typical Alexandria Dry Vault Filter, as shown in Figure 9, can easily be made up of precast segmental units. Based on the treatment volume needed for a particular situation, the capacity of each chamber can be increased or decreased by adding or subtracting precast units. Almost all of the filter and vault type BMPs work for this type of standardization.

Hydraulic Properties Study of Key Technologies

The most significant weakness in all of the BMP performance literature, particularly with respect to retrofitting, is the lack of research and information on hydraulic performance. Hydraulic performance is a critical consideration in retrofitting an existing drainage system. In general, the issue is resolved by placing any new BMP off-line. That is, the water is diverted from the main conveyance channel into a treatment structure, allowing any excess volume to bypass the structure. This assumes that there is no energy loss in the upstream diversion or the downstream discharge point. This is not a good assumption, particularly in areas of very flat terrain where any loss of head can lead to hazardous driving conditions and flooding.

There needs to be an effort to evaluate the hydraulic performance of selected BMP technologies so that the addition of stormwater quality treatment can be added to existing systems without reducing the performance of the existing drainage system.

The problem of hydraulic performance is also a matter of national concern. TxDOT may wish to consider leading a pooled-fund study in this area or adopting the hydraulic performance criteria to the suggested pooled fund aimed at a better understanding of water quality performance. This may indeed be the better approach because hydraulic performances under different conditions will likely impact water quality performance.

Development of Field-based Cost Data

Cost information on construction and maintenance is very limited. Manufacturers of proprietary BMPs appear very reluctant to address the issue of cost. While there have been some efforts to develop cost related to construction and maintenance, costs are virtually undocumented. This is a matter of considerable concern. An effort to look at TxDOT and City of Austin expenditures on BMP maintenance was helpful, but most of the information was related to hazardous materials traps and large filter structures in the Austin District. This allowed the projection of maintenance costs for maintaining surface structures, but it has not been possible to develop cost information on proprietary technologies or other underground, small footprint technologies. This is important because long-term maintenance of any underground installation will likely be significantly higher, which raises long-term sustainability questions. For this reason, the researchers recommend TxDOT consider an effort to document the long-term costs associated with the various BMPs.

Prioritization Process

The prioritization process outlined in this report is yet untried. While it closely follows the basic process developed by the Washington State Department of Transportation, researchers suggest that TxDOT calibrate this process in order to meet regional differences in Texas, probably on a district-by-district basis. The original project proposal has included an option for a second year in which this type of calibration could be done. Since TNRCC will likely begin developing TMDLs that will impact TxDOT, and there will be a need to allocate resources for stormwater quality retrofit activities, TTI researchers support implementing a pilot project that would calibrate this system in order to best meet TxDOT's needs.

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APPENDIX
PROPRIETARY TECHNOLOGIES

As part of the review of available technology, researchers contacted companies dealing in proprietary stormwater treatment technologies. Twelve products were identified in this phase of the research. They are:

- Downstream Defender (Storm King) – Dynamic Separator
- V2B1 – Dynamic Separator
- Vortechs – Dynamic Separator
- Stormceptor – Dynamic Separator
- Hydrasep – Gravity Separator
- CDS Gross Pollutant Traps – Dynamic Separator
- BaySaver – Gravity Separator
- Gullywasher – Filtration System
- AquaShield – Filtration System
- StormFilter – Filtration System
- StormTreat – Bio-gravity Filtration System
- Infiltrator Chamber – Infiltration System

Of this group, five technologies use dynamic separation; two use gravity separation; four use filtration; and one uses infiltration to achieve reduction in transported constituents. Most focus on removal of total suspended solids. Some are oriented more toward oil and grease removal. General details on these technologies are presented in Table 25.

Table 25. Proprietary Technologies.

Trade Name	Manufacturer	Construction and Physical Properties	Operational Characteristics	Operational Flow Rate	Water Quality Performance Claimed	Other Comments
Storm King	H.I.L. Technologies Inc. www.hil-tech.com. Mfg can be contacted for questions about retrofit applications.	Custom designed hi-grade stainless steel set in cast-in-place reinforced concrete above or below grade	Dynamic separator Online or offline	Design flow rates from 0.75 cfs to 13 cfs. Max operating flow rate 25 cfs.	TSS 84% at design flow rate (16gpm/cubic foot volume) TSS 50-60% @ max operating flow rate. Traps floatables	Recommended system design sent upon request (end-user to provide flow rate, performance required, and water quality of influent). Can be used for disinfection. Req's 1" fall thru structure (3" for mult. inlets). Can fit a variety of pipe types & sizes.
V2B1	Environment 21, LLC www.env21.com	2 circular pre-cast concrete units constructed above or below grade	Dynamic separator Online or offline	Treatment flow rates from 1 cfs to 7 cfs. Max operating flow rate to 32 cfs	TSS 80% at treatment flowrate. Traps floatables	Sized according to recurrence interval and flow rate info for storm drain design. Target 80% removal of TSS. Can be used for disinfection.
Vortechs	Vortechnics, Inc. www.vortechnics.com	Single unit, 3-chamber tank (grit, oil, flow control)	Dynamic separator Online or offline	Design flow rates from 1.6 to 25 cfs	Net annual TSS 80%. Traps floatables	Unit size based on design flow rate.
Stormceptor	Hydro Conduit http://www.rinkermaterials.com/stormceptor/	Single chamber sub-grade unit. Three models available: inline, series, and submerged	Dynamic separator Online or offline	Not specified, determined during design	TSS 80%, Oil 97% Traps floatables	Undersized system does not work well at all.
Hydrasep	Hydrasep www.hydrasep.com	Underground tank 38" to 111" diameter Sized for 2-yr storm	Gravity separator in-line	Up to 643 gpm Special designs to 10,000 gpm	99.9% oil removal. TSS not reported and not targeted	Principally designed for oil removal.
CDS Gross Pollutant Traps	CDS Technologies www.cdstech.com	Small units comprise single fiberglass tanks Large units are concrete, may be cast-in-place	Dynamic separator Online or offline	Treatment flow rates from 1 cfs to 360 cfs	O&G 80%-90% removal TSS 50% to 70%, depending on size distribution Traps floatables	
BaySaver	BaySaver, Inc. www.baysaver.com	Two cylindrical pre-cast or cast-in-place units	Gravity separator Online or offline	Treatment flow rates from 1 cfs to 3.8 cfs. Design flows to 50 cfs.	TSS removal of about 80% from limited tests	
Gullywasher	Aqua Treatment Systems, Inc. www.gullywasher.com	Below grade vault	Filtration system	Treatment flow rates of 0.8 cfs and 3.0 cfs Traps oil and grease and floatables	No data	

Table 25. Proprietary Technologies (continued).

AquaShield CF-200 Series SD-100	Remedial Solutions, Inc. www.remedialsolutions.com	Separator plus filter bed, below grade	Proprietary filtration filter tank online or offline	Separator alone to 34 cfs; combined system peak flow rates of 14.5 cfs with flows exceeding 20% of peak to bypass filtration bed.	TSS 80% 90%-95% oil and grease	Filter life not given.
StormFilter	Stormwater Mgmt, Inc. www.stormwatermgt.com	Cast-in-place or precast, concrete filter vault. May have floatables trap prior to filter vault	Cartridge filtration inline or offline High flow bypass	Varies w/ design #	TSS > 95%	Custom-designed for each application.
StormTreat	Storm Treat Systems Inc. www.stormtreat.com/home.htm Can be contacted	Pre-fabricated wetland system. Tank portion is below grade.	Multi-stage filter, constructed wetland	One or two units per acre depending on design requirements	TSS 99%* Fecal Coliform 97% COD 82% TKN 77% O&G 90% Lead 77% Chromium 98% Phosphorous 90% Zinc 90%	Targets treatment of first flush.
Infiltrator Chamber	Infiltrator Systems Inc. www.infiltratorsystems.com case studies are given $	34" x 75" x 12" tall chambers store up to 122 gal (16.3 cf) of runoff	Underground Infiltration Offline	No data	No data	Designed for septic-system leach fields. Possible use for storm water infiltration.