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16. Abstract

Implementation of the National Pollutant Discharge Elimination System (NPDES) and Texas Pollutant Discharge Elimination System (TPDES) requires that the Texas Department of Transportation (TxDOT) adopt a variety of stormwater quality measures to meet Clean Water Act, Section 401 requirements. The permanent water quality structures that have been required in the Austin, Edwards Aquifer Zone are relatively expensive when compared to some other options. TxDOT wished to examine a variety of options for meeting stormwater quality requirements and to develop a cost comparison index that could be used to identify the most cost effective type of structure.

This report concludes that a number of stormwater quality structures will meet TxDOT's needs. Furthermore, the research addresses the question of cost effectiveness by examining the lifecycle cost in relation to the structures' efficiency in removing TSS, the primary index pollutant in storm water. The research suggested that a cost index of this kind was only meaningful if special site considerations and land costs were ignored. Therefore, the most cost-effective alternative for a specific site will likely be determined by considerations other than design, construction, and maintenance costs. The report further suggests ways that TxDOT can better utilize the roadside to improve water quality, thereby reducing the cost of end of channel structures. It also provides design methods for estimating pollutant loads and sizing selected structures.

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DESIGN METHODS, SELECTION, AND COST-EFFECTIVENESS OF STORMWATER QUALITY STRUCTURES

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The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation (TxDOT) or the Federal Highway Administration (FHWA). This report does not constitute a standard, specification, or regulation.

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design, or composition of matter, or any new useful improvement thereof, or any variety of plant, which is or may be patentable under the patent laws of the United States of America or any foreign country.

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INTRODUCTION

In response to both federal and state requirements, TxDOT has been required to develop a variety of permanent structures designed to improve the quality of stormwater being discharged into adjacent water bodies. In Texas the greatest concentration of permanent structures is in the Austin District, which straddles the Edwards Aquifer. Most of the structures installed on TxDOT rights-of-way in the Austin District are complex structures and have proved very costly to construct and maintain.

Under Phase II of the National Pollutant Discharge Elimination System (NPDES), Municipal Separate Storm Sewer System (MS4), most TxDOT districts will be required to include stormwater quality Best Management Practices (BMPs) in new construction and to evaluate retrofitting existing transportation facilities with BMPs. For this reason, TxDOT initiated a study to determine the performance difference between higher cost, "high-end" BMPs and lower cost, "low-end" technologies.

Specific objectives of this literature review are:

- Identify new or emerging technologies with the potential to lower the life-cycle cost of meeting stormwater discharge quality requirements.
- Develop a taxonomy of "low-end/high-end" BMPs for meeting stormwater quality requirements.
- Develop a table of BMP performance based on the percent removal of index pollutants.
- Develop a table of average life-cycle costs for design, construction, and maintenance of stormwater quality BMPs.
- Develop a cost-effectiveness index relating BMP performance to life-cycle cost.

As conceived, project researchers anticipated that the literature review would provide the data needed to satisfy the objectives of this study. This proved not to be the case as demonstrated in the discussion that follows.

DEFINITIONS

Best Management Practices

The Code of Federal Regulations (CFR) defines Best Management Practices as:

> "…a means of practice or combination of practices that is determined by a state (or designated area-wide planning agency) after problem assessment, examination of alternative practices, and appropriate public participation to be the most effective practicable (including

technological, economic, and institutional considerations) means of preventing or reducing the amount of pollution generated by non-point sources to a level compatible with water quality goals (Title 40, 130.2)."

This definition recognizes cost as a key factor in overall effectiveness of any BMP. Further, the definition infers that the most effective BMP accomplishes maximum pollutant removal efficiency at minimal cost.

Non-Structural BMPs

Non-structural BMPs include a range of pollution prevention, education, institutional, management, and development practices designed to limit the conversion of rainfall to runoff and to prevent pollutants from entering runoff at the source of runoff generation (US EPA 1999). Non-structural BMPs do not involve fixed, permanent facilities. Practices include activities such as street sweeping, which reduces opportunities for pollutants to make contact with runoff.

Schueler, Barrett, and others have considered non-structural BMPs in some studies. They are an integral part of any stormwater management plan, but are not investigated further in this study.

Structural BMPs

Structural BMPs are used to treat stormwater at either the point of generation or the point of discharge to either the storm sewer system or to receiving waters. Structural BMPs require a substantial capital investment for land and other structural improvements. In addition they require a long-term commitment to maintenance.

Structural BMPs comprise a wide variety of methods that range from simple vegetated strips to complex multi-stage structures. Because the pollutant removal methods and structures vary significantly, the terminology used to describe structural BMPs is often inconsistent.

The American Society of Civil Engineers (ASCE) is in the process of developing a comprehensive database on BMP performance under a cooperative agreement with the United States Environmental Protection Agency (EPA). At this time, several phases of the project have been completed, including the master BMP bibliography, which aided the compilation of the National Stormwater BMP Database intended to provide nationwide urban stormwater runoff BMP effectiveness information. The classifications of BMPs in this document will aid in standardizing stormwater BMP terminology. The ASCE/EPA classification of stormwater quality BMPs is shown in Table 1.

Table 1. ASCE Classification of Stormwater Quality BMPs.

Structural BMPs	Infiltration	Infiltration Trench/Basin
		Porous Pavement
	Filtration	Vegetated Filter Strips/Buffers
		Grassed Swales
		Sand Filters/Filtration Basins
	Detention	Dry and Wet Ponds
		Wetlands
		Oil/Grit Separators/Catch Basins
Non-Structural BMPs	Planning/Land Use	
	Post-Development	Urban Housekeeping
		Lawn Maintenance
		Street Sweeping
		Road Deicing
		Road Maintenance

Source: National Stormwater BMP Database, ASCE

While the ASCE classification system appears simple it is important to remember that these structures vary significantly in size and complexity. In some cases, multiple technologies are combined in a single structure, or structures may be combined with hazardous materials traps or flood control structures.

Low-End BMP

The term "low-end BMP" is not a common term in reviewed literature. TxDOT used this term to mean structures or practices that have lower life-cycle costs than the more complex and costly stormwater quality structures. For the purpose of this study, the category of "low-end" includes BMPs that are based on simple earth detention structures using sand filtration or detention to remove pollutants or other simple technologies such as vegetated filter belts, grassed swales, and channels.

STRUCTURAL BMP TYPES AND OPERATION

No single BMP, structural or non-structural, removes all pollutants common in highway runoff. While detention structures generally remove pollutants like total suspended solids (TSS) and can reduce a portion of nutrients and heavy metals, housekeeping activities have been demonstrated to be more effective in controlling some pollutants such as iron and zinc.

Removal of runoff-borne pollutants may be accomplished by infiltration, filtration, and detention. EPA (1999) defines these as follows:

> ***Infiltration*** – water is captured, enters the soil, and percolates into the ground. Pollutants are captured in the soil medium or transported and diluted in any saturated layer(s) below.
>
> ***Filtration*** – water is filtered through media such as vegetation, sand, gravel, peat, or compost to remove stormwater pollutants.

Detention – water is detained and released to the receiving stream or storm sewer through a controlled outlet over a specified time period. Removal of the pollutants is by sedimentation.

Many structural BMP designs use all these basic processes. For example, a basin that has a sand bottom and drainage field detains water while it is moving through the filter media. The detention allows sedimentation of heavy particulate before the water is filtered.

In some regions of Texas, geological conditions, such as Karst topography or sandy soils overlying major aquifers are such that infiltration is not appropriate. In these situations, there is a danger that infiltration BMPs could contribute to groundwater pollution. The Edwards Aquifer is particularly vulnerable to this type of pollution. Therefore, infiltration is not a viable tool in those areas that overlie the Edwards.

The focus of this study is the performance of permanent, structural stormwater quality BMPs that have practical use in highway transportation applications. These generally include:

- **Filter Strips** (buffer strips) – vegetated sections of land that have moderate slopes designed to accept runoff as overland sheet flow. Filter strips achieve pollutant removal through velocity reduction, filtration by vegetation, and infiltration.
- **Grassed Swales** – vegetated channels that convey stormwater and remove pollutants by filtration through grass and infiltration into site soils.
- **Sand Filters** – use sand to remove sediment and pollutants from first flush runoff. Sand filters are well suited for space-limited areas.
- **Extended Dry Detention Ponds** (basins) – depressed basins that temporarily store a portion of stormwater runoff following a storm event. These facilities do not have a permanent water pool.

BMP types that have application for TxDOT but are considered “high-end” BMPs are:

- **Wet Ponds** (basins) – an in-line permanent pool or pond which removes pollutants through settling and biological activity. Wet ponds hold a permanent pool of water between storm events. These are not generally considered appropriate for TxDOT applications because of liability issues associated with standing water.
- **Constructed Wetlands** – similar to wet ponds but a major portion of the surface area contains wetland vegetation. Pollutant removal is accomplished through evaporation, sedimentation, adsorption, and/or filtration as well as biological processes including microbial decomposition and plant uptake for removal of nutrients. These types of facilities are practical if favorable site hydrology and sufficient space is available to develop a sustainable plant/soil community. Wetlands perform best when linked with upstream sediment control structures.

POLLUTANTS IN HIGHWAY RUNOFF

Highway runoff pollutants generally come from three sources:

- vehicular contributions,
- atmospheric deposition, and
- road bed material.

A variety of constituents including nutrients, organics, oil and grease, and heavy metals come from these sources (Irish et al. 1995). Pollutants can be found in both soluble and particulate forms and may impact receiving water differently depending on the form present.

EPA's Nationwide Urban Runoff Program (NURP), the Federal Highway Administration's manual, Evaluation and Management of Highway Runoff Water Quality, and others focused on the following pollutants:

- total suspended solids (TSS),
- biochemical oxygen demand (BOD),
- chemical oxygen demand (COD),
- total phosphorus (TP),
- soluble phosphorus (SP),
- total Kjeldahl nitrogen (TKN),
- nitrate + nitrite (N),
- total copper (Cu),
- total lead (Pb), and
- total zinc (Zn).

EPA includes all the above constituents as potential stormwater pollutants from highways. However, many constituents are either not present or have such low concentrations that they cannot be deemed significant (Irish et al. 1995).

Texas agencies and governmental units that have jurisdiction over regional water resources have stormwater quality monitoring programs related to their specific missions. The City of Austin monitors 11 pollutants, while the Lower Colorado River Authority (LCRA) measures only three pollutants: TSS, total phosphorus, and oil and grease. Texas Natural Resource Conservation Commission's (TNRCC) publication, "Complying with the Edwards Aquifer Rules: Technical Guidance on Best Management Practices," suggests TSS as the primary indicator of water quality (Barrett 1999). The pollutants monitored by the City of Austin, LCRA, and TNRCC are listed in Table 2.

Table 2. Stormwater Pollutants Monitored by Other Agencies.

City of Austin	LCRA	TNRCC
Total Suspended Solids (TSS)	Total Suspended Solids (TSS)	Total Suspended Solids (TSS)
Total Phosphorus (TP)	Total Phosphorus (TP)	Oil and Grease
Total Nitrogen (TN)	Oil and Grease	Dissolved Oxygen
Chemical Oxygen Demand (COD)		Total Dissolved Solids
Biochemical Oxygen Demand (BOD)		Metals
Total Lead (Pb)		Organics (PCB)
Fecal Coliform (FC)		Fecal Coliform (may change soon to E.Coli and primary)
Fecal Streptococci (FS)		Chloride
Total Organic Carbon (TOC)		Ph
Total Cadmium (Cd)		Sulfate
Total Zinc (Zn)		

TSS is the simplest of the pollutants to monitor and test. Some researchers have demonstrated a significant relationship between TSS and other common stormwater pollutants. Based on these findings some have suggested that by reducing TSS there will be a corresponding reduction in other target pollutants. However, not all researchers agree with this conclusion. Work by Sansalone and others (1993) shows the relationship of TSS to other constituents is highly related to particle size distribution and other TSS variables. They argue that without specific knowledge of these variables it is not possible to relate the removal of other constituents to reductions in TSS. Therefore, it remains unclear whether simply monitoring TSS as the primary index pollutant will be widely accepted.

In recent studies conducted for TxDOT around the Austin, Texas, area, several pollutants, including TSS, COD, TOC, nitrate, TKN, zinc, and iron, were monitored (Keblin et al. 1997). In contrast, Young et al. (1996) recommend that any highway runoff-monitoring program include dissolved oxygen (DO), TSS, total phosphorus, and metals.

Researchers can in large measure attribute the variation in these recommendations to differing objectives of the studies. For example, Young's recommendation for monitoring DO was related to unobstructed flow of runoff into receiving water bodies. However, in this case, monitoring DO would serve little purpose since the design of the structures being studied would have little significant impact on DO. The same is true for other constituents like COD, BOD, fecal coliform, and fecal streptococci.

Based on the information in the literature and on those permanent BMPs being considered with the ability to significantly reduce target constituents, the following list of index pollutants was selected:

- total suspended solids,
- total phosphorus,
- total Kjeldahl nitrogen,
- lead,
- zinc, and
- oil and grease.

The performance achieved in removing these constituents will serve as the basis for developing the performance to cost index and for developing data for comparison of BMPs. This list of pollutants is consistent with those monitored previously by TxDOT in the Austin District and by other state agencies.

NEW STORMWATER QUALITY BMPS OR TECHNOLOGIES

No new or innovative technologies for meeting stormwater quality requirements were identified. Numerous proprietary devices are being marketed for improvement of stormwater quality, but these are relatively expensive in terms of installation and maintenance and have limited treatment capacity. While these devices may have application in some tight urban situations and do merit further evaluation, they are beyond the scope and intent of the current study.

A review of research-in-progress found several studies that are addressing issues of improving stormwater quality. However, they are all focused on the use of existing structural technologies. Furthermore, current field practice, both in Texas and nationally, tends to focus on site-specific facilities and do not include cost-effectiveness data. Agricultural and trade publications, as well as international literature, offered little that would translate to transportation practice.

This finding is consistent with other studies examining stormwater quality improvement. Most significantly, EPA (1999) reports, "There is still a great need for focused research in certain areas, particularly for newer and innovative structural BMP types…." EPA's finding underscores the fact that solving the stormwater quality equation will require a continuing commitment to research and development.

STORMWATER DATA AND EVALUATION

Numerous stormwater mitigation BMP performance studies have been conducted. These studies were filtered to determine which of them contained reliable information that could be used to meet the objectives of the current study. Therefore, researchers systematically evaluated sources for their applicability using the following criteria:

- studies that included pollutant removal efficiency data and/or cost-effectiveness data;
- federal and state (Texas) regulatory publications (EPA, FHWA, TNRCC, LCRA, etc.) that contained standards, approved methods, data, or other evaluative techniques that applied to improving stormwater quality;
- permanent structural BMP monitoring research conducted in regions of Texas to improve stormwater quality; and
- monitoring research conducted for TxDOT on permanent structural BMPs.

In addition to the use of the above criteria to focus the literature search, sources were further limited based on their timeliness, age, and/or the geographic area in which the research was conducted. For instance, certain studies included monitoring criteria and data but were not usable because the research was conducted in areas of significantly differing climatic and resource conditions. In these cases, it was possible to learn something about logistics and general performance but, due to environmental variations, application of results from these studies could be very misleading if conclusions about performance and costs were transferred to Texas.

SUMMARY OF LITERATURE ON POLLUTANT REMOVAL EFFICIENCIES

EPA's "Preliminary Data Summary of Urban Storm Water Best Management Practices," EPA-821-R-99-012, is a current compilation of existing stormwater information and data. This report describes structural and non-structural BMPs available to control and/or reduce pollutants in stormwater runoff. EPA considered issues of BMP performance, efficiency, costs, and benefits. Based on the compiled information, EPA concluded that existing BMP monitoring data offer some indication of the pollutant removal efficiencies of various BMPs. However, the majority of BMP performance studies produce site-specific data, which do not promote adaptability to significantly varying locations. Likewise, variations in sampling methods, constituents measured, and techniques used to compute performance make it impossible to set a fixed numerical percent or even a usable range of percent pollutant removal for each BMP type.

In Texas, the data for studies conducted to date do not allow meaningful comparison of similar facilities. The periods of monitoring range from single storm events to scattered data obtained sporadically over two to three-year periods. Some data from the City of Austin were collected as much as 20 years ago. However, the norm in most studies is short-term monitoring, beginning at the completion of construction and extending over a period of six months to a year. At first glance, the long-term information from the City of Austin appeared to offer a base for developing a comparison, but variation in sampling method, constituents, and data format make meaningful comparisons questionable. On the other hand, these data do raise some questions about potential degradation of performance over time.

Nationally, Austin is a unique situation since the city has long-term experience with permanent stormwater quality structures. Nowhere in the nation is there a greater concentration of structures devoted specifically to the improvement of stormwater quality for such a long period. From some twenty years of experience, the City of Austin favors the use of sedimentation/filtration basins and wet ponds over all other permanent structural BMPs (1991). Therefore, they provide design guidelines and corresponding pollutant removal efficiency data for only those specific BMPs. Furthermore, efficiency data are based on systems designed according to their strict specifications as well as reports from more than ten years ago.

Lower Colorado River Authority provides BMP performance data for many permanent structural facilities (1998). When LCRA's design criteria are met for a vegetative BMP, they expect removal efficiency to be 376 pounds of constituent removed per acre annually. This number assumes the structure is in good condition with at least 95 percent of the surface vegetated. An extended detention pond which meets sizing, configuration, slope, vegetation, settling, and depth recommendations removes 50 to 80 percent of TSS, 35 to 55 percent of TP, and 35 to 60 percent of oil and grease.

For their applications, LCRA separates sand filtration basins into two groups: full sedimentation/ filtration basins or partial sedimentation/filtration basins. A full sedimentation/filtration basin, which detains the full capture volume for release over a 24-hour period to the sand filtration bed, is reported to remove 75 percent of TSS, 40 percent of TP, and 70 percent of oil and grease. A partial sedimentation/filtration basin, so named because a sedimentation chamber not designed to achieve a specific drawdown period precedes it, removes 70 percent of TSS, 35 percent of TP and 60 percent of oil and grease.

According to LCRA, wet ponds and constructed wetlands are capable of removing the greatest amount of constituents. Properly designed, constructed and maintained, LCRA suggests that a wet pond removes 70 - 80 percent TSS, 65 - 75 percent TP, and 70 - 75 percent oil and grease. A constructed wetland is reported to remove 60 - 80 percent TSS, 55 - 75 percent TP, and 60 - 80 percent oil and grease.

LCRA's pollutant removal efficiencies are applicable to those BMPs that are designed specifically according to their guidelines. In contrast to most other sources, this manual does not categorize vegetative BMPs with structural BMPs (sand filters, extended detention, wet ponds, etc.). Although the reason for the distinction is not evident, it could be based on cost differences, or it could be based on the amount of construction required for these facilities. While LCRA does offer a performance range for their approved BMPs, data were not available to support these findings, and no sources were cited to support their conclusions.

A study funded by TxDOT monitored three sites along the MoPac Expressway. Researchers collected runoff samples for a period of almost two years. In results from this project, researchers reported that a grassy swale is effective for reducing concentrations of runoff constituents such as TSS, nitrogen, phosphorus, oil and grease, lead, and zinc. For instance, they reported that the grassy swale removed 74 percent of TSS and 88 percent of oil and grease. Furthermore, they assert, "significant pollutant removal occurs for all constituents except bacteria and dissolved carbon." These findings were based on a limited number of samples collected during the monitoring period (Barrett et al. 1998).

Tenney et al. (1995) studied TxDOT-installed vertical sand filters. They reported unfavorable hydraulic performance. The sand infiltrated the installed filter fabric, partially blocking the pores, creating a sand-filter fabric that reduced the drainage rate. A reduced drainage rate reduces the overall pollutant removal efficiency of the system as designed because water remained in the structure between events, thereby decreasing the quantity of runoff captured and treated. If the pollutant removal data are examined, the ineffectiveness and inefficiency of these systems is evident. The Tenney study is significant because it illustrates that without adequate design guidelines for materials, pollutant removal efficiencies and water quality will not achieve design objectives.

Keblin et al. (1997) studied a complex TxDOT water quality structure in Austin, Texas, for a period of 18 months. This pond had four major components: an influent channel, a hazardous materials trap, a sedimentation basin, and a sand filter. This sedimentation/filtration system was reported to be exceptionally efficient in the removal of TSS, COD, TOC, nitrate, TKN, zinc, and iron. However, the removal rates occurred as a result of a clogged sand filter leading to the conclusion that the treatment was related more to detention time than filtration. The clogged filter also resulted in an increased amount of bypass thus reducing the overall effectiveness of the structure.

The Keblin study demonstrates the results of a neglected sedimentation/filtration system. Clearly, the pollutant removal data are not indicative of a system that operates as designed. In fact, the authors point out that due to a lack of maintenance, the sedimentation/filtration system began functioning like a wet pond. While the wet pond produced better nutrient removal, size limited the capacity of this accidentally transformed water quality structure. The study demonstrates that without proper maintenance BMPs do not perform as intended.

The structure studied by Keblin et al. continues to experience frequent clogging. Therefore, it is necessary to service the structure approximately every six months in order to maintain the proper operation of the facility. At the conclusion of the study, the researchers suggested that a dry extended detention pond would be a more feasible alternative to sedimentation/filtration systems.

At best, the literature provides general estimates of the expected overall pollutant removal efficiencies for properly sized, designed, constructed, and maintained BMPs. However, the target removal efficiencies have such wide ranges that it is difficult to translate reported constituent removal efficiencies into design solutions that can be used with any degree of confidence. Based on results reported in the literature, Table 3 was constructed by US EPA to present constituent removal efficiencies.

Table 3. Structural BMP Expected Pollutant Removal Efficiency.

	Typical Pollutant Removal (Percent)				
BMP Type	**Suspended Solids**	**Nitrogen**	**Phosphorus**	**Pathogens**	**Metals**
Dry Detention Basins	30 - 65	15 - 45	15 - 45	<30	15 - 45
Wet Pond (Basins)	50 - 80	30 - 65	30 - 65	<30	50 - 80
Constructed Wetlands	50 - 80	<30	15 - 45	<30	50 - 80
Grassed Swales	30 - 65	15 - 45	15 - 45	<30	15 - 45
Vegetated Filter Strips	50 - 80	50 - 80	50 - 80	<30	30 - 65
Surface Sand Filters	50 - 80	<30	50 - 80	<30	50 - 80

Source: US EPA 1999. Adapted from US EPA, 1993c.

It is interesting to note that vegetated filter strips and surface sand filters show constituent removal efficiencies equal to or better than wet ponds which are often cited as the most efficient of all BMPs. The one exception is that the vegetated filter strip only goes to 65 percent for heavy metals whereas the wet pond and surface sand filters show a range up to 80 percent removal.

POLLUTANT REMOVAL COMPARISON: "HIGH-END" BMPS AND "LOW-END" BMPS

Researchers compared pollutant removal efficiency and cost-effectiveness of wet ponds and sedimentation/filtration basins in a City of Austin study (1998). They reported that a properly designed wet pond is as effective at removing pollutants as a properly designed sedimentation/ filtration basin. While the City of Austin indicates that wet ponds might be most cost-effective for large treatment areas, the study cautions that treatment efficiency may decrease during extremely wet periods or when storage capacity is exceeded.

In addition, the authors of the study reported that sedimentation chambers do not necessarily provide additional or enhanced pollutant removal efficiencies when used as pretreatment structures for sand filters. The main purpose of the sedimentation chamber is to increase time required between sand filter maintenance cycles. Consequently, when a sedimentation chamber offers no additional pollutant removal efficiency, it is possible that costs to construct and maintain this chamber do not justify its use.

If this is the case, then a sand filter alone, without the use of a pretreatment sedimentation basin, achieves pollutant removal rates very similar to those of a wet pond. This suggests that of the two, sand filters, which qualify as low-end BMPs, may be the most cost-effective BMP available.

In addition, results of both TxDOT and City of Austin studies suggest that grassed waterways clean water better than concrete storm sewers. Schueler (1987) also determined that grassed waterways (swales) are more economical than concrete storm sewers. While there are variations in the reported pollutant removal efficiencies of grassed swales, Barrett et al. (1998) reports that the use of vegetative controls for stormwater treatment is effective for highway related pollutants.

Furthermore, vegetated controls (grassed swales) appear to have pollutant removal rates that are comparable with removal rates of sand filters (see Table 3). Grassed swales cost considerably less to construct and maintain than sand filters and, in the case of highways, are integral parts of the right-of-way. For this reason the water quality contribution of the vegetated borrow ditch should be considered an integral part of the stormwater quality program for highways.

Maintenance Considerations and Facility Degradation

No matter how well the BMP removes pollutants, periodic maintenance is required to ensure continued satisfactory performance. The City of Austin (1991) states "proper maintenance is as important as engineering design and construction in order to ensure that water quality controls will function effectively." Maintenance requirements can be classified as routine and non-routine. Routine maintenance consists of mowing, site inspections, removal of debris and litter, erosion control, etc. Non-routine maintenance includes structural repairs, replacement of filter media, and sediment removal.

BMP efficiency is significantly influenced by maintenance. Keblin et al. (1997) reported that lack of maintenance caused a clogged sand filter, which affected the overall hydraulic performance of the sedimentation/filtration system. This neglect resulted in a reduction in the capture volume of the structure, compromised the design of the facility, and created a chronic failure of the system.

Although maintenance plays a key role in the performance of a BMP, evidence indicates that even with proper maintenance, structure performance may degrade over time. The procedures presented in LCRA's manual adjusts pollutant removal efficiencies. This adjustment is based on two significant considerations: the amount of runoff designed facilities are able to collect and the expected degradation or aging of BMPs. While they cite design standards as the explanation of why larger storm events cause some escape of runoff from facilities, they offer no evidence to explain the expected degradation in facilities. Despite the lack of evidence to support this claim, the affect that degraded facilities may have on effectiveness is a subject worthy of additional investigation.

Cost Analysis

The cost of constructing any BMP is variable and depends largely on site conditions and drainage area (US EPA 1999). Many research studies report construction costs in real dollar values. However, most cost values are based on specific designs such as Schueler's swale design and the resulting costs, which range from $5 to $15 per linear foot, depending on dimensions (1992). In addition, costs are often documented as base costs and do not include land costs, which according to EPA (1999), are the largest variable influencing overall BMP cost.

While most sources provide some base construction costs, very few sources offer the two other significant cost considerations, design and maintenance. Young et al. (1996) compiled the results of past highway runoff research into a single-volume user's manual for highway practitioners. This manual provides a construction cost formula or general cost data for each BMP, yet it lacks cost data for design and maintenance. Similarly, Keblin reports costs in average dollars for maintenance and restoration, but does not present cost data for design or construction of the pond (1997).

Perhaps the Southeastern Wisconsin Regional Planning Commission (SWRPC) (1991) documents the most comprehensive analysis of construction and maintenance costs. They assert that cost estimates can be modified to reflect differing site conditions. On the other hand, cost estimates are recommended for use only in the planning and preliminary engineering stages. They recognize that local conditions and costs necessitate a very site-specific analysis at the final design stage.

What can be obtained from the literature is an abstract overall cost comparison between permanent structural BMPs. For instance, the majority of literature seems to agree with Barrett's conclusion that grass swales and filter strips are the least expensive stormwater treatment options and cost less to construct than curb and gutter drainage systems (1999). However, extended detention ponds are often cited as the least expensive BMP available (Schueler 1992), while wet ponds appear to cost more. Constructed wetlands are reported to be approximately 25 percent more expensive than wet ponds (US EPA 1999). Sand filter systems may require additional land area, which can add substantially to the cost, while the structure itself is one of the least expensive of the structural BMPs when compared to wetlands or wet ponds.

Factors such as site location, sizing, and complexity of structure affect cost throughout the literature. Thus, in most cases, it is extremely difficult to obtain and compare dollar estimates for design, construction, and maintenance costs of individual BMP types. For example, if earth berms or excavated depressions are used to form a basin, the structure will be much less expensive than one that utilizes cast-in-place concrete to form the storage area. In these situations, the decision to use concrete is usually because the concrete is cheaper than the additional land requirement.

COST-EFFECTIVENESS INDEX

The literature review indicated that the development of a rating or numerical value for cost-effectiveness would greatly enhance the offerings of stormwater BMP studies. Sources claim that particular BMPs are cost-effective (Schueler 1987). In general, the primary considerations of cost-effectiveness found in the literature include the factors of initial construction cost and maintenance cost. In contrast, recent studies have suggested that using construction and maintenance costs to compute cost-effectiveness is insufficient.

According to the City of Austin's Environmental Criteria Manual (1991), the factor of drainage area for the analysis of cost-effectiveness in addition to the above costs is a consideration. Keblin et al. (1997) considers design parameters as the factor affecting the effectiveness of a BMP. For example, this study found that detention time was more important than outlet design for achieving better removal of constituents in runoff. Therefore the ordering of design and planning parameters will impact efficiency and ultimately cost-effectiveness.

Thus, a real measure of cost-effectiveness includes design, maintenance, and construction costs as well as the pollutant removal efficiencies of a selected BMP. A cost-effectiveness index derived from lifetime costs, volume, and pollutant removal efficiencies could potentially offer the best guidance for choosing and implementing stormwater BMPs.

Thus, cost-effectiveness would be:

$$\text{Cost-effectiveness} = \frac{\left(\dfrac{\text{Lifetime Cost}}{\text{Per Unit of Stormwater Treated}}\right)}{\text{Constituant Removal (Percent)}}$$

This simple relationship accounts for cost and efficiency as well as the issue of volume treated. It is important to note, that even the most efficient BMPs are very limited in their capacity and thus have a much higher cost per unit of stormwater treated. This method can be used as an index for individual pollutants, or a weighted average can be developed if some pollutants are considered more important than others.

Nowhere in the literature was cost-effectiveness reported as a number derived from lifetime cost per unit of pollutant removed as suggested above. Furthermore, while researchers can obtain a close estimate for pollutant removal efficiencies, much of the reported cost data lack all the factors used to establish lifetime costs. As such, the literature did not provide a model for computing an index for cost-effectiveness.

Finally, there still remains a question of reliability. While it will be possible to develop a cost-effectiveness index from information developed in this study, it is likely that such an index will only be useful as a guide. This is because there remains, in general, a level of uncertainty with respect to long-term performance levels of BMPs. There are efforts underway that, if successful, will markedly increase the level of confidence in predicted performance. However, until this information is available the use of the cost-effectiveness index will require some professional judgment.

CONCLUSIONS

- No new technologies or products were identified from the literature review that show promise of increasing efficiency or reducing the cost of permanent stormwater mitigation practices.
- The literature indicates a wide variability in performance values as well as in cost data. While a close estimate can be obtained for pollutant removal efficiencies, much of the reported cost data lacks components necessary to develop a reliable cost-effectiveness index. Given this wide range of data and differences in the interpretation, it is not feasible to draw any conclusions about performance or cost-effectiveness from the literature.
- Maintenance is a major consideration in the performance of a BMP. Even with proper maintenance, structure performance may degrade over time. This suggests that larger and higher cost permanent structural stormwater facilities will degrade in performance over time. If so, then higher cost facilities may lose a greater measure of performance over time than low-cost, lower technology facilities.
- Barrett et al. (1998) demonstrated the efficiency of simple vegetative BMPs. However, it is difficult to compare the value of these measures in the highway to more complex BMPs, since the basic highway cross-section already includes these as an integral part of the design,and their effect has not been studied in any detail. Even though swales and natural filter belts constituted by the grassed shoulder and back slope of the right-of-way are not necessarily intended as water quality measures, evidence suggests they function in the same way. Figure 1 illustrates this basic principle.

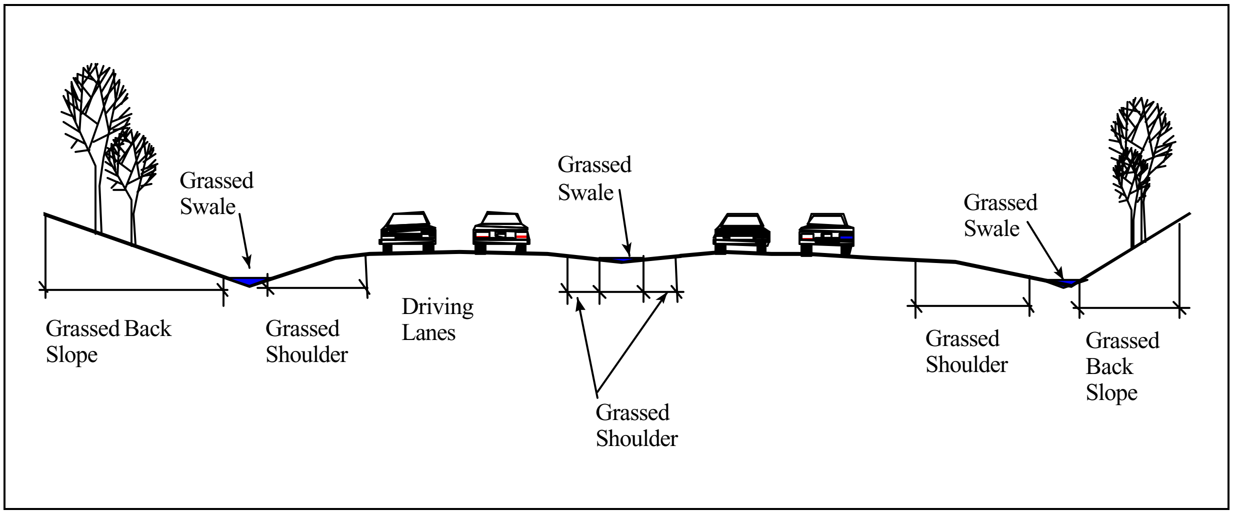

Figure 1. Grassed Swale.

Based on the conclusions developed from the literature review, the following changes were made in the original plan of work:

- Arrangements were made to monitor the pollutant removal efficiencies of select BMPs in the Austin area. This addressed the fact that the literature review did not produce pollutant removal data that allowed valid comparison for reasons of variations in monitoring technique, time, and variety of structures monitored.
- Since the objective is to compare the performance of high-end and low-end structures, several structures will be selected based on criteria of age as well as type of BMP and cost.
- Lifetime cost data will be developed for each structure. Where data are not available for a structure, detailed estimates will be developed from TxDOT and City of Austin records.
- Based on the results of the monitoring program and cost-gathering efforts, a cost-effectiveness index will be developed.
- Finally, guidance materials will be developed for selecting and designing BMPs for TxDOT applications.

ESTIMATING POLLUTANT LOADS FOR STORMWATER QUALITY

INTRODUCTION

There are two general methods used to estimate stormwater pollutant loads in the process of sizing mitigation structures. The first uses numerical or statistical mathematical models based on site-specific or regional data to develop estimates of constituent loads. Examples of these types of model are the United States Environmental Protection Agency Storm Water Management Model (SWMM) and the Natural Resource Conservation Service (NRCS), TR-55 model.

The second general method for estimating pollutant loads is a simplified approach based on pre-developed statistical interpretations of local and regional data. The Nationwide Regression Equation (Tasker and Driver 1988) was developed to provide estimates of mean loads. This study was based on a regression analysis of water quality parameters based on the predictive variables: drainage area, impervious area, urbanization, commercial land use, mean annual rainfall, and mean minimum January temperature. Other methods that estimate peak discharge or total runoff are generally based on the rational method.

Statistical and Mathematical Models

The Storm Water Management Model

First released in 1969, the Storm Water Management Model has been revised and improved with subsequent versions released in 1971, 1975, 1981, and most recently, 1993 (Version 4.3). The model is a public domain software and can be obtained from the Oregon State University SWMM web page, http://www.ccee.orst.edu/swmm.

SWMM, a PC based computer program, is capable of single event modeling or continuous simulation of basins with storm sewers, combined sewers, or natural drainage. SWMM simulates all components of urban hydrologic and water quality cycles including: rainfall, snow melt, flow routing, storage, and water quality treatment. Statistical routines are available to perform analysis on long term precipitation data or data generated from continuous simulation output. Because of the comprehensive nature of the model, it can be useful in both planning and design applications.

The data required to run SWMM includes: catchment areas, percent impervious area, average slope, channel and surface roughness, channel width and shape, watershed depression storage, and evaporation and infiltration parameters for the Green-Ampt equation. Additional data is required for simulation of snow melt, surface drainage, and/or infiltration. Calibration of the model to specific locations requires the development of measured hydrographs and pollutographs. Without proper calibration, SWMM results should only be used for comparison between water quality practices.

The literature emphasizes that SWMM is designed for use by engineers and scientists with experience in water quality and urban hydrology processes. Firm scientific grounding and experience in these areas is essential to make input decisions and to interpret the output from the model properly. Input and processing of the data is also time consuming.

TR-55: Hydrology for Small Urbanizing Watersheds

The Natural Resource Conservation Service TR-55 model was first created as a simple manual method for hydrologic modeling. Since that time, a PC based model has been developed that simplifies the computational tasks. The model provides a set of simple tools for estimating peak discharges, total runoff, composite hydrographs, and detention volumes. The data required for using TR-55 are: catchment areas, land-use/land-cover areas, average slope, channel and surface roughness, channel shape, hydrologic soil type, and runoff curve number. It is also necessary to make adjustments for the percent of surface water empoundments in the watershed and for connected impervious areas.

What makes the TR-55 attractive in some respects is its ease of use, the fact that the model is calibrated for urbanizing watersheds, and that the state NRCS office has calibrated the model for most of the state of Texas. However, development of all the data required for the model can be very time consuming. Furthermore, it is often very difficult in urban areas to identify watershed boundaries and estimate flow paths because the data is not available. Therefore, any benefit that may have accrued from the use of a more sophisticated tool is lost.

Simplified Methods for Estimating Runoff and Pollutant Loads

A widely accepted method presented by Thomas R. Schueler (1987) is a "simplified" approach that uses storm rainfall depth, the runoff coefficient, event mean concentration of the target constituent, and drainage area to estimate runoff and pollutant loads.

The format of Schueler's equation is:

$$L = \left[P \cdot P_j \cdot \frac{R_v}{12}\right] \cdot C \cdot A \cdot 2.72$$

where:

P = rainfall depth (inches) over the desired time

P_j = factor that corrects P for storms that produce no runoff

R_v = runoff coefficient, which expresses the fraction of rainfall converted into runoff

C = flow-weighted mean concentration of the pollutant in urban runoff

A = area of site in acres

12 and 2.72 are unit conversion factors.

The variable *P* represents the annual depth of rainfall for analysis. Because not all storm events produce significant rainfall, an adjustment factor, P_j, is included. This represents the fraction of storms that produce runoff when considering precipitation depths that encompass multiple events. The runoff coefficient (R_v) is the standard rational method runoff coefficient. The variable C is the flow weighted mean concentration of the pollutant of interest. The value of C depends on land use and constituent type.

This model gives reasonably conservative values that compare favorably with the pollutant loadings observed in a number of East Coast studies and even more conservative when compared to observations by the City of Austin (1989, 1997) and Barrett et al., *Effects of Highway Construction and Operation* (1996).

The only data required for the use of the "simple method" are:

- mean annual precipitation in inches,
- percent of rainfall events that produce no runoff,
- area of the drainage basin, and
- runoff coefficient.

However, unlike SWMM or TR-55, the simple method provides no related information with respect to flow rates or other hydrologic characteristics. If needed, this information must be developed by different models like SWMM or TR-55.

RECOMMENDED METHOD FOR TxDOT

A highway system is linear in form. That is, the right-of-way spans great distances crossing numerous drainage basins along its path. Seldom does a single stretch of road occupy a sufficient percentage of a drainage basin to significantly impact its overall hydrologic performance. For this reason, the time and cost required to develop complex model applications such as SWMM or TR-55 for a portion of a highway corridor would be difficult to justify, particularly since the values provided by the simple method would likely yield very similar results. Therefore, the utility of a model like SWMM or TR-55 is probably limited to a very few specialized applications where the highway right-of-way constitutes a spatially significant impact on the drainage basin. In these situations, TxDOT engineers or appropriate consultants with substantial hydrologic modeling experience should prepare model applications.

Due to its simplicity, it is recommended that TxDOT adopt the method used by LCRA (1998). This is a modified version of the simple method presented by Schueler in 1987. It is recommended that this method be used for estimating pollutant loadings for routine water quality design problems encountered by TxDOT designers. The annual constituent load is given by:

$$L = A \cdot RF \cdot R_v \cdot 0.226 \cdot C$$

where:

L = the annual pollutant load in pounds

A = the contributing drainage area (acres)

RF = average annual rainfall volume (inches)

R_v = average annual runoff/rainfall ratio for the percent of impervious cover (graph provided for estimating R_v)

0.226 = units conversion factor

C = average annual constituent concentration (mg/l) as specified in Table 4

Using the LCRA version of the "simple method" as modified by LCRA yields a more conservative value and should be more acceptable to regulators. The tables and graphs used by LCRA for determining the values of C and R_v are provided in Figure 2.

Impervious Cover	Runoff
0.05	0.05
0.10	0.07
0.15	0.09
0.20	0.12
0.25	0.15
0.30	0.18
0.35	0.21
0.40	0.25
0.45	0.29
0.50	0.33
0.55	0.38
0.60	0.42
0.65	0.47
0.70	0.53
0.75	0.58
0.80	0.64
0.85	0.70
0.90	0.77

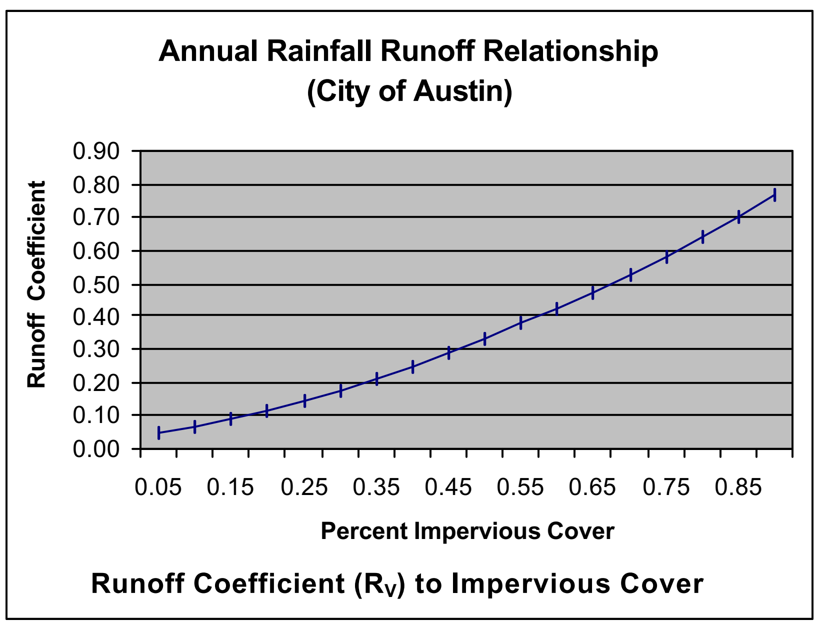

Figure 2. Runoff Coefficients per Percent Impervious Cover, Austin, Texas.
Source: LCRA (1998), City of Austin (1991).

Table 4. Average Annual Stormwater Consituent Concentrations (mg/l).

Constituent	Background Conditions (mg/l)	Developed Conditions (mg/l)
Total Suspended Solids	48	130
Total Phosphorous	0.08	0.26
Oil and Grease (O&G)	0	5.0

Source: LCRA (1998), City of Austin (1991).

The LCRA values for TSS are somewhat lower than those reported by Driscoll et al. (1990) of 142 mg/l. However, the 130 mg/l value suggested by LCRA is consistent with the values reported by Barrett et al., *Water Quality and Quantity Impacts,* (1996) for highway runoff in Austin. Earlier work by Driscoll (1983) and others had suggested that there may be a need to make an allowance for increases in TSS loading based on land use type and percent imperviousness. Research since that time by the City of Austin and others seems to suggest that land use and imperviousness have less to do with the event mean concentration than the increase in sediment loads caused by stream bank erosion related to increased runoff volumes. For this reason, the values given in Table 4 are probably reasonable for the urbanized portions of the state and appear to be consistent with current TNRCC requirements.

ESTIMATING STORMWATER QUALITY VOLUME

INTRODUCTION

The water quality volume of a structural BMP is ultimately a rule-based decision related to the percent of runoff to be captured in order to achieve a selected pollutant reduction level. Because the relative pollutant removal efficiency varies significantly with each constituent and BMP type, the size of the BMP will have to be tailored to the needs of each individual site. Furthermore, water quality standards continue to evolve with environmental regulation and promulgation of new rules. Therefore, this section only provides an outline procedure for determining water quality volumes. More specific sizing recommendations are provided in the discussion of specific BMPs.

A PROCEDURE FOR SIZING WATER QUALITY BMPS

Since the ultimate water quality volume or size required of a BMP is dependent on the total pollutant volume that must be removed, it is difficult to provide a "one-size-fits-all" solution. The following procedure is suggested to guide the designer through the design process:

- Determine the required pollutant removal volume required for the appropriate indexpollutants.
- Calculate the background or predevelopment pollutant load using the simple method recommended in the previous section. Adjust values of R_v and *RF* to meet regional characteristics.
- Calculate the pollutant load for the developed condition. Allowance should be made for contributions from off right-of-way areas unless these contributions bypass the structure.
- Calculate the required reduction for the index pollutant(s) by subtracting the background or predevelopment load from the estimated developed load. Design the structure to remove the appropriate percentage of the difference between background and developed load.
- Estimate the volume (basins or ponds) or length (channels, swales, and trenches) of the BMP necessary to remove the required pollutant volume.

Current standards that impact TxDOT are the Edwards Aquifer Recharge rules and LCRA water quality rules. Other requirements can be anticipated as the Section 303(d) requirements of the Clean Water Act come into force. Because these requirements will be based on locally determined distribution of Total Maximum Daily Loads for impaired water bodies, it is not possible to provide any specific recommendations.

For projects within LCRA jurisdiction in Travis, Burnett, and Llano counties the current performance requirements are given in Table 5.

For the Edwards Aquifer Recharge zone, the current rules require that BMPs remove 80 percent of TSS. Eight counties are affected by the TNRCC Edwards Aquifer Rules: Kinney, Uvalde, Medina, Bexar, Comal, Hayes, Travis, and Williamson. These eight counties impact the Austin, San Antonio, and Laredo Districts.

Table 5. LCRA Performance Standards for Annual Removal of Index Pollutants.

County[a]	Property Location	Total Suspended Solids (Percent)	Total Phosphorous (Percent)	Oil and Grease (Percent)
Travis	Inland	70	70	70
Travis	Near Shore	75	75	75
Burnet	Any	70	70	70
Llano	Any	70	70	70

a. LCRA has jurisdiction over a 54 county area of Texas but only has water quality regulations for these three counties which encompass Lake Travis and the Highland Lakes.

Figure 3 shows the approximate outcrop zone of the Edwards aquifer. The outcrop affects 8 counties: Kinney, Uvalde, Medina, Bexar, Comal, Travis, and Williamson. This area includes the metropolitan corridor of I-35 between San Antonio and Austin. The TxDOT Districts impacted by the Edwards Rules are San Antonio, Austin, and Laredo.

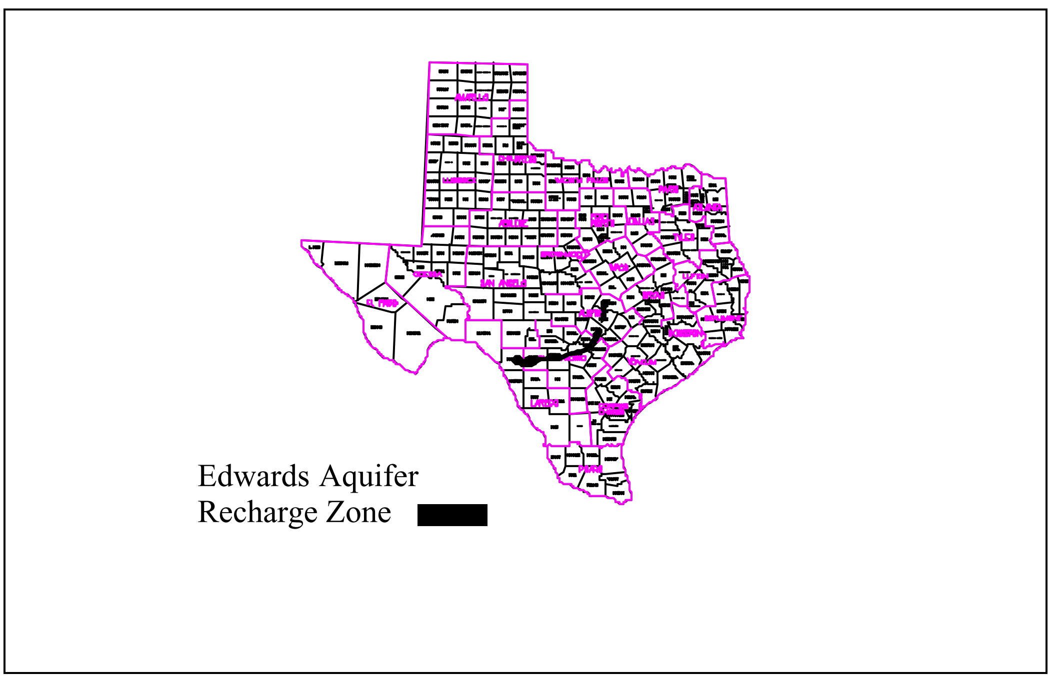

Figure 3. Outcrop of the Edwards Aquifer in Relation to Counties and TxDOT Districts.

In other areas of the state, projects may encounter water quality requirements related to the total maximum daily load (TMDL) requirements for receiving waters listed under 303(d) of the Clean Water Act. A copy of the 303(d) list of Impaired Water Bodies for Texas is provided in Appendix D. This list has been broken into impaired water bodies by TxDOT district for easier reference.

The TNRCC is in the process of initiating TMDL guidance for each of the listed projects per an established priority. The exact impacts of the TMDL program on TxDOT practice is not particularly clear at this time. However, the Environmental Division is in conversation with TNRCC and should be consulted if a project is proposed or in design within the watershed boundaries of a listed water body.

Depending on the pollutant(s) and site conditions, such as right-of-way available, soil type, substrate, vegetation, and relationship to a primary receiving water body, two or more BMPs may be needed in combination to achieve the required removal rate.

In highway practice, consideration should be given to making maximum use of roadside and median drainage channels part of the BMP process. With very simple additions, such as check dams, roadside channels can help remove many of the common constituents in highway runoff. While their efficiency is seldom sufficient to meet the overall requirement, they can make a significant contribution which will reduce the size and cost of other end-of-channel BMPs.

The next section discusses a broad range of BMPs available to improve stormwater quality. The focus is on BMPs and BMP configurations relevant in highway transportation applications.

STORMWATER QUALITY BMPS

INTRODUCTION

This section presents a full range of technologies available for improving stormwater quality from transportation rights-of-way. While the purpose of the study concentrated on low-cost methods to meet stormwater quality goals, further analysis demonstrates that the lowest construction and maintenance costs will not necessarily be the most cost-effective in every situation. For this reason, the full range of best management practices that have applications in highway transportation is presented.

Each BMP description will include the following:

- application,
- selection and design recommendations, and
- cost per pound of pollutant removed.

This information is also compared to other BMPs that could be used to accomplish a similar water quality goal. This approach recognizes that each site and each project will have constraints that cannot be anticipated by a one-size-fits-all approach. Final selection of the most cost-effective BMP will continue to require sound professional judgment.

BMP CLASSIFICATION

There is no common classification of BMPs in the literature. Each source tends to classify the BMPs by technology or by physical characteristics. ASCE (1998) uses a broad two-part classification of structural and non-structural BMPs. Structural BMPs are permanent structures that intercept stormwater and treat it before it is discharged into a receiving water body. Non-structural methods are generally housekeeping techniques or policy directed at removing target pollutants before they become suspended in runoff. Since the focus of the study is on the comparison of performance among permanent structural BMPs, non-structural methods are not considered further.

Structural BMPs

For structural BMPs, the current literature usually groups stormwater quality structures by the primary pollutant removal mechanism. The most recent and comprehensive classification of structural BMP types is provided in the EPA's August 1999 report, "Preliminary Data Summary of Urban Stormwater Best Management Practices." This method of classification is used as the basis for organizing the discussion in this section of the report. The EPA classification divides structural BMPs into eight groups:

- infiltration,
- detention,

- retention,
- constructed wetlands,
- filtration,
- vegetated systems or biofilters,
- minimization of directly connected impervious surfaces, and
- miscellaneous and vendor supplied systems.

This grouping embraces the broadest range of available stormwater quality technologies.

COST-EFFECTIVENESS INDEX FOR BMPS

A major objective of this study was to develop a cost-effectiveness index for the available BMPs. TxDOT's primary interest was in the relative cost of a particular BMP in relation to its water quality performance. That is the unit cost of pollutant removed compared to the cost of building and operating the structure.

Variables Affecting Cost-Effectiveness Index

In reviewing the literature and current stormwater quality BMP installations, it became clear that there is a great deal of variability in the types of structure, as well as the physical design of the facility itself. To illustrate this, consider the four sand filter structures shown in Figures 4 and 5.

Illustration A in Figure 4 is an early City of Austin structure which uses berm and a sand filter bed to treat the stormwater. Treated water is discharged from the sand bed to the drainage way immediately to the right of the berm.

Illustration B is a similar structure that uses an excavated basin and a sand filter bed. These are the simplest forms of sand filtration BMPs used in the Austin area and provide no pretreatment of water prior to entering the sand filter chamber.

A B

Figure 4. Older Earth Sand Filter Basins Used in Austin, Texas.

The photographs in Figure 5 are sand filter BMPs typical of more recent practices in Austin. The structure in 5-A utilizes a concrete dam rather than an earthen berm between the pretreatment chamber to the left and the sand filter to the right. Illustration 5-B is a large TxDOT structure that uses concrete as the primary containment material for the entire structure.

A B

Figure 5. Typical Sand Filter Structures Used in Austin, Texas.

All these structures are sand filters, yet the older earthen structures, shown in Figure 4, would be much less expensive to construct. On the other hand, without pretreatment, more frequent reconstruction of the sand filter bed will be necessary to maintain the needed level of performance. This has been demonstrated in studies on filter structures by Driscoll et al. (1990) and other researchers in the early 1990s.

Cost Development Parameters

Since there is so much potential variability within a single BMP type due to site conditions, space, soil, and other variables, it would not be particularly informative to make comparisons of actual cost. In addition, it was not possible to find reliable costs for many BMPs that may have application to TxDOT practice. Therefore, costs were developed on the basis of a typical BMP based on materials used and size required to service a selected watershed area.

Based on the literature and discussions with TxDOT and City of Austin personnel, BMPs were divided into two groups (Driscoll 1990), (Schueler 1987), (Young et al. 1995), and (US EPA, 1993, 1995a, 1995b, 1995c, 1997c, 1999):

- small watersheds of five acres or less, and
- large watersheds of greater than five acres up to 50 acres.

For each BMP type within the large watershed group, cost estimates were developed for five different sizes based on three different types of construction. The construction types were:

- all earthen structures with minimum use of concrete and stone for stabilization of inlets, outfalls, and emergency spillways,
- earthen basins with the use of concrete for dams rather than earth berms, and
- all concrete containment.

All the BMPs that serve larger watersheds are basin type structures with two compartments. That is, they have a pretreatment chamber that is primarily for stilling and sedimentation and then a second chamber to provide primary treatment. Although there are significant differences between BMPs that use basins, the primary differences are in volume and whether there is a permanent water pool within the basin. The schematic in Figure 6 shows the configuration of the water quality BMPs used to develop costs. Consideration is given to the size and type of inlet and outlet control structure, emergency spillway configuration, access stabilization, etc.

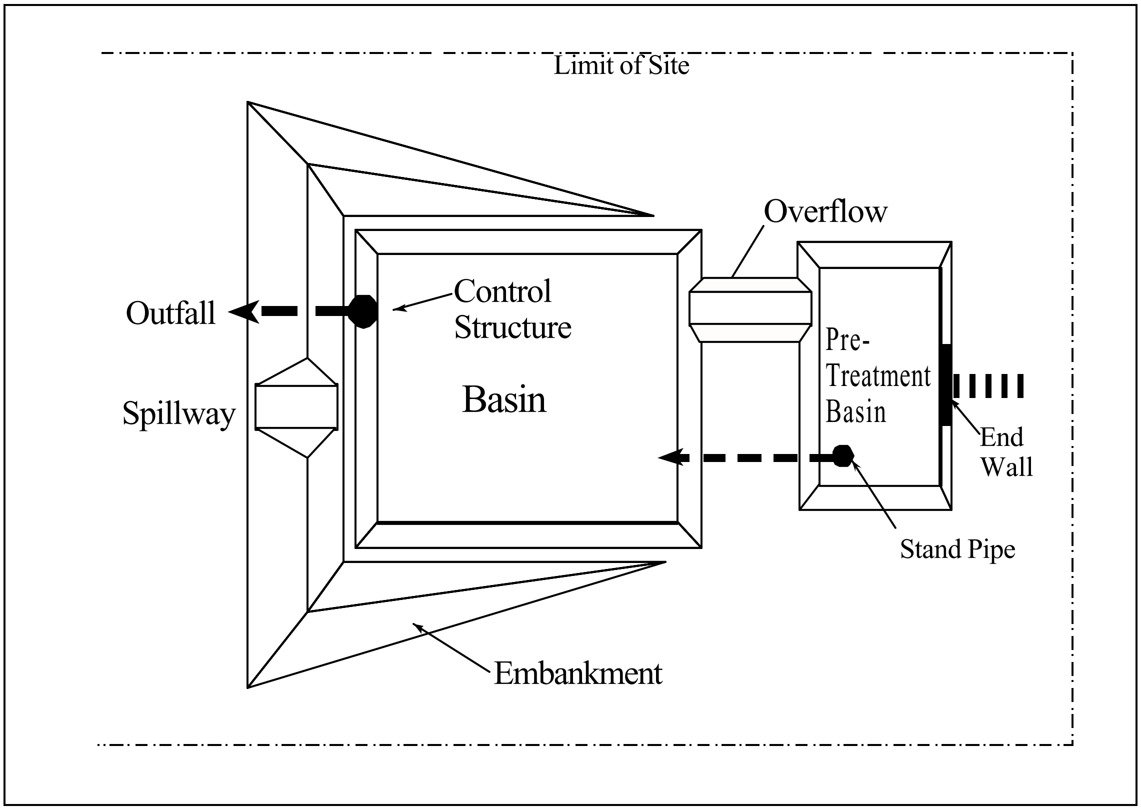

Figure 6. Schematic of Water Quality Basin Used for Development of Cost.

In the case of small watershed BMPs, it was not necessary to develop three different categories for construction materials. These structures have reasonably consistent cross-sections and increase in area in proportion to the size of the drainage basin served. Therefore, costs were developed for five different watershed sizes.

Design, construction, and maintenance costs for the water quality BMPs were considered. Design and construction costs were amortized over an assumed structure life of 20 years. Maintenance costs were developed based on annual routine tasks and include distributed costs for renovation and reconstruction over the 20-year service period.

Land costs have deliberately been omitted from the estimates of cost. While it is recognized that land can significantly impact the overall cost of a particular BMP, it tends to be an independent variable that will ultimately determine the most feasible BMP for a particular situation. This is going to be particularly true of dense urban environments where high land costs will make many surface-intensive BMPs infeasible.

POLLUTANT REMOVAL EFFICIENCY

The pollutant removal efficiency used to develop the cost to performance indices is based on values found in EPA's National Pollutant Removal Performance Database (2000), Young et al. (1996), and studies conducted in the Austin area by TxDOT, TNRCC, and the City of Austin.

Depending on the amount of data available, conservative values were used to account for normal degradation in performance over time. Adjustments were also made for increased pollutant loadings as the watershed size increased (Driscoll 1983).

Individual BMP performance efficiency ratings from key sources are shown in tabular form with the discussion of the individual BMPs.

COST-EFFECTIVENESS

The ultimate cost-effectiveness and selection of a BMP is a function of many quantitative and qualitative variables, many of which are site specific. However, since this study was intended to focus on the relationship between cost, design, construction, and maintenance of BMPs in relation to their pollutant removal performance, this report addresses only these basic parameters. There is no effort to further evaluate BMPs with respect to public acceptance, nuisance potential, or other qualitative measures.

The initial concept of the study was to develop a single cost-effectiveness measure. However, further study and evaluation suggested that a single measure could prove misleading. On the one hand, the costs for constructed elements, excavation, grading, embankments, inlet, and control structures, etc., are generally consistent for a particular BMP type. These costs can be reasonably compared to the expected efficiency of a BMP to provide a general cost to performance index. The problem occurs when the land costs are factored in to the cost equation because land costs are highly variable. In fact, in some heavily urbanized areas, land simply may not be available for installation of surface type BMPs.

Cost to Efficiency Indices

For these reasons, two indices are suggested as a better measure of the cost to efficiency relationship of BMPs; they are:

- **Operational Cost Index**: the simple comparison of design, construction, and maintenance costs to the pollutant removal efficiency, and
- **Feasibility Index**: a more complex comparison that factors in land costs.

Since the Feasibility Index is tied directly to land cost, it should be calculated on a project by project basis and compared with other options that require less land. Doing so will show the point at which a BMP with a higher operational index will become a more cost-effective and feasible alternative.

For example, the graph in Figure 7 shows a comparison between using a surface sand filter and underground separators to serve a drainage basin of 10 acres (4 ha). The separator has a slightly higher construction cost and significantly higher maintenance cost but a very small surface land requirement. While it would be unusual to use separator technology to serve a 10 acre basin, it is clear that when land prices reach the area of $125,000 per acre, the underground technology becomes a more cost-effective technology. Since land prices easily reach this range in urban areas, the Feasibly Index should be considered as one evaluation tool in selecting a stormwater BMP.

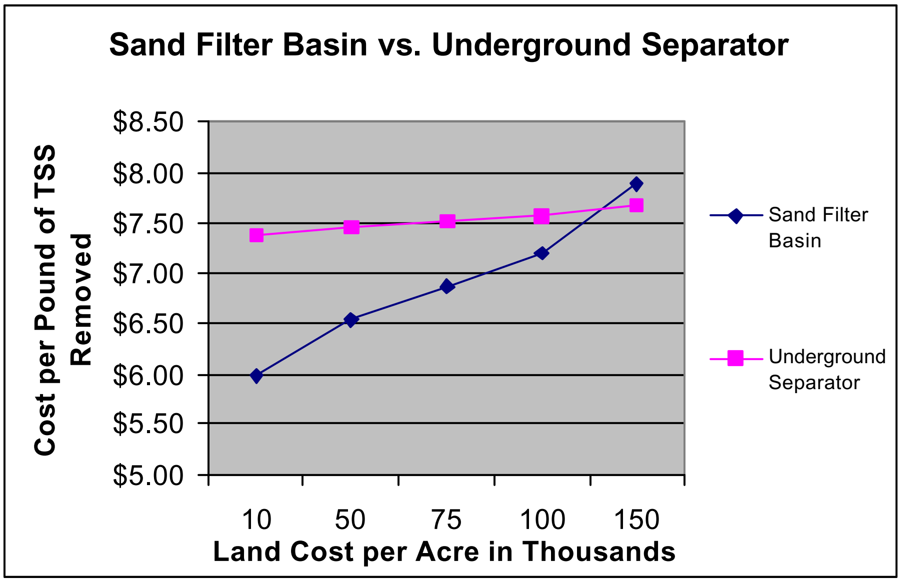

Figure 7. Feasibility Index Comparing Surface Sand Filter with a Separator.

As outlined in the previous section, design construction and maintenance costs are developed for a representative BMP and compared to the pollutant removal efficiency of each BMP giving the Operational Index, given as the cost per pound of pollutant removed. In the following section on BMPs, the Operational Index measure is tabulated for each individual BMP.

Costs for BMPs that utilize surface basins, wet ponds, infiltration basins, etc., were calculated for three different structural types. In practice, it was found that surface BMPs may be built with earth basins and berms, or they may utilize concrete as dams and basin lining. As the percent of concrete increases, the construction cost increases. While there is usually a corresponding decrease in the land area requirement, it does not offset the cost of using concrete. After the costs were developed in this way, they were compared to the actual costs for some TxDOT structures and found to be very consistent with those costs.

To be cost-effective, surface basin type BMPs need to serve drainage basins of five to 50 acres or more. For this report, costs were developed on the basis of structures that served watersheds of 10, 20, 30, 40, and 50 acres (4, 8, 12, 16, and 20 ha). The numbers clearly show that the structures become more cost-effective as the size of the drainage basin served increases, with the most significant break in the 25 to 30 acre range. Unfortunately, highway projects often cross numerous small basins.

For the BMPs that do not use surface basins, infiltration trenches, grass swales, porous pavements, etc., only a single cost figure was developed because there is little variation in material or configuration that impacts cost. These BMPs are also different because they are only effective for small drainage basins in the range of 1 to less than 10 acres (0.4 to 4 ha). For these BMPs, researchers developed costs for drainage areas of 1, 2, 3, 4, and 5 acres (0.4, 0.8, 1.2, 1.6, and 2 ha).

INFILTRATION SYSTEMS

Introduction

Infiltration systems are designed to catch a portion of a storm event, retain it, and infiltrate the water into the substrate. Infiltration BMPs are usually located off line. That is, the structures catch only a portion of a runoff event, such as the first one half inch, and allow the remaining runoff to bypass the structure. As the captured stormwater moves through the layers of substrate, natural filtration of particulate matter occurs. This removes not only the solids but many of the other pollutants such as metals that attach to the soil particles. Microorganisms in the soil tend to degrade organic pollutants carried by the stormwater.

Infiltration as a means of improving stormwater quality must be used with a clear understanding of the substrate. Infiltration should not be used when the surface overlays a groundwater reservoir that is a primary source of potable water due to the potential for contamination. Areas of karst topography, which are common to the Balconies Escarpment Zone of Texas, actually must be protected to ensure that no infiltration can occur because there is an almost direct connection between surface water and the ground water reservoir. However, in other areas of the state where groundwater contamination does not pose a significant hazard to the groundwater supply, infiltration may be a useful tool in meeting stormwater quality goals. Infiltration BMPs include infiltration trenches, porous pavements, and infiltration basins.

Infiltration Trenches

Infiltration trenches are shallow, linear excavations backfilled with coarse material. Figure 8 shows an example of an infiltration trench. These trenches provide a water storage reservoir that contains the water until it can be infiltrated to the soil layers below. In developing areas, infiltration trenches can help minimize the change in predevelopment hydrology by helping to maintain interflow and recharge.

Applications and Constraints

Infiltration trenches can be a useful tool to intercept sheet flow from pavements and drives. Use is generally restricted to small watersheds of 1 - 5 acres where ponds are not practical.

Because infiltration trenches are highly susceptible to clogging, pretreatment of runoff is recommended. LCRA requires pretreatment and only allows the use of an infiltration trench as secondary or tertiary practice downstream of other BMPs. Because of the cost and the need for pretreatment, infiltration trenches have very limited application in highway transportation.

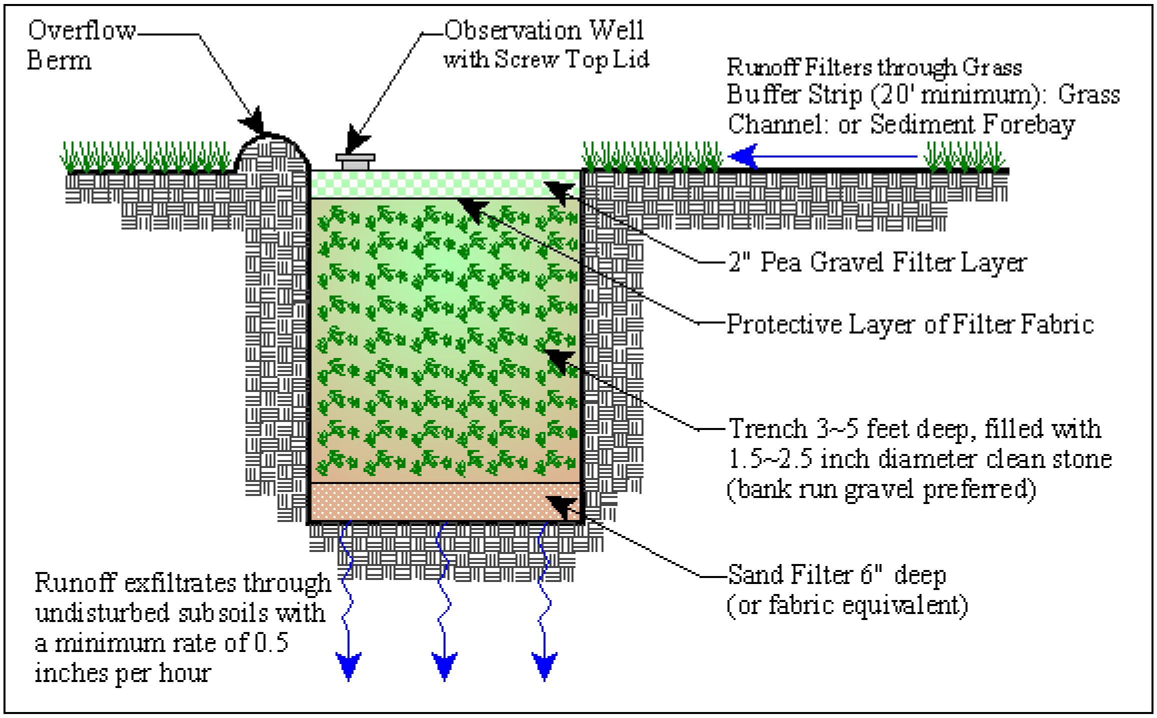

Figure 8. Infiltration Trench - Highway Application.

Pollutant Removal Performance

According to the literature, pollutant performance of infiltration trenches varies with design, soil type, backfill, and age. The current EPA Pollutant Removal Database (EPAPRD) gives a TSS removal rate of 100 percent. However, data points are limited and there is no allowance for aging. The earlier values by Schueler (1987) and others seem to be more reasonable for estimating purposes. The values from Schueler, EPA, and FHWA are shown in Table 6.

Table 6. Pollutant Removal Efficiency for Infiltration Trenches.

Infiltration Trench Pollutant Removal Capability (Percent)					
Pollutant	FHWA Evaluation and Management of Highway Runoff Quality [1]	National Pollutant Removal Performance Database [2]	0.5 in Runoff per Impervious Acre [3]	1.0 in Runoff per Impervious Acre [3]	2-Year Design Storm Treatment Acre [3]
TSS	99	100	60-80	80-100	80-100
Total Phosphorous	65-75	42	40-60	40-60	60-80
Total Nitrogen	60-70	42	40-60	40-60	60-80
Metals	96-99	N/A	60-80	60-80	80-100
Oil and Grease	N/A	N/A	N/A	N/A	N/A

Source: [1] Young et al. (1996); [2] Winer (2000); [3] Debo and Reese (1995); Schueler (1987).

Design Requirements

Infiltration trenches have limited application in areas of karst topography or where there is a direct connection to an aquifer used as a potable water supply. However, in areas where ground water contamination is not a hazard, areas with small contributing watersheds, and narrow rights-of-way infiltration trenches can be a useful tool. Some specific design recommendations for infiltration trenches follow:

- Storage volume should be based on the median design storm for the region. See section on determining BMP volume.
- Storage volume is dependent on the coarseness of the backfill material. LCRA suggests avalue of 35 percent of the excavated volume of the trench as a reasonable value.
- Soils should have a minimum infiltration rate of 0.5 in/hr and no more than 5 in/hr (Schueler 1987).
- A minimum of 3 ft of undisturbed soil over the water table is required.
- Backfill should be a washed inert material of 1.5 to 3 in. This material should be protected from outside soil contamination by a layer of filter fabric on the sides of the trench.
- Recommended drawdown time, 48 hours (LCRA 1998) to 72 hours (Schueler 1987), dependent on the probability of the recurrence of a storm event that would produce runoff equal to the storage volume of the infiltration trench.

Maintenance Requirements

Proper maintenance is critical to the performance of an infiltration trench. This is particularly true during the construction period. Infiltration trenches are post-construction BMPs and should not be installed, or must be carefully protected, until the contributing watershed has been stabilized with a permanent cover. The following maintenance requirements should be performed when needed:

- Trenches must be inspected about four to five times per year on a regular basis. Trash and grass clippings should be removed from the top.
- Renovation, including removal and replacement of the coarse backfill and/or replacement of the filter fabric, will be required every two to three years depending on site conditions.
- Depending on soil conditions, some deterioration in performance must be expected as the pour space in the native soil becomes clogged with fines.

Cost

Infiltration trenches are only useful for watersheds of up to five acres in size. They are most cost-effective for areas of between three and five acres assuming there is sufficient space in the right-of-way for installation of the required length. Items that contribute to the relatively high cost to pound of TSS removed ratio include:

- frequent inspection in order to ensure proper operation, and
- need for total removal and replacement of backfill material, resulting in high renovation costs. In addition, renovation requires protection and repair of adjacent development. Likewise, if access is limited to the site, maintenance costs will increase significantly.

As shown in Figure 9, the overall cost per pound of pollutant removed using infiltration trenches ranges from $4.53 for an acre or less, to about $4.42 for a five acre drainage area.

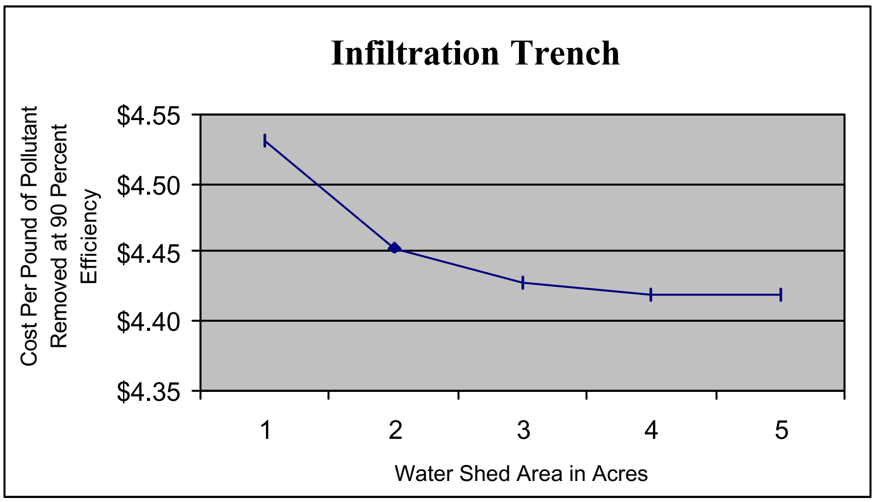

Figure 9. Cost per Pound of TSS Removed for Infiltration Trenches at 90 Percent Efficiency.

Porous Pavements

Description

Porous pavements are flexible pavements composed of open-graded aggregate bituminous pavements, pervious concrete segmental pavements, and concrete or plastic grid modules filled with soil and vegetated. The purpose of the porous pavement is to allow water to penetrate the upper pavement layer into a storage layer of coarse material below. Water, then infiltrated into the undisturbed native soil, may be distributed to the soil by a subdrainage system (Debo and Reese 1995) (Schueler 1987).

A porous pavement consists of four layers:

- a minimally compacted sub-base;
- a reservoir base consisting of 1.5 - 3 in (38-76 mm) material. The depth of the base course depends on the water quality storage volume needed, the bearing strength of the sub-base and the frost depth;
- a 2 in layer of 1.5 in aggregate provided above the reservoir base, to act as a filter layer preventing fines from clogging the pour space; and
- a 2 in layer of 1.5 in aggregate provided below the reservoir base, to act as a filter layer preventing fines from clogging the pour space.

Applications and Constraints

Porous pavements are limited to light duty parking pavements that have little or no heavy traffic and must be designed so that they do not receive drainage from adjacent pervious areas or from other surfaces that may contribute additional solids or oil and grease. The addition of solids or oil and grease will clog the filter layer and prevent proper operation.

Given these constraints, particularly the requirement for light duty traffic, the need to limit sources of solids, as well as large areas of the state with expansive soils, porous pavements will have little application in highway transportation in Texas.

Pollutant Removal Performance

The pollutant removal performance is relatively high when compared to some other types of BMP (see Table 7). However, the maintenance requirements are high and maintenance oversights would be very unforgiving and expensive to correct.

Table 7. Pollutant Removal Performance: Porous Pavement.

Porous Pavement Pollutant Removal Capability (Percent)					
Pollutant	FHWA Evaluation and Management of Highway Runoff Quality[1]	National Pollutant Removal Performance Database[2]	0.5 in Runoff per Impervious Acre[3]	1.0 in Runoff per Impervious Acre[3]	2-Year Design Storm Treatment Acre[3]
TSS	82-95	95	60-80	80-100	80-100
Total Phosphorous	65	65	40-60	40-60	60-80
Total Nitrogen	80-85	83	40-60	40-60	60-80
Metals	99 (Pb) 98 (Zn)	99 (Zn)	40-60	60-80	80-100
Oil and Grease	N/A	N/A	N/A	N/A	N/A

Source: [1] Young, et al. (1996); [2] Winer (2000); [3] Debo and Reese (1995); Schueler (1987); LCRA (1998).

Design Requirements

If porous pavements are considered as a stormwater quality option, the following design criteria are recommended:

- Storage volume is dependent on the coarseness of the backfill material. The 35 percent of the excavated volume of the trench recommended by LCRA for infiltration trenches is probably a reasonable value.
- To avoid excessive solids, pervious areas must be graded so that water from vegetated surfaces does not flow onto the porous pavement.
- Backfill should be a washed, inert material of 1.5 to 3 in (38 mm - 76 mm). This material should be protected from outside soil contamination by a layer of filter fabric between the fine gravel upper layer and the reservoir layer and between the reservoir layer and the native soil.
- Bituminous pavement surfaces must be of a 1.5 in to .75 in (12 mm - 19 mm) aggregate laid in a single course 2.5 in to 4 in (60 mm -100 mm) thick. Soils should have an infiltration rate of 0.5 in./hr (12mm).
- Recommended drawdown time: 48 hours (LCRA 1998).

Maintenance Requirements

Porous pavements require frequent attention. Any lack of maintenance can result in severe clogging of the pore space and loss of pollutant removal capacity. The following list provides general maintenance recommendations for porous pavements:

- Porous pavements must be protected from fine sediment during construction.
- Oil and grease spills must be cleaned from the surface immediately
- Surface must be vacuumed approximately every four months, followed by pressure washing of the entire surface. Frequency must be increased in dirty areas.
- If clogging occurs, drilling the surface may restore some capacity; if not, replacement of the entire surface is required.

Cost

The cost per pound of TSS removed for porous pavement is high and is only recommended for use on watersheds of five acres or less. Figure 10 displays the cost per pound of TSS removed by porous pavement. Items that have a measurable impact on long term cost include:

- frequent inspection requirement in order to monitor the drawdown rate of the reservoir;
- recommended maintenance operations occurring three times per year and required more often in dirty environments such as roadside applications or in areas with high amounts of wind erosion; and
- renovation costs that would be at least equal to or higher than original construction costs.

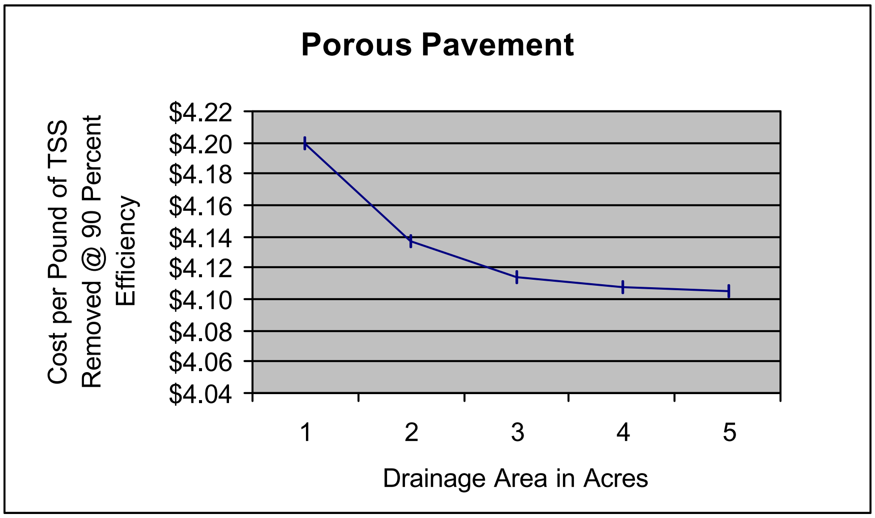

Figure 10. Cost per Pound of TSS Removed: Porous Pavement.

Infiltration Basins

Description

An infiltration basin is a surface structure that captures a predetermined water quality volume and treats the water by allowing it to infiltrate into the native soil. As water percolates through the soil layer, natural filtration and other biological processes remove the sediment and other soluble constituents. Pollutants are trapped in the upper layers of the soil as the water percolates downward. Infiltration basins only contain water immediately after a storm and should be dry within 48 to 72 hours depending on the soil and the desired drawdown time.

Infiltration basins do remove soluble pollutants, which is not true of many surface BMPs. On the other hand, the pore space of infiltration basins are prone to clog with solids, causing them to be short lived. When a basin is clogged, renovation becomes necessary, which can be costly depending on accessibility and the type of substrate. In general, infiltration basins are effective for watersheds in the five to 50 acre range. Figure 11 illustrates the basic design of an infiltration basin.

Infiltration basins have very limited application in Texas. They cannot be used in areas of karst topography, such as the Edwards Aquifer Outcrop, or in areas with very tight soils. These are generally soils that fall into the NRCS hydrologic soil groups (HSG) C and D. These soils are very common to the Clay Pan, Blackland Prairie, Coastal Prairie, Coastal Plain, and Plains resource regions of the state.

The East Texas Pine Forest is probably the most feasible for the application infiltrating type BMPs.

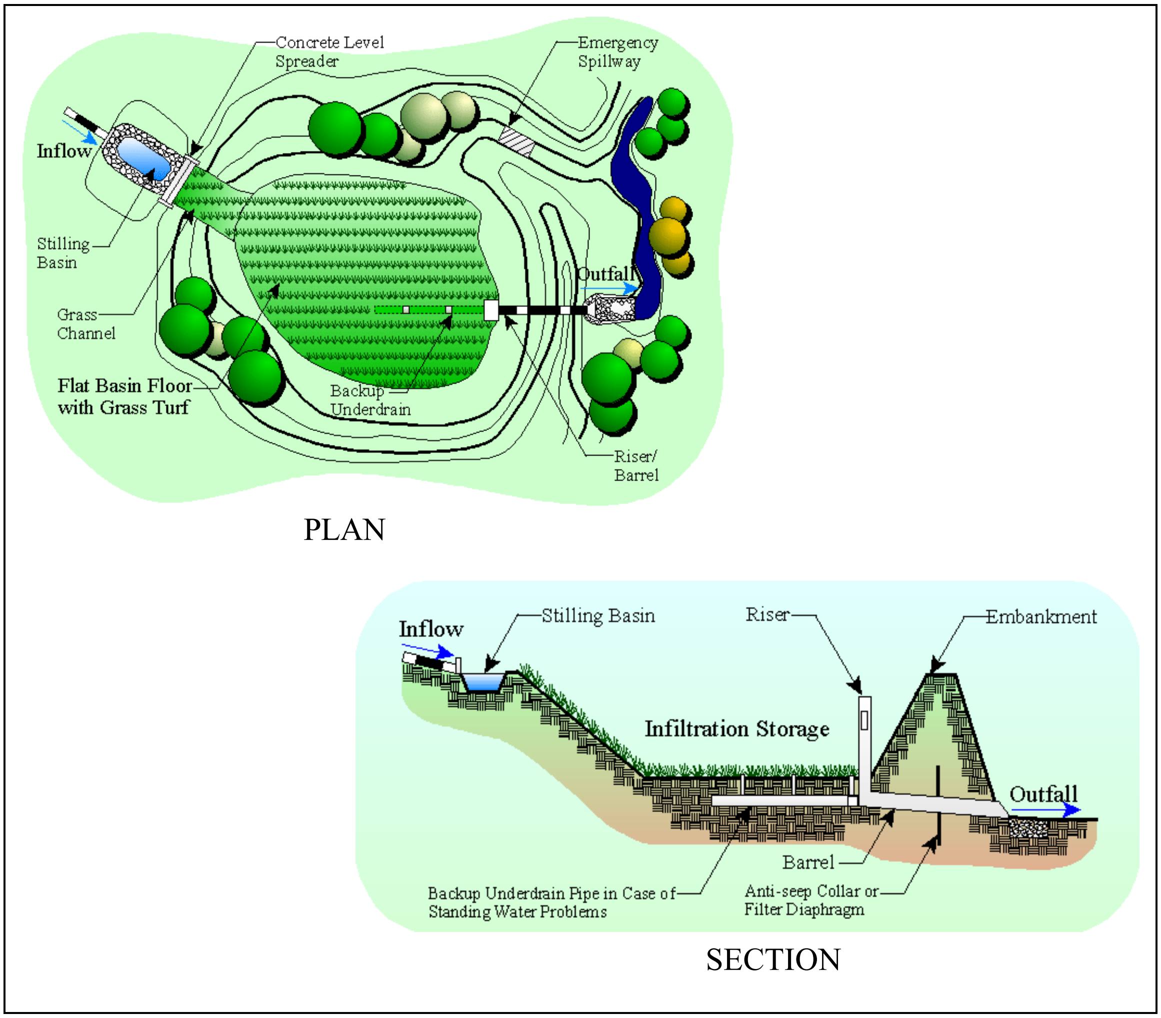

Figure 11. Infiltration Basin: Plan and Section.

Applications and Constraints

The primary constraints to the use of infiltration basins are ground water pollution hazards over karst geology and rapidly drained or impermeable soils. However, where there is no hazard to ground water and there are reasonably large watersheds to be served, infiltration basins can be a very cost-effective water quality management tool.

Design Requirements

The following site characteristics are required for practical usage of infiltration basins:

- a minimally compacted sub-base;
- minimum of 48 in or more of soil cover over the substrate;
- slope of the basin should be less than 5 percent;

- depth of the basin should be limited to provide drawdown times of 48-72 hours. Times will vary with political jurisdiction;
- provide pretreatment equal to 25 percent of the basin volume;
- soils should have an infiltration rate of 0.5 in./hr;
- provide an emergency spillway to bypass volumes greater than the designed water quality volume; and
- protect all inlets with appropriate armor and energy dissipation.

Pollutant Removal Performance

There is very little in the literature to substantiate the performance levels of infiltration basins. The values given in the 1996 FHWA study are repeated from Schueler's 1987 document. In the section on infiltration basins, Schueler clearly states that the values are estimates of removal rates that might be achieved under various sizing rules. The June 2000 National Pollutant Removal Performance Database (Winer) provides no values for infiltration basins. In this publication they caution that while infiltration practices tend to show very good results, it is difficult to monitor infiltration BMPs, and very few have actually been monitored.

Table 8. Pollutant Removal Performance: Infiltration Basins.

Infiltration Basin Pollutant Removal Capability (Percent)					
Pollutant	FHWA Evaluation and Management of Highway Runoff Quality [1]	National Pollutant Removal Performance Database[2]	0.5 in Runoff per Impervious Acre[3]	Runoff from 1 in x R_v x A[3]	Two Year Runoff Volume[3]
TSS	75	N/A	75	90	99
Total Phosphorous	50-55	N/A	50-55	60-70	65-75
Total Nitrogen	45-55	N/A	45-55	55-60	60-70
Metals	75-80	N/A	75-80	85-90	95-99
Oil and Grease	N/A	N/A	N/A	N/A	N/A

Source: [1]Young et al. (1996); [2] Winer 2000; [3] Schueler 1987 and US EPA 1999 [4] Given as a mean for all wet ponds in data set.

Maintenance Requirements

Because a simple infiltration basin uses native soil as the primary treatment medium, it is important to guard against compaction and clogging of the pore space. It is also important to remove the sediment on a regular basis since it will rapidly decrease the infiltration ability of the basin. Maintenance operations include the following tasks:

- Remove sediment on a regular schedule (three to four times a year).
- Provide regular inspection.
- Remove trash and other floatables.
- Mow on a regular basis using high flotation tires to avoid compaction.
- Deep plow when times exceed 25 percent of the designed drawdown time.

Cost

In terms of cost per pound of pollutant (TSS) removed, the infiltration basin is the most cost efficient of all the large drainage area BMPs. Based on a conservative estimate of 70 percent eficiency, Figure 12 shows the cost range is as low as $0.15 per pound, with a large watershed and an earthen structure, to a high of $3.28 per pound for a structure with an all concrete basin. The annual maintenance costs for an infiltration basin are minimal when compared to filtration basins or ponds with permanent water pools.

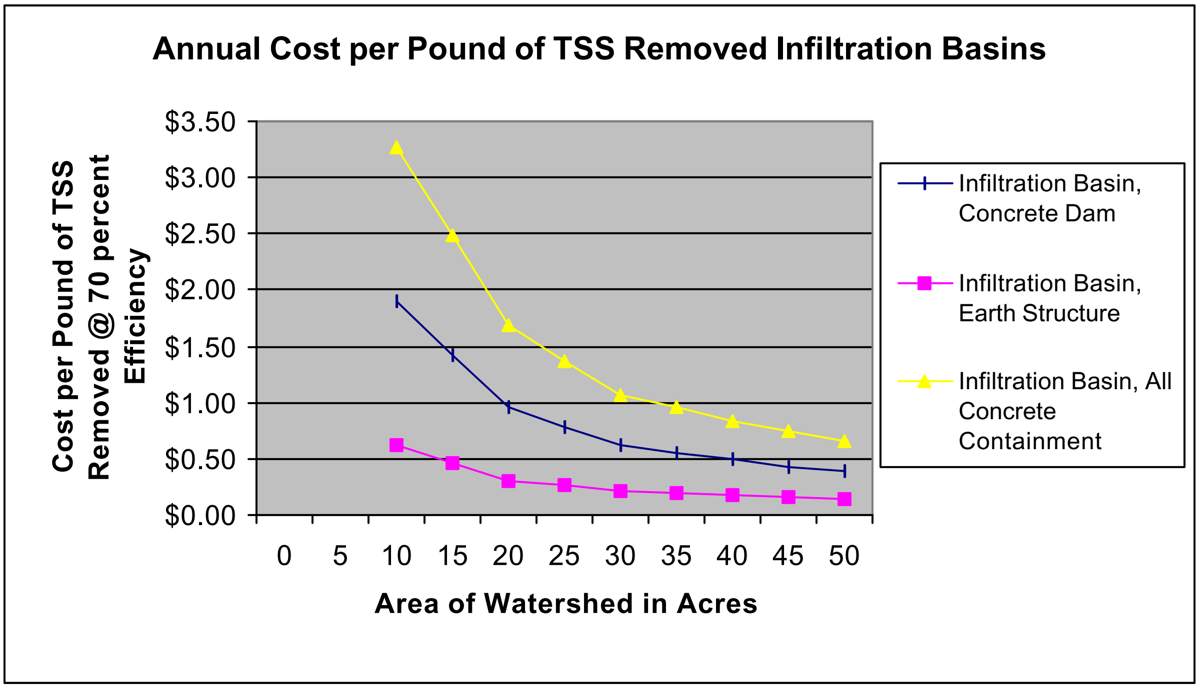

Figure 12. Cost per Pound of TSS Removed: Infiltration Basin.

RETENTION STRUCTURES

Introduction

Retention structures have a permanent water pool and are designed to capture and hold a predetermined volume of runoff above the permanent pool until it is exfiltrated, evaporated, or displaced by another storm. These pollutant removal structures rely on sedimentation as the primary pollutant removal mechanism supplemented by biological processes that take place in the permanent water pool. They range in complexity from very simple earthen structures to complex underground facilities.

Wet Ponds

Description

Wet ponds can be fairly simple structures composed of a pretreatment basin and a main ponding basin with an emergency spillway. They may also incorporate more complex devices such as hazardous material traps, spreader and separator boxes, and filtered outfall structures.

In their simplest form, wet ponds are designed to retain the full stormwater quality volume of the design event until it is replaced by a subsequent storm event. Primary pollutant removal is accomplished by sedimentation which removes the suspended solids. The permanent pool of water supports aquatic vegetation which utilizes nutrients and can degrade some organic contaminants. The permanent pool also helps prevent the resuspension of sediment that collects in the pond. The storage volume of a wet pond is the volume of water that can be stored above the permanent pool elevation. Figures 13 and 14 show the basic elements of a wet pond.

Applications and Constraints

All the literature and studies done on the performance of wet ponds suggest that they are one of the best means of treating stormwater for solids, metals, nutrients, and other dissolved pollutants. The expense and size requirement of a wet pond requires that they have a watershed area of ten acres or more.

The standing pool of water can be a nuisance, as well as a hazard, and requires that the facilities be fenced for reasons of safety and liability. The permanent water pool must be maintained at all times or trapped pollutants may be resuspended. Therefore, there must be a reliable water source. In general, it will be difficult to naturally maintain the permanent pool in parts of the state where evaporation potential exceeds annual runoff. This is generally the area west of the 24 in per year line.

Design Requirements

Wet ponds are useful water quality tools for watersheds of 10 to 50 acres in size. The required site size is in the range of 1.4 acres (0.56 ha) to 4.7 acres (1.9 ha). They are usually best situated immediately upstream from where highway drainage channels or storm lines discharge into natural drainage ways.

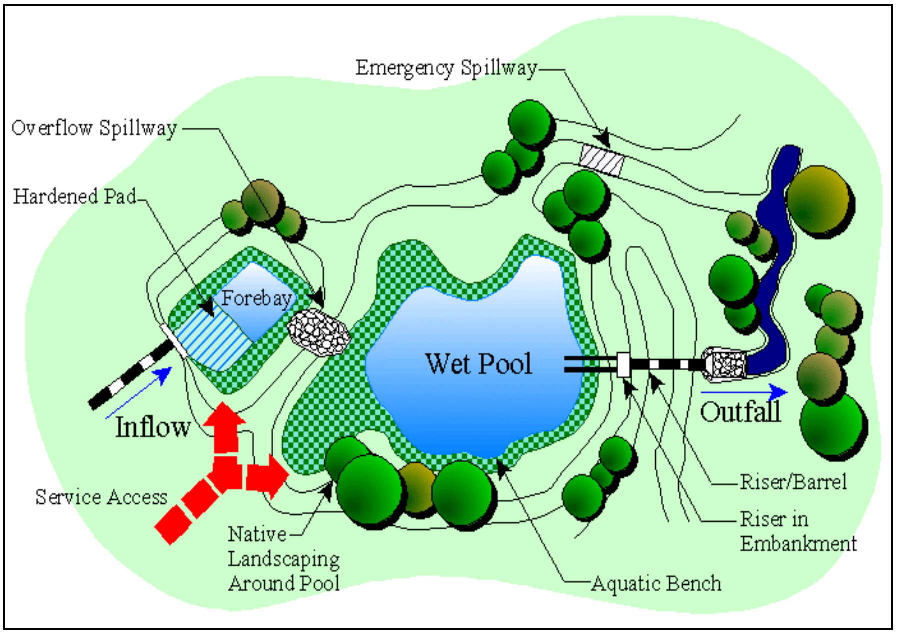

Figure 13. Wet Pond-Plan.

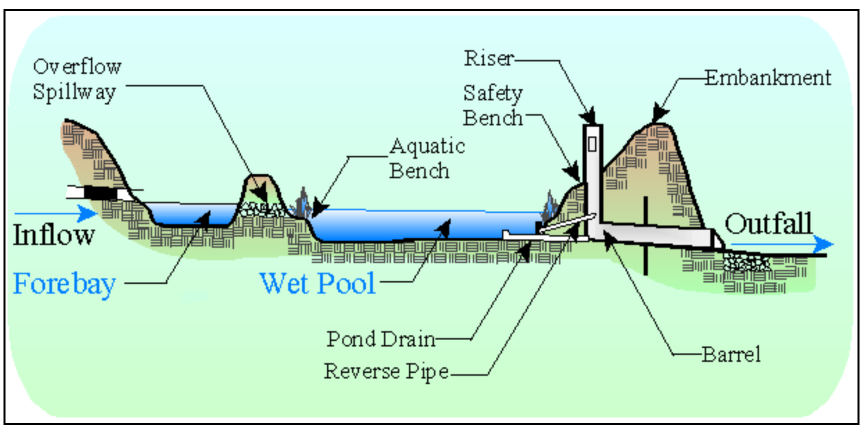

Figure 14. Wet Pond-Profile.

In some cases, such as large interchanges, it may be possible with minimum modification to use the highway embankment and the drainage structure as a water level control device to establish a wet pond.

In order to maintain the permanent water pool, it is necessary to have a natural base flow to the structure or a means of providing make-up water to the structure. Basic design requirements are as follows:

- Watershed must be sufficient to support permanent pool, or supplemental water source must be available.
- Soil should have low infiltration rates to maintain permanent pool. Soils in the NRCS hydrologic soil groups C and D are preferred. If native soils are in NRCS hydrologic soil groups A and B, a clay or geotextile liner will be required.
- The volume of the permanent pool should be equal to the calculated water quality volume of the basin (TNRCC) plus 20 percent for sediment storage. Other sources give recommendations that vary from a low of 0.5 in (12 mm) distributed over the impervious area of the watershed to a volume three times the water quality volume of the basin. Consensus is that the larger the permanent pool, the more effective the structure will be (WSDOT 1995) (Schueler 1987) (Young et al. 1996).
- The pond must have a length to width ratio of 2:1 or higher. Young et al. (1996), Schueler (1987), and others cite preferred ratios of 4:1.
- The depth of the permanent pool should be 3 ft (1 m) to 6 ft (2m). Shallower depths may result in resuspension of pollutants. For safety reasons, a moderately sloped bench (3 - 4 percent) at least 10 ft (3 m) wide should be provided and the 6 ft (2 m) depth should be considered maximum.
- A sediment pretreatment area should be provided with a volume equal to 25 percent of the water quality volume. This recommendation is generally consistent across all sources (Schueler 1987) (Young et al, 1996), and (Barrett, Edwards Aquifer Technical Manual, 1999).
- The margins of the basin should be well vegetated to minimize added sediment and to assist in treatment.
- Planting aquatic species in the permanent pool further enhance the performance of the pond. Lists of appropriate aquatic species are available from the NRCS, TNRCC, and the City of Austin.
- The influent and effluent structures should be sized to meet the hydraulic requirements of the basin. The two structures should be offset.
- An emergency spillway must be provided to pass flows greater than the designed water quality volume.

Pollutant Removal Performance

The performance of wet ponds varies somewhat more than other BMPs based on the size of the permanent pool and the contributing watershed. The values given in Table 9 show that the most recent values given by the National Pollutant Removal Performance Database are in line with values reported by Schueler and others earlier.

Table 9. Pollutant Removal Efficiency: Wet Ponds.

Wet Pond Pollutant Removal Capability (Percent)					
Pollutant	FHWA Evaluation and Management of Highway Runoff Quality [1]	National Pollutant Removal Performance Database[2]	0.5 in Runoff per Acre[3]	0.5 in Runoff per Impervious Acre[3]	2.5 Times the Runoff of the Mean Storm[3]
TSS	74	79	60-90	60	85-90
Total Phosphorous	49	49	40-60	35-40	65
Total Nitrogen	34	32	N/A	N/A	N/A
Metals	69 Pb, 59 Zn	65 (Zn)	N/A	N/A	N/A
Oil and Grease	N/A	N/A	N/A	N/A	N/A

Source: [1]Young et al. (1996) ; [2] Winer (2000); [3] Schueler (1987) and USEPA (1999); [4] Given as a mean for all wet ponds in data set.

The EPA (1986) and Walker (1986) projected the pollutant removal potential as a function of permanent pool size to the volume of runoff from the mean storm. This suggests, as shown in Figure 15, that even higher rates of pollutant can be removed if the size of the permanent pool is increased in proportion to the runoff from the mean storm.

The increased pollutant removal potential has not been documented in any of the studies reviewed in preparation of this report. But it could be useful in cases where increased performance is needed and space is available for increased permanent pool size. This might occur where a highway is close to a water body that receives a particularly low total maximum daily load classification. In this situation, there may be justification to increase the permanent pool size to achieve a higher treatment efficiency if low-cost land and an appropriate water supply are available

Maintenance Requirements

Wet ponds have some basic requirements that, if observed, will keep the structure operating at or near designed levels. The primary concern is to keep excess sediment from moving into the permanent pool resulting in loss of biologic processes. Primary maintenance activities include:

- Drain pond and remove sediment on a regular schedule, approximately once per year.
- Provide regular monthly inspection.
- Remove trash and other floatables quarterly.
- Mow and maintain vegetative cover above water line.

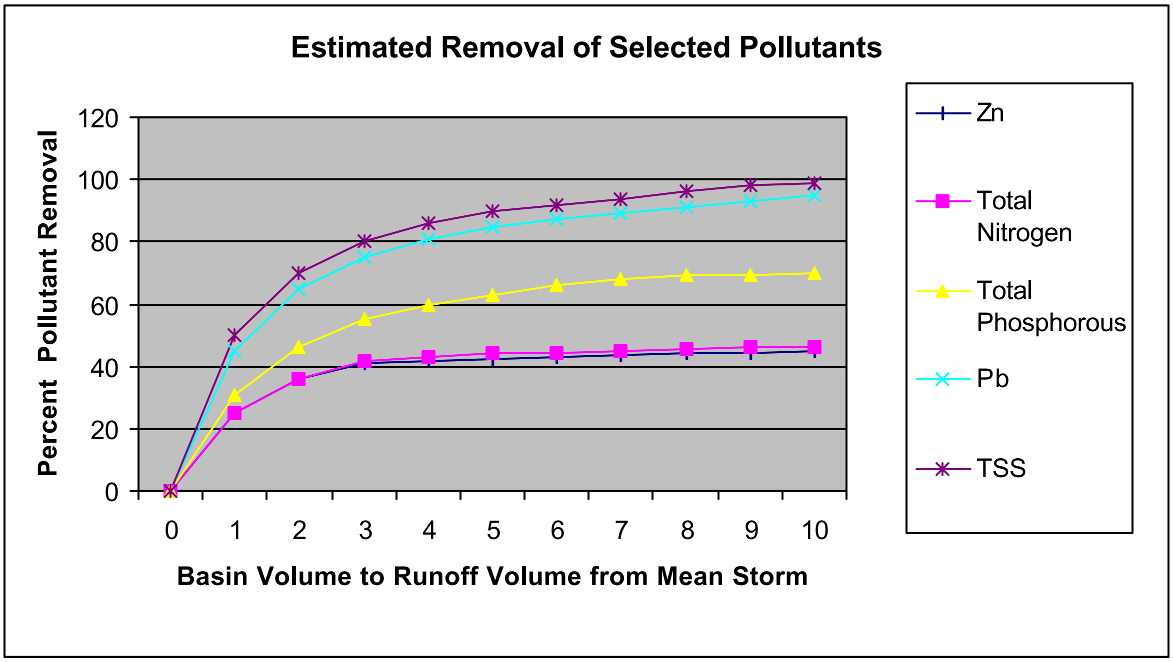

Figure 15. Estimated Pollutant Removal for Wet Ponds on Permanent Pool Size.

Cost

Wet ponds are more expensive in terms of cost per pound of TSS removed than infiltration basins but somewhat less expensive than filtration structures. This assumes that the basic configuration of the wet pond is an earthen structure with a simple earthen pretreatment basin. If concrete is used for containment and/or other structures are added such as spreaders or separation boxes then the costs will increase accordingly. This is reflected in Figure 16. If a simple earthen structure is used, the cost per pound is as low as $0.52. However, if a concrete structure is used to contain the pond, costs may increase to as much as $5.13 per pound of TSS removed.

For reference purposes, the actual construction costs for TxDOT structures on MoPac and U.S. 290 are shown. Each of these structures utilizes concrete rather than native soil for containment with a corresponding increase in overall cost. In each case, the lack of sufficient space and topsoil to use earthen containments necessitated the use of concrete.

Underground Wet Structures

Underground wet structures generally take the form of a tunnel or vault. Like the wet pond, these structures retain the entire water quality volume until it is replaced by a subsequent storm event. The storage volume of the wet underground structure is the total volume of the structure less the volume of the permanent water pool.

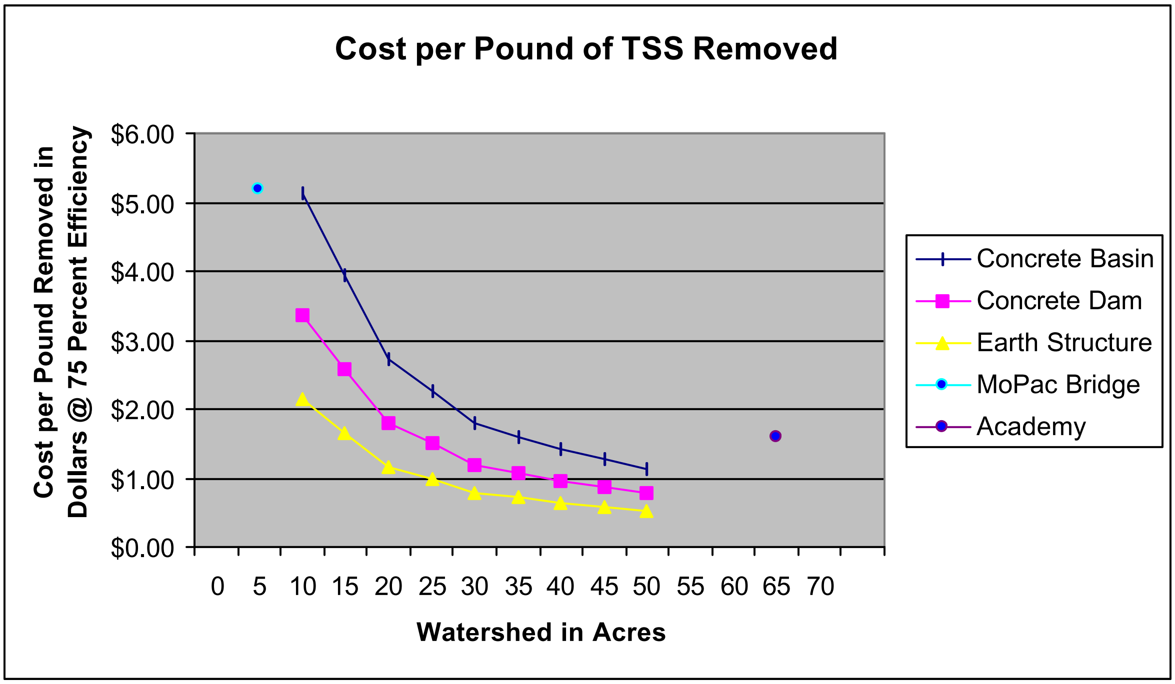

Figure 16. Cost per Pound of TSS Removed for Various Wet Pond Configurations.

Sedimentation acts as the primary pollutant removal mechanism supplemented by chemical and biochemical processes that further reduce nutrients. The activity of microorganisms in the permanent pool assists in removing nutrients and degrading some organic pollutants. However, since these structures are underground and usually not exposed to direct sun, no aquatic vegetation can be supported to further enhance pollutant removal.

Constructed Wetlands

Description

Constructed wetlands are very similar to wet ponds, but common to some natural wetland types, the permanent water pools may not remain full at all times of the year. Wetlands collect and store the full stormwater quality volume of a design event until it is either replaced by a subsequent storm event, naturally evaporated, or infiltrated.

Pollutant removal in a wetland is accomplished by physical treatment, which includes evaporation and sedimentation, adsorption, and filtration. In addition, chemical processes such as chelation, precipitation, and chemical adsorption occur in wetlands. These chemical processes, paired with biological processes like decomposition, nutrient utilization, and degradation contribute to the primary advantage of the wetland over a wet pond. When the two are compared, a wetland's working plant/soil community results in greater chemical and biological processing of pollutants. Figures 17 and 18 show a plan and profile of a constructed wetland.

Some authors have suggested that natural wetlands can be used or enhanced for stormwater treatment. However, this is not acceptable under current regulations. Only constructed wetlands are recommended for stormwater treatment.

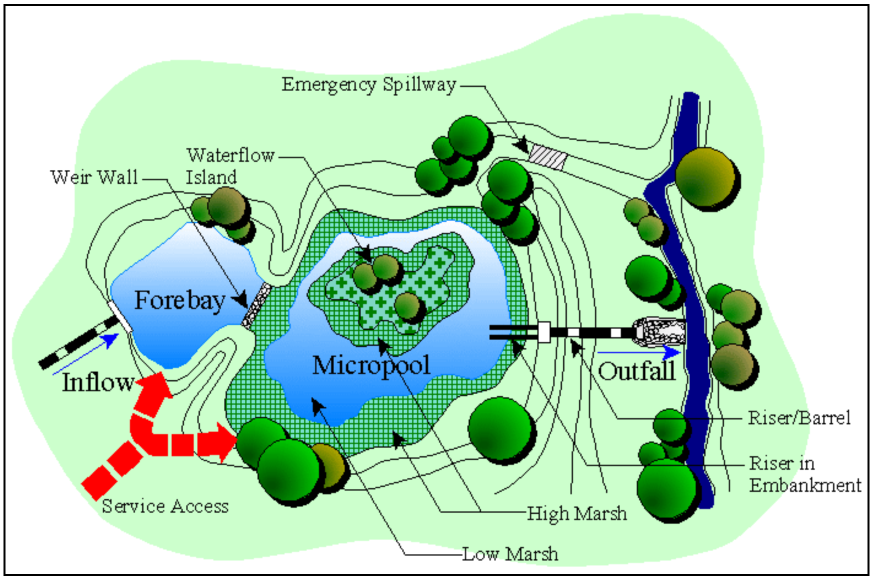

Figure 17. Plan of a Constructed Wetland.

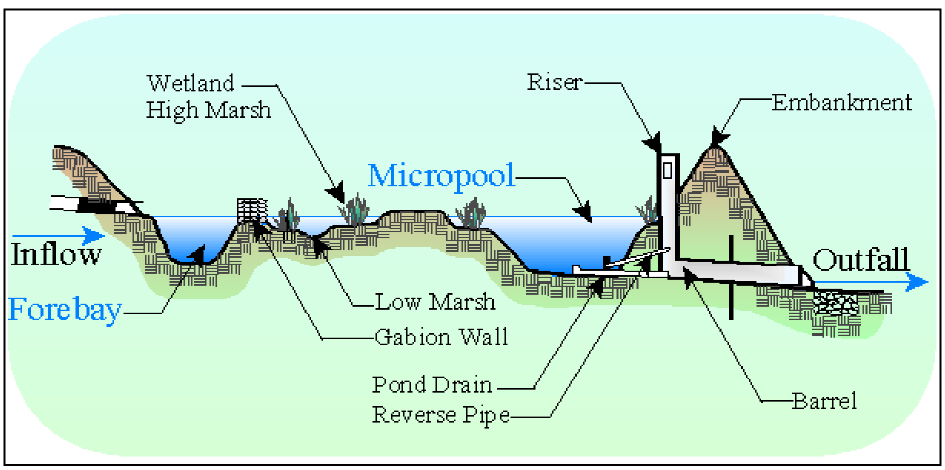

Figure 18. Profile of Constructed Wetland.

Design Requirements

Wetlands are useful water quality tools for watersheds of five to 50 acres in size. They may also be designed to provide additional runoff volume storage in integrated stormwater management programs. In cases where the water supply may not be sufficient to fully maintain a permanent pool, the vegetation should be selected so that it can withstand a period of drought. Alternatively, the design may provide for artificial irrigation as a means of maintaining the wetland vegetation.

Constructed wetlands are best located where channels or storm lines discharge into drainage ways or on the upstream side of culverts. In some cases, such as large interchanges, it may be possible with minimum modification to use the highway embankment and the drainage structures as a water level control device for establishing a wetland. Some basic design recommendations are as follows:

- Watershed must be large enough to support a permanent pool, or a supplemental water source must be available.
- The water flow path through the structure should be maximized. Provide extensive use of rock on inundated portions of the wetland to support wetland plants in order to improve the removal of nitrogen.
- Soil should have low infiltration rates to maintain the permanent pool. Soils in the NRCS hydrologic soil groups C and D are preferred. If native soils are in NRCS hydrologic soil groups A and B, a clay or geotextile liner will be required.
- The volume of the permanent pool should be equal to the calculated water quality volume of the basin (TNRCC) plus 20 percent for sediment storage. Other sources give recommendations that vary from a low of 0.5 in distributed over the impervious area of the watershed, to a volume three times the water quality volume of the basin. Consensus is that the larger the permanent pool, the more effective the structure will be.
- The pond must have a length to width ratio of 2:1 or higher. Young et al. (1996), Schueler (1987) and others cite preferred ratios of 4:1.
- The depth of the permanent pool should be 3 ft (1 m) to 6 ft (2 m). Shallower depths may result in resuspension of pollutants. For safety reasons, a moderately sloped bench (3-4 percent), at least 10 ft wide, should be provided and the 6 ft depth should be considered maximum.
- A sediment pretreatment area should be provided with a volume equal to 25 percent of the water quality volume. This recommendation is generally consistent across all sources (Schueler, FHWA, and TNRCC).
- The margins of the basin should be well vegetated to minimize added sediment and to assist in treatment.
- Planting aquatic species in the permanent pool further enhances the performance of the pond. Lists of appropriate aquatic species are available from the NRCS, TNRCC, and the City of Austin.
- The influent and effluent structures should be sized to meet the hydraulic requirements of the basin. The two structures should be offset.
- An emergency spillway must be provided to pass flows greater than the designed water quality volume.

Applications and Constraints

All the literature and studies done on the performance of wetlands suggest that they are one of the best means of treating stormwater for solids, metals, nutrients and other dissolved pollutants. The expense and size requirement of a wet pond requires that they have a watershed area of 10 acres or more.

The standing pool of water can be a nuisance, as well as a hazard, and requires that the facilities be fenced for reasons of safety and liability. The permanent water pool must be maintained at all times or trapped pollutants may be resuspended. Therefore, there must be a reliable water source. In general, it will be difficult to naturally maintain the permanent pool in parts of the state where evaporation potential exceeds annual runoff. This is generally the area west of the 24 in per year line.

Pollutant Removal Performance

The performance of wetlands varies somewhat more than other BMPs based on the size of the permanent pool and the contributing watershed.

Table 10. Pollutant Removal Efficiency: Constructed Wetlands.

Constructed Wetland Pollutant Removal Capability (Percent)					
Pollutant	FHWA Evaluation and Management of Highway Runoff Quality [1]	National Pollutant Removal Performance Database[2]	0.5 in Runoff per Acre [3]	0.5 in Runoff per Impervious Acre[3]	2.5 Times the Runoff of the Mean Storm[3]
TSS	74	79	60-90	60	85-90
Total Phosphorous	49	49	40-60	35-40	65
Total Nitrogen	34	32	N/A	N/A	N/A
Metals	69 Pb, 59 Zn	65 (Zn)	N/A	N/A	N/A
Oil and Grease	N/A	N/A	N/A	N/A	N/A

Source: [1] Young et al. (1996); [2] Winer (2000); [3] Schueler (1987). These are the same values given for wet ponds because constructed wetlands were not specifically addressed in the 1987 publication.

Maintenance Requirements

Performance of regular maintenance is critical to the performance of all BMPs. Wetlands have some basic requirements that, if observed, will keep the structure operating at or near designed levels. Primary maintenance activities include:

- Drain pond and remove sediment on a regular schedule approximately once per year.
- Provide regular inspection monthly.
- Remove trash and other floatables quarterly.

- Mow and maintain vegetative cover above water line.

Cost

As evidenced in Figure 19, wetlands are more expensive in terms of cost per pound of TSS removed. Only sand filter systems are more expensive in terms of cost per pound of TSS removed. The type of materials used for the structure also impacts the long-term cost. The cost range is as low as $0.53 per pound with a large watershed and an earthen structure to a high of $5.13. For comparison, the costs for two TxDOT structures being monitored are shown as points of reference. These structures use concrete as the primary containment. These are sand filter type structures which are slightly more expensive than wet ponds, but they provide points of reference.

Overall, the cost per pound ratio becomes most efficient when the contributing watershed is 30 acres or greater.

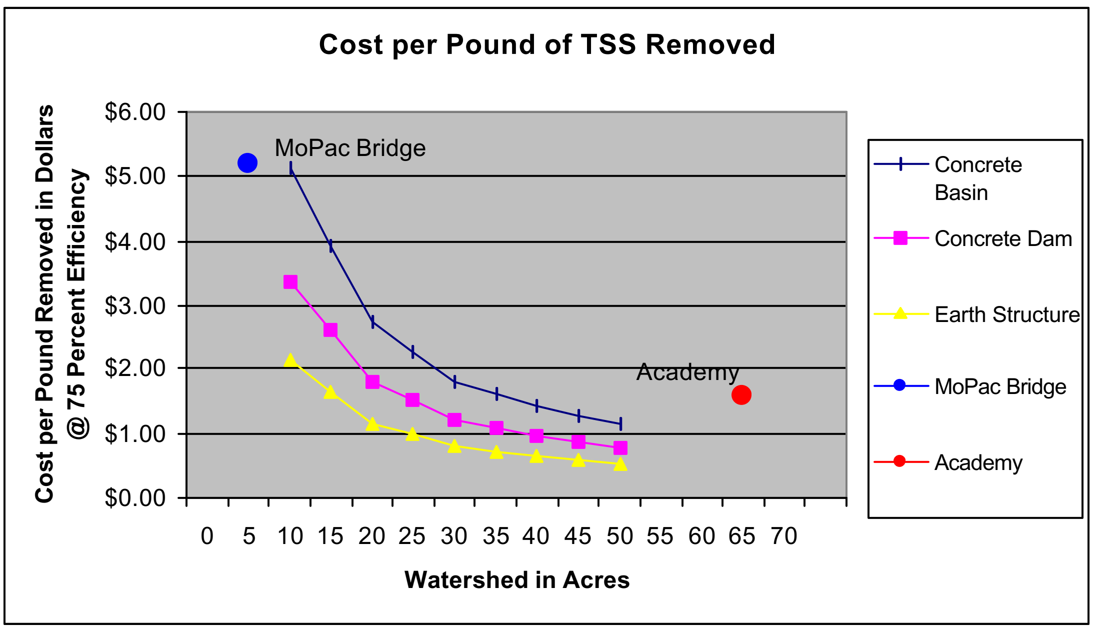

Figure 19. Cost per Pound of TSS Removed: Constructed Wetlands.

DETENTION STRUCTURES

Detention structures are most often associated with stormwater quantity control rather than water quality control. While the primary function of a detention structure is to minimize downstream flooding, the stilling effect of the detention structure allows a percentage of suspended material to settle out. The pollutant removal efficiency of a detention structure increases as the time of detention increases.

Extended Detention Ponds

Description

Extended detention ponds are normally dry structures. Figures 20 and 21 show an extended detention pond plan and profile. The primary means of removing pollutants is sedimentation which results from the stilling effect of detention, allowing heavier sediments to settle out of suspension. The longer the detention time, the greater the pollutant removal will be. If detention of the water quality volume can be extended to 48 hours or greater, removal of up to 90 percent of suspended solids is possible (Young et al. 1996). The removal of nutrients is also reasonably effective for detention times of 48 hours or more.

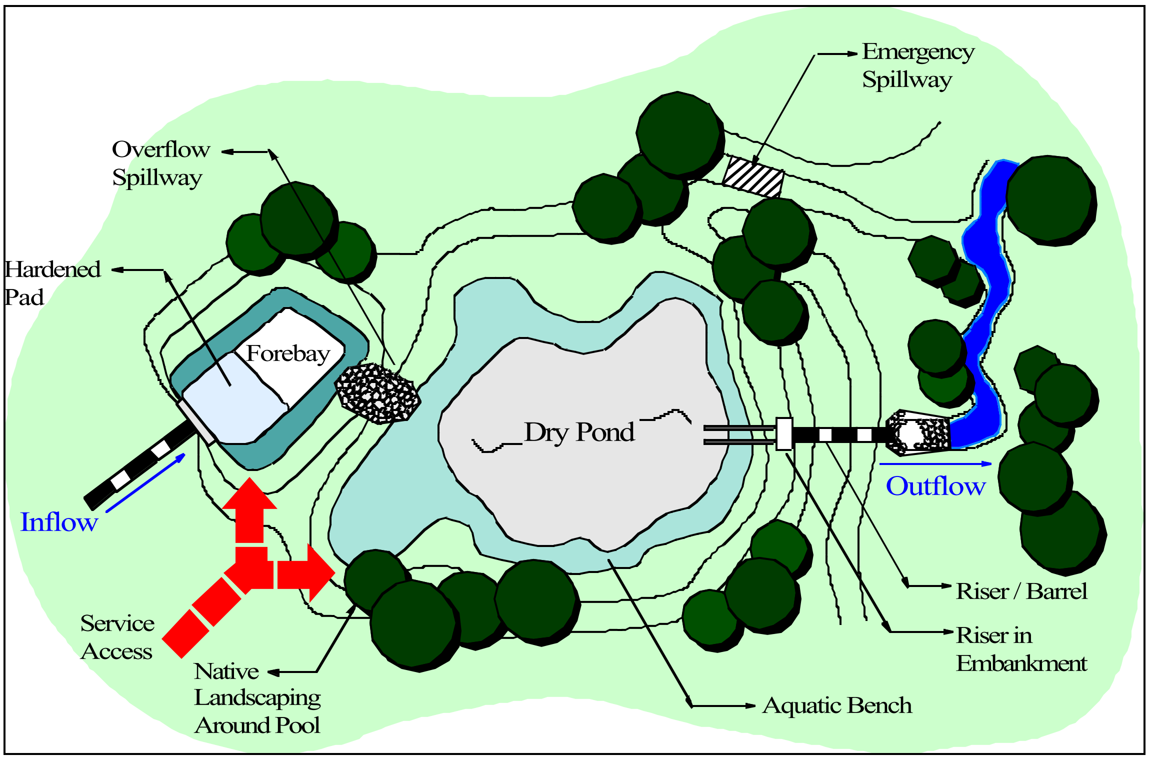

Figure 20. Extended Detention Pond: Plan.

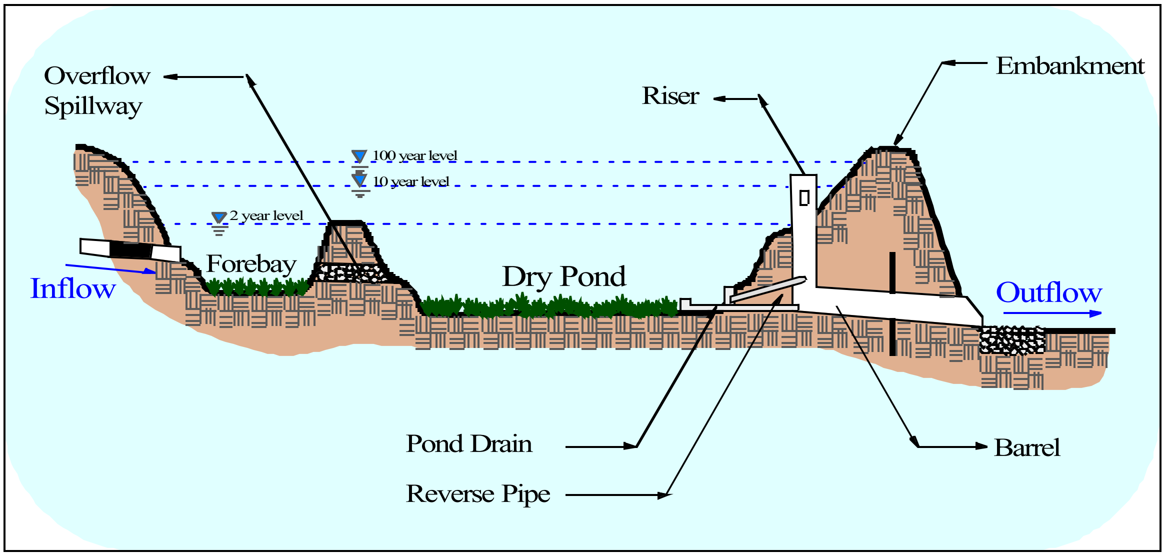

Figure 21. Extended Detention Pond: Profile.

Applications and Constraints

Detention structures should be sited off the main drainage way and outside of any existing wetlands. It is critical to check this carefully. A detention structure should be placed low in the watershed near the primary drainage way, which is also an area where wetlands may occur.

The removal of TSS and other suspended pollutants is comparable to sand filters, and nutrient removal is as high as 50 percent for detention times of 48 hours. However, detention structures are much less efficient in removing dissolved pollutants. Likewise, long detention times can be a nuisance in urban settings.

Even with more frequent maintenance requirements necessary to remove trapped sediment, the long term cost of extended detention structures makes them very cost-effective. The biggest constraint to the use of detention structures is the availability of sufficient right-of-way to accommodate the basin.

Design Requirements

Detention basins used for water quality purposes should be off-line structures sized to the full water quality volume. The recommended procedure for determining volume is the same as for sand filters. The discharge structure should be designed to detain the water quality volume for 24 to 48 hours and must have a release rate that will not exacerbate downstream flooding for estimated peak discharges of one or more storm return frequencies. Detention structures can be used for watersheds of 10 acres (4 ha) to 30 acres (12 ha).

- For highway applications, detention basins should be located to minimize intercepting offsite contributions. This may mean actually routing offsite contributions around the detention structure.
- The water flow path through the structure should be maximized to increase the detention time. Most sources recommend a length to width ratio of 3:1 or greater.
- The soil should have low infiltration rates if detention occurs over ground water reservoirs that could be contaminated. Soils in the NRCS HSG D are satisfactory. For soils in HSG A, B, and C, a pond liner may be required.
- Drainage areas may range from 10 acres (4 ha) to greater than 30 acres (12 ha) or more.
- Detention basins cannot be placed in existing wetlands.
- Base flow from any ground water source must be accommodated in the design of the outlet structure.
- Inlet structures should provide energy dissipation and erosion protection.
- Provide permanent emergency spillway to accommodate excessive flows.

Pollutant Removal Performance

As seen in Table 11, the performance of extended detention ponds increases significantly for TSS and Lead with time. According to most sources, there is little significant change in the removal of other pollutants after a 24-hour period. The data for dry detention ponds are hard to interpret because detention times are not always reported. In the few studies that do report detention times, the longer times result in improved pollutant removal efficiency. Because the data reported for these types of BMP are limited and show little consistency, dry detention structures must be used with caution if a particular standard of performance is necessary.

Maintenance Requirements

The primary maintenance requirements for extended detention structures are normal housekeeping operations, such as mowing and trash pickup. Beyond these basic considerations, allowance should be made for repairs to the containment structure(s) and regular removal of accumulated sediment. Sediment removal two to three times per year is recommended to help minimize resuspension of sediment during heavy rainfall events.

Costs

Extended detention basins appear to be one of the most cost-effective stormwater treatment methods, using the measure of cost-effectiveness developed for this report. But this could be misleading if taken out of context. Detention basins will provide TSS removal rates of 70 percent or better as reflected in Figure 22. However, detention basisns are not particularly cost-effective in removing other soluble pollutants, particularly nutrients and some metals. In general, detention basins

Table 11. Pollutant Removal Efficiency: Extended Detention Ponds.

Pollutant Removal Performance: Extended Detention Ponds (Percent)							
Pollutant	FHWA Evaluation and Management of Highway Runoff Quality [1]			National Pollutant Removal Performance Database [2]	Schueler (1987) Controlling Urban Runoff [3] (After Occoquan Watershed Monitoring Laboratory, report for the Washington Area NURP Project 1983)		
	12 hr	24 hr	48 hr	N/A [4]	6 hr	12 hr	24 hr
TSS	68	75	90	61	55	69	75
Total Phosphorous	42	45	50	20	25	44	45
Total Nitrogen	28	32	40	31	22	25	32
Metals	42 (Zn) 68 (Pb)	45 (Zn) 75 (Pb)	50 (Zn) 90 (Pb)	29 (Zn)	31 (Zn) 64 (Pb)	44 (Zn) 74 (Pb)	44 (Zn) 81 (Pb)
Oil and Grease							

Source: [1]Young et al. (1996); [2] Winer (2000) (only one case reported a detention time of 20 hr; [3] These values are adapted from Schueler 1987 and the Occoquan Watershed Monitoring Laboratory report for the Washington Area NURP project 1983; [4] Only two cases reported detention times: 20 hours Occoquan Watershed Monitoring Laboratory 1987 Study number 4 and 72 Hours for North Carolina Study No. 6.

would have to be used in conjunction with some other type of BMP in order to remove a full range of common pollutants found in highway runoff. Given this limitation where water quality is concerned, extended detention structures are less cost-effective than retention or filtration structures. In some recent publications, extended detention ponds are not considered as water quality structures.

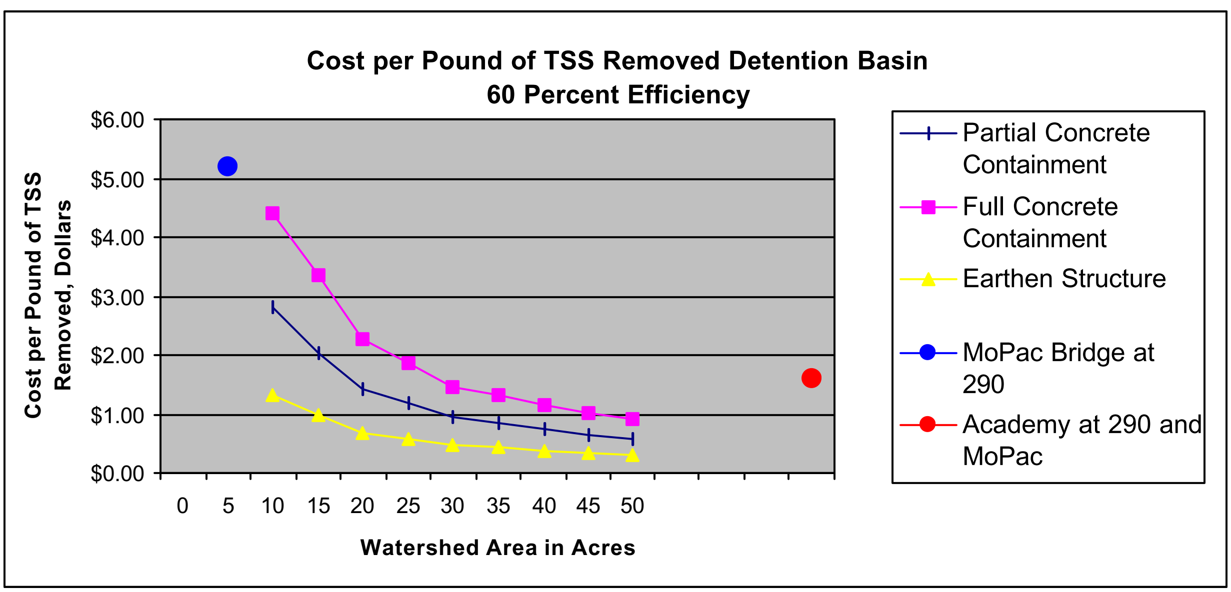

Figure 22. Cost per Pound of TSS Removed: Extended Detention Basin.

FILTRATION BMPs

Introduction

Of all water quality BMPs, filtration structures probably have the greatest variation in size and type. The simplest and most common form of filter is what has become nationally known as the Austin Sand Filter, so named after the design commonly found in Austin, Texas, over the Edwards Recharge Zone. Numerous variations of the basic Austin design have been developed and will be covered in more detail in this section. Overall, the literature suggests that a filtration type structure is one of the most positive long term performers of all the available BMP technologies.

The structural configuration of stormwater quality filters is generally consistent in that they consist of an inlet structure, a pretreatment chamber, a filtration bed, and a discharge structure. The primary differences in stormwater filtration systems are in the filter medium, size, and the construction materials.

Several different types of filter media have been used. These include materials like peat, gravel, charcoal, and compost. Of all the media, sand is the most common.

The size of a filtration structure varies with the size of the watershed, with the optimum watershed size being between 25 and 50 acres. Construction materials vary from simple earthen basins to underground concrete vaults. The common sand filter found in the Austin district will be discussed in detail in the following section. The basic design considerations apply to the other filter types. Other variations of the sand filter are:

- the Delaware;
- Washington, D.C. Underground Filter;
- Delaware Slotted Curb Sand Filter; and
- Alexandria Dry Vault Underground Filter.

The Austin Sand Filter

The Austin Sand Filter consists of an inlet structure designed to divert the desired water quality volume into the pretreatment chamber, allowing the excess flow to bypass the structure. The sediment chamber is linked to the filter chamber by way of a perforated riser, which discharges into a spreader box. The spreader box is a level trough that fills and spreads the water onto the filter bed uniformly. The filter bed is 1.5 ft (0.45 m) to 2 ft (0.6 m) underlain with perforated pipe. Discharge is by way of a 6 in to 8 in pipe. The essential parts of the Austin Sand Filter are shown in Figure 23.

There are numerous variations of this basic design in and around the Austin area. The simplest of the variations allows stormwater to flow directly from the storm drain into a sand bottom basin. The basins are lined with clay or an impervious geotextile liner to prevent infiltration to the substrate. Other than the erosion control at the inlet, a discharge line, and a reinforced overflow spillway there are no other structures. Because of their simplicity, this configuration is the least expensive form of the basic sand filter system. Most structures of this type were installed in the early to mid 1980s and have not been used in recent years. Researchers included two of these structures in the monitoring portion of this study.

Another early variation of the sand filter uses an earthen pretreatment basin that discharges through a stand pipe, culvert, or gabion filter to an adjacent sand filter bed. No bypass structure is provided at the inlet to the pretreatment chamber, and no spreader box is used between the pretreatment chamber and the filter bed. Only an emergency spillway is provided to handle excess volume.

The most recent version of the Austin Sand Filter uses a simple headwall inlet with energy dissipaters. The pretreatment is provided in a simple earthen basin which is connected to an adjacent sand filtration bed. Water is distributed to the sand bed by way of a concrete spreader box or a gabion separator. Several structures of this type were also included in the study. Figure 23 shows the basic components of the Austin Sand Filter in plan. The actual configuration of the individual parts are a function of the available site.

The performance of each variation of the structure will be discussed in the section on monitoring.

Applications and Constraints

The Austin Sand Filter and its variations are one of the most common and best documented water quality BMPs in Texas. It has been applied successfully in a variety of site conditions and all over the upper section of the Edwards Aquifer Recharge.

Sand filters are most effective for watersheds greater than 10 acres (4 ha) to greater than 50 acres (20 ha). The most desirable sites for sand filters are those with slopes in the range of 3 to 5 percent and sufficient right-of-way to allow all earthen containment. When right-of-way is limited, the cost of using concrete containment structures or underground vaults must be weighed against the cost of acquiring additional right-of-way.

Rocky, karst sites will complicate excavation. Therefore, basins must be lined to prevent contamination of the groundwater. Filtration structures must not encroach on natural wetlands.

Design Requirements

Current design methods recommend use of a pretreatment basin. The pretreatment basin may provide full or partial pretreatment. The following design information is based on research by the City of Austin and guidance in the FHWA study, Evaluation and Management of Highway Runoff Water Quality (1995) and the LCRA Non-Point Source Pollution Control Technical Manual (1998).

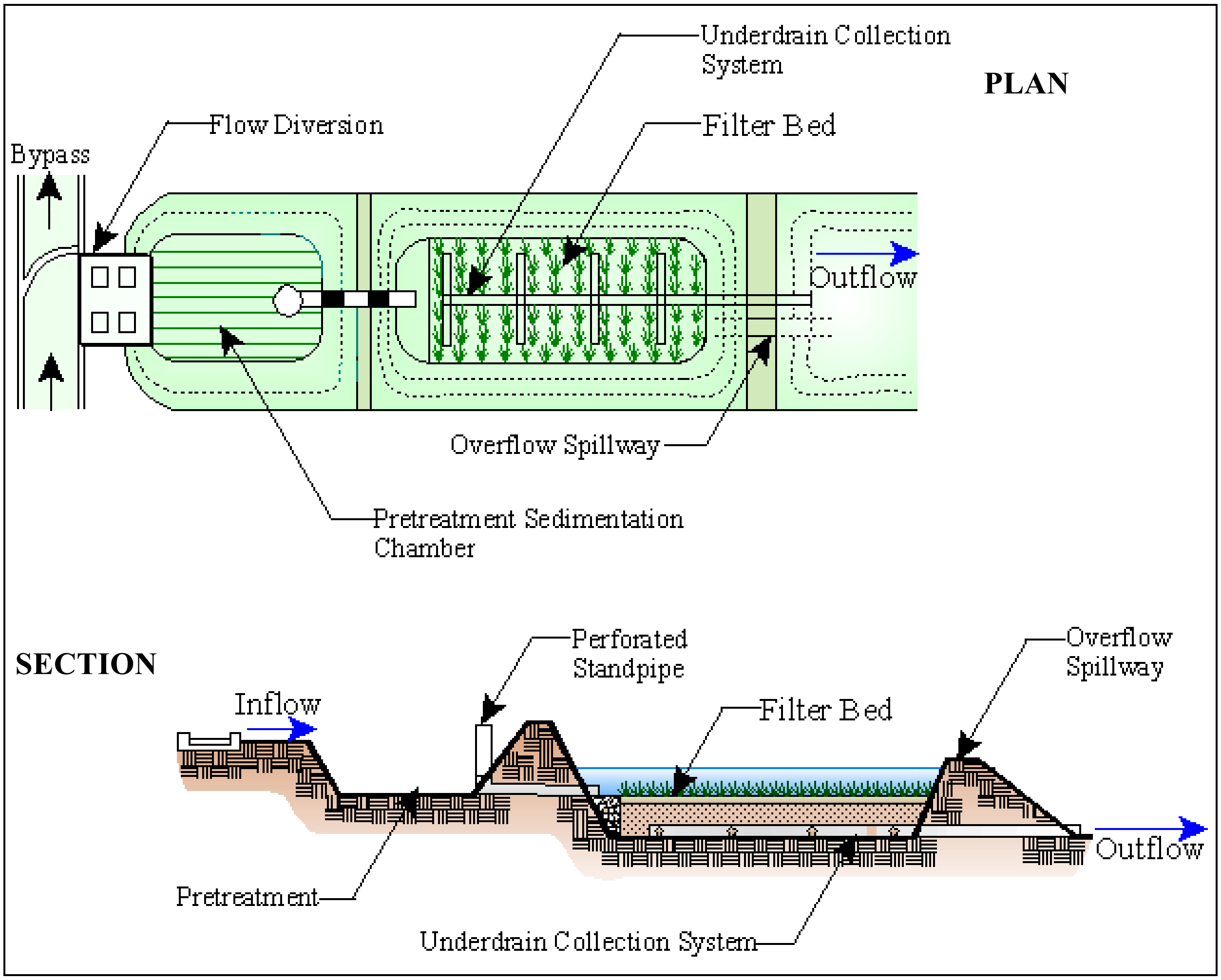

Figure 23. Austin Sand Filter: Plan and Section.

Pretreatment Capture Area

Two types of pretreatment designs are used for sand filters:

Full Sedimentation: The pretreatment basin is sized to capture the entire water quality volume. It is recommended that the sediment basin used to pretreat a sand filter be large enough to capture the entire water quality volume and meter it to the filter chamber. This is called full sedimentation treatment.

Partial Sedimentation: The pretreatment basin is sized to capture less than the full water quality volume. The LCRA technical manual requires that the volume of the pretreatment basin and the filter basin equal the water quality volume. Most other sources suggest that the pretreatment basin be 25 percent to 75 percent of the total water quality volume.

The partial sedimentation option is recommended to minimize the size of the basin. Claytor and Schueler (1996) recommend a sediment chamber equal to 75 percent of the water quality volume. They point out that the sedimentation chamber continues to drain into the filter chamber during the course of a storm, and for this reason only short duration, high intensity storms would be likely to exceed the capacity of the sediment chamber. The full sedimentation option is based on the logical assumption that with a large pretreatment capacity, the filter medium will not be clogged as quickly, and therefore less maintenance will be required to maintain the desired level of performance. However, this assumption does not appear to be born out by the data.

A simple method of estimating pond volume is given by LCRA as:

$$V = 1.50 \cdot R_v \cdot A \cdot \frac{43,560}{12}$$

where:

V	=	the required stormwater capture volume (CF)
1.50	=	rainfall depth in inches
$R_{v1.50}$	=	ratio of runoff to rainfall for a 1.50 in. event over the contributing watershed where $R_{v1.50}$ = 0.0081(percent of impervious cover)+0.0011. See Figure 24.
A	=	watershed area in acres

The 1.50 in value is based on the statistical fact that 90 percent of all storm events in the central and eastern portion of Texas reach depths of 1.5 inches or less. Therefore, sizing the basin according to this rule assumes that the basin will capture all the runoff from 90 percent of the storm events.

Other methods found in the literature set basin volume on capture of the first 0.5 in of rainfall. While the first 0.5 in rule has been widely used, some recent research has demonstrated that this allows a significant water volume to bypass the structure. This amount of bypass is significant, and as a result, these smaller volume structures do not appear to meet quality goal. This is particularly true for areas with impervious areas on the order of 70 percent (Chang et al. 1990). Therefore, the 1.50 in rule would seem reasonable for a majority of projects.

% Impervious Cover	$R_{V\,1.50}$
10	0.08
20	0.16
30	0.24
40	0.33
50	0.41
60	0.49
70	0.57
80	0.65
90	0.73

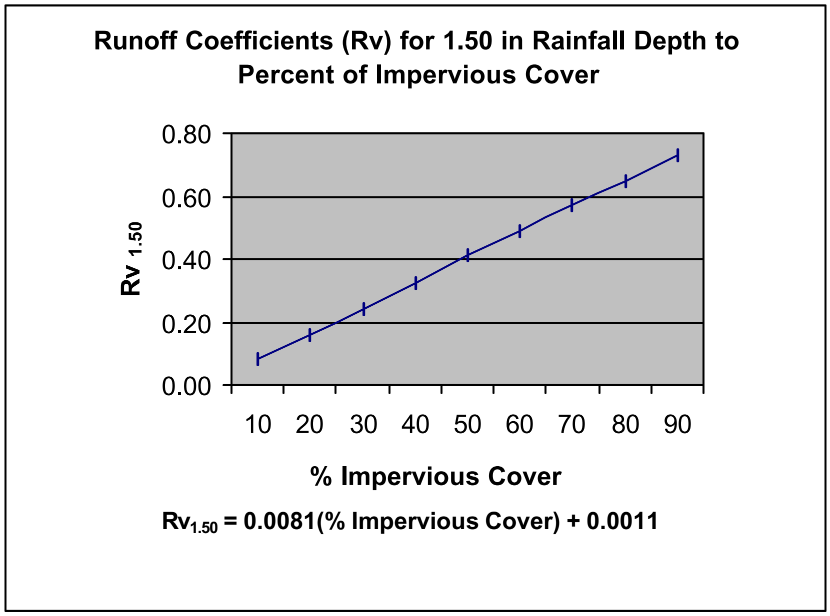

Figure 24. Values of $R_{v1.50}$.

The method recommended by Claytor and Schueler for determining the surface area of the sedimentation basin is derived from the Camp-Hazen Equation.

$$A_S = -\left(\frac{Q_O}{w}\right) \cdot \ln(1 - E)$$

where:

A_s = sedimentation basin surface area in sf

E = trap efficiency or the target pollutant removal efficiency

w = particle settling velocity for target particle size. For impervious areas less than 75 percent of the watershed use silt: w = 0.0004 ft/sec; for impervious areas of 75 percent and greater use w = 0.0033 ft/sec.

Q_o = rate of outflow from the basin. This is equal to the water quality volume (*WQV*) divided by the desired detention time (t_d). Claytor recommends 24 hours. However, longer detention times will result in higher sediment removal and reduce the basin size.

Given the basic assumptions above, the required surface areas for sedimentation can be found as follows:

$$Q_o = \frac{WQV}{t_d}$$

$$A_s = \frac{WQV}{[24^{\text{hr}} \cdot 3600^{\text{sec/hr}} \cdot 0.0004^{\text{ft/sec}}]}$$

$$A_s = 0.066 \cdot WQV$$

For watersheds with impervious areas of 75 percent or greater, the sedimentation area required would be:

$$A_s = 0.0081 \cdot WQV$$

Each of these equations assumes a detention time of 24 hours and a target removal of 90 percent of suspended solids. This method is essentially the same as the method recommended by Young et al. (1996).

Filter Basin Area

The City of Austin uses the following relationship to determine the surface area of a sand filter bed. This method assumes that the required surface area is a function of the infiltration rate of the filter medium, the depth of the filter bed, the head, and the sediment loading.

$$A_f = WQV \cdot \frac{d_f}{[k \cdot (h_f + d_f) \cdot (t_f)]}$$

where:

A_f	=	surface area of the filter bed sf
WQV	=	water quality treatment volume cf
d_f	=	filter bed depth
k	=	infiltration rate of the filter medium in ft/day
h_f	=	average depth of water over the filter bed (0.5 of the maximum depth)
t_f	=	time for water quality volume to pass through the filter medium

Water quality volume can be found by the simple method given earlier in this section. The depth of the filter bed is usually between 18 and 24 inches (0.45 m - 0.60 m). The average head should be between 2 ft and 6 ft depending on the site conditions. Forty to 48 hours is reasonable for the water to pass through the filter bed.

The infiltration rate through the filter medium should be established by lab testing the proposed material. Experience in the Austin district suggests that there is such wide variation in the performance of natural materials that testing is the only way to determine the infiltration rate (k). For preliminary estimates, a value of 3.5 ft/day can be used. This is based on testing conducted by the City of Austin in 1988. However, final design should be based on a tested material available from a known source.

Other design considerations are as follows:

- Provide maintenance access to each chamber of the basin. Depending on the soil type, it may be desirable to stabilize a portion of vegetated area of the sediment basin to facilitate access and sediment removal.
- Ramps into the individual chambers should be stabilized with concrete or turf reinforcing materials.
- The surface of the filter bed must be level. The sand filter materials should be lab tested to determine the optimum compaction density to maintain the design permeability.
- Sand has no specific TxDOT Item, but should follow the criteria outlined in Appendix C.
- Perforated pipe should meet TxDOT Item 556.
- Distribution boxes should be provided and set level to ensure good distribution to the filter media.
- Discharge pipes should be protected with appropriate end treatments.
- Slope of subdrains should be set at a minimum of 0.005 ft/ft.
- Provide cleanout access to underground pipe.
- Hydroseeding the appropriate TxDOT seed mix is recommended for the basins within the recommended planting season. Outside the specified planting season, sodding is recommended.
- Grass should be established on the filter bed. For most situations, sodding over the bed should be avoided since this will likely introduce clay soils and impair the permeability of the sand bed. The sand bed should be seeded during the growing season with an appropriate TxDOT seed mix.
- Headwalls, endwalls, and concrete work that may be required should meet the appropriate TxDOT specification per the Standard Specification for Streets Highways and Bridges.

Pollutant Removal Performance

The pollutant performance of sand filters appears to have been over estimated in early studies. In 1987, Schueler had reported 99 percent removal of TSS and values of up to 70 percent for removal of total nitrogen. Since that time, other studies have reported significantly lower efficiencies.

Table 12. Pollutant Removal Performance: Surface Sand Filters.

Pollutant Removal Performance: Surface Sand Filters (Percent)			
Pollutant	FHWA Evaluation and Management of Highway Runoff Quality [1]	National Pollutant Removal Performance Database [2]	Scheuler: Controlling Urban Runoff, 1987 [3]
TSS	70-86	87	99
Total Phosphorous	50-65	59	65-75
Total Nitrogen	31-47	32	60-70
Metals	79-85 (Pb) 78-84(Zn)	80(Zn) 49(Cu)	95-99
Oil and Grease	N/A	N/A	N/A

[1] Young et al. (1996); [2] Winer (2000); [3] Schueler (1987). Note: In Schueler's first publication the Austin Sand Filter was grouped with infiltration trenches. It has since been recognized as a separate BMP type, probably because it does not infiltrate water into the substrate but into a surface water conveyance.

In their 1996 publication, "Design of Stormwater Filtering Systems," Claytor and Schueler are suggesting significantly lower performance values. For example, they suggest only 35 percent for total nitrogen and 85 percent for TSS. These values are reasonably consistent with the values currently reported in the EPA's National Pollutant Removal Database. These lower values are also consistent with sampling conducted by the City of Austin and by Keblin et al. (1997).

Maintenance Requirements

Regular routine maintenance is essential for all types of stormwater filter systems. Normal maintenance tasks consist of trash removal, inspection, and mowing earthen structural components, sediment basins, and the grassed filter surface.

It is essential that any surface channels, embankment faces, and berms be maintained in a well-vegetated state and that sediment be removed from the pretreatment basin regularly. Poor vegetation cover in the immediate vicinity of a surface filter or resuspension of sediment in the pretreatment basin will result in excessive sediment transfer to the filter media and reduce the effectiveness of the filter. When this occurs, the filter media will usually have to be removed and replaced.

Specific maintenance activities include:

- removal of sediment when it reaches a depth of 6 in (150 mm);
- renovation of filter media when the drawdown time exceeds twice the designed time. Renovation will usually be required every three to five years, depending on the level of sediment reaching the filter bed;
- removal of trash and debris from the chambers regularly. Actual time depends on the location of the facility. Structures in heavily urbanized areas will likely require more frequent servicing to remove trash and floatables;
- mowing to maintain acceptable appearance. Mowing heights of four to six inches in most situations, and
- rutting of the sand filter medium should be avoided since a level surface is essential to efficient operation of the filter.

Costs

Filter type BMPs are most cost-effective for watersheds of 10 acres (4 ha) or greater. Good preventative maintenance that includes frequent removal of trash and sediment and maintaining good vegetative cover around and upstream of the basin is essential to keeping long-term costs reasonable. Poor maintenance will lead to a need for more frequent renovation, which can be a significant cost.

Figure 25 shows the cost per pound of TSS removed for structures that are primarily earthen, partially concrete, or principally concrete. The two dots shown on the graph are the actual construction costs for two sand filter type structures built by TxDOT. Both structures are principally concrete. Both structures are located on very difficult sites comprised of odd shapes, steep slopes, and rocky substrate. The slightly elevated costs over the prototype used for estimates probably account for most of the difference in cost.

What this example underscores is the efficiency and reduced cost that accrues from treating the largest possible drainage area. The structure at Academy and 290, for example, had a construction cost of approximately $1.3 million dollars. In contrast, the MoPac 290 bridge site was just under $300,000. But when the cost is compared in terms of dollars per pound of pollutant removed, the Academy structure is significantly more cost-effective by a factor of 68 percent.

Grass Swales (Borrow Ditches and Median Swales)

Description

Grass channels or swales are a common part of every rural highway section. Driving lanes are usually drained to a borrow ditch that conveys water parallel to the driving lanes until the road intercepts a crossing drainageway or stream. Likewise, most divided highways have a vegetated center median that also carries water parallel to the road in a vegetated channel. The primary difference between these channels and water quality channels is whether they are designed and maintained as water quality BMPs.

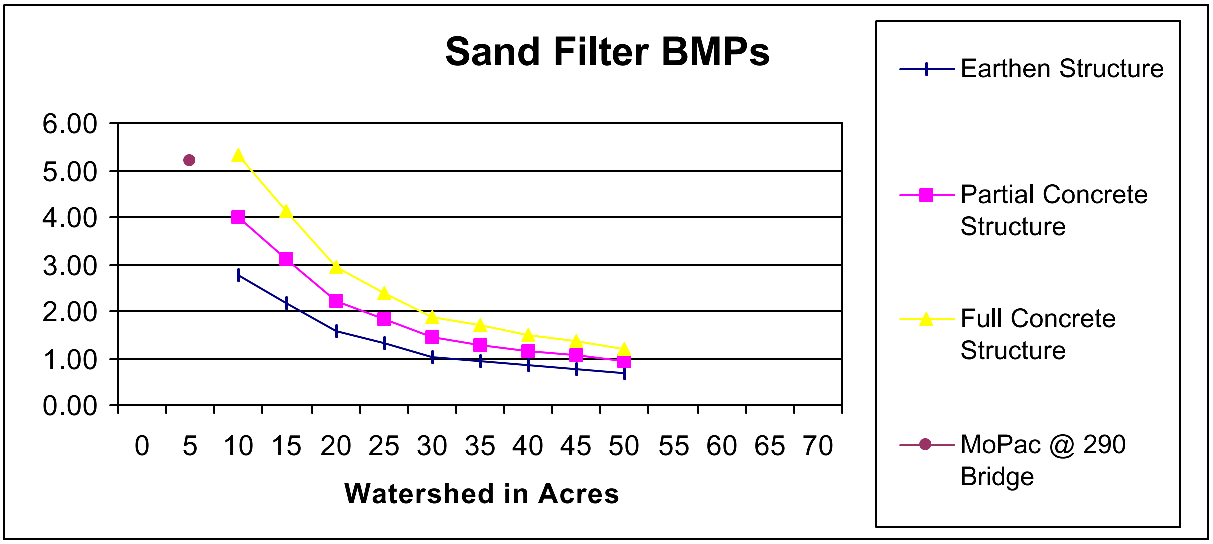

Figure 25. Cost per Pound of TSS Removed for Various Sand Filter Configurations.

Numerous studies including Keblin et al. (1997), Oakland (1983), and Yousef et al. (1985), have demonstrated that grassed channels have positive water quality effects. However, the reported efficiencies vary greatly among studies. In 1996, Claytor and Schueler examined 16 studies in an effort to explain the variability between observed results. From this effort they concluded the following:

- For the most part, channels designed simply as drainage ways performed poorly as water quality structures.
- Channels that were specifically designed as water quality channels or had soil, slope, and water table properties that effectively met the properties of a vegetated water quality swale were much more consistent in their performance.

This comparison strongly suggests that grass swales and channels can be very effective water quality management tools. However, to be effective, simple design guidelines should be followed.

Applications and Constraints

When site conditions are satisfactory, grass swales and channels are a significant and viable water quality BMP. They are particularly useful where well-vegetated borrow ditches and median swales can be developed parallel to a roadway at slopes of 1 percent to 5 percent, and where soils are relatively permeable (NRCS hydrologic soil groups A through C). Soils in hydrologic soil group D may or may not be appropriate. This means that a large percentage of state maintained right-of-way has some potential for water quality purposes.

Table 13. Performance of Grass Swales Based on Design Type[g].

Drainage Channels (10) (Percent)					BioFilter Swale 200 ft (1) (Percent)					Water Quality Swales[a] (6) (Percent)				
TSS	**TP**	**TN**	**Zn**	**Pb**	**TSS**	**TP**	**TN**	**Zn**	**Pb**	**TSS**	**TP**	**TN**	**Zn**	**Pb**
Neg-68[b]	Neg-60[c]	Neg-37[d]	Neg-55[e]	Neg-49[f]	83	29	Neg	63	67	81-98 **(88)**	18 - 99 **(49)**	40 - 99 **(74)**	60-99 **(79)**	50-99 **(78)**

a. Bold numbers indicate the mean for all reported values. No negative values were reported.
b. Five cases were negative or not statistically different.
c. Five cases were negative.
d. Eight cases were either not reported, negative, or not statistically different.
e. Five cases were either not reported, negative, or not statistically different.
f. Five cases were negative or not statistically different.
g. Adapted from Claytor and Schueler (1996).

Vegetative features in general are not particularly useful in removing most nutrients except in those cases where mechanisms were provided to increase infiltration and detention time. While the mechanisms are not clear, research shows that grass channels are quite efficient in removing metals. Properly designed swales also appear to be efficient in removing solids and petroleum hydrocarbons.

Although grass swales and ditches have been demonstrated to be a very positive water quality tool for meeting the requirements outlined in the Clean Water Act, Section 401, it is not clear how utilization might be impacted by Section 404 requirements. At this time it appears that this will have to be negotiated with the regulatory agencies. Overall, the cost and benefits of using existing and new grass swales and ditches as a water quality tool would weigh heavily in favor of their use.

Design Requirements

The primary factors that will determine the suitability of a grass swale or channel as a water quality structure are: soil type, slope of the contributing drainage basin, imperviousness of the drainage basin, and the cross section of the swale. Grass channels can be used to service drainage areas of as much as 10 acres (4 ha). Specific criteria for improved grass swales to be used as water quality BMPs include:

- The average slope of the watershed should be 5 percent or less.
- Maximum use should be made of natural topographic features such as natural swales, draws, and depressions.
- Soils should have infiltration rates of 0.18 in/hr (4.5 mm/hr). Heavy clays typical of NRCS Hydrologic Soil Group D are generally not acceptable.
- The seasonal high groundwater table should be at least 10 ft (3 m) below the surface of the channel.

- The cross section of the channel should be designed to carry normal flows at a depth of the normal vegetation height. Mowing heights of 4 in (100 mm) to 6 in (150 mm) are standard for most TxDOT roadsides.
- A longitudinal slope of 1 percent is preferred. LCRA allows slopes of up to 4 percent or where a velocity of 1.5 ft/sec is exceeded. Greater slopes are acceptable with the introduction of check dams to reduce velocity and increase detention times.
- Channel bottom width should be between 2 ft and 6 ft. Channels may be wider but it is difficult to achieve uniform flow over the channel bottom at low flows which can reduce the overall water quality effectiveness.
- Where check dams are used the minimum distance between dams can be determined as follows:

$$L = \frac{h}{g}$$

Where:

L = the minimum horizontal distance between check dams

h = the height of the check dam (2 ft or less)

g = the longitudinal gradient of the channel

The LCRA suggests a check dam spacing equal to six times the minimum spacing. Therefore, the recommended spacing based on the LCRA recommendation is:

$$L = 6 \cdot \frac{h}{g}$$

The following procedure is recommended for the design of grass-lined water quality channels and is based on Claytor and Schueler (1996) and LCRA (1998):

- The channel capacity should be based on the runoff from a rainfall depth of 1.5 in. (This is the value that would capture the runoff of 90 percent of all storm events.)
- Compute the peak discharge (Q_p) for the design storm by an approved method.
- Use the peak discharge (Q_p) to size the channel or check the size of an existing channel being improved. Use Manning's equation. Figure 26 provides suggested values for Manning's "n" for grass-lined channels flowing at various depths.

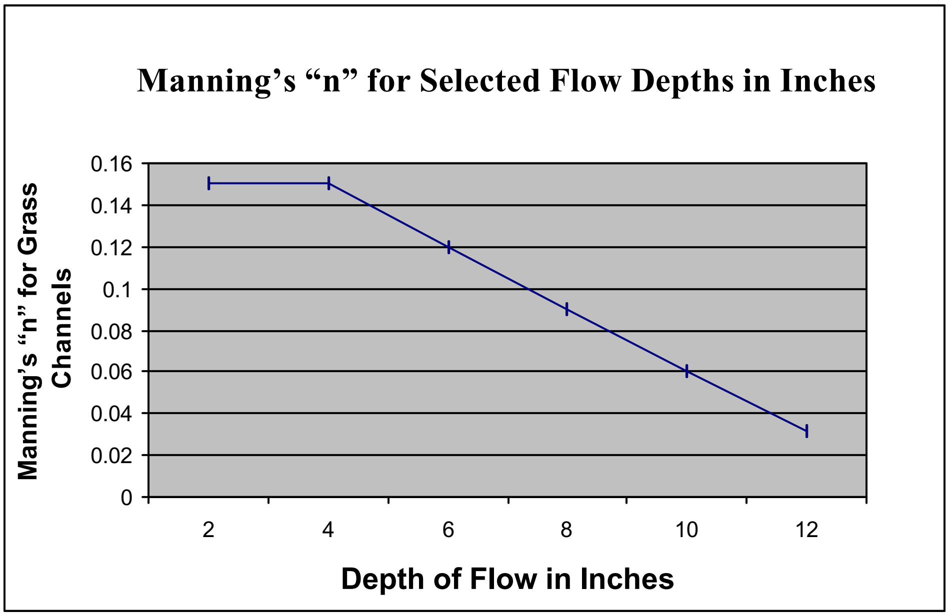

Figure 26. Suggested Values for Manning's "n."

Adapted from Claytor and Schueler (1996).

- The following equation represents LCRA's quick trial and error method for grass channel design.

  Find the depth of flow in a channel by:

  $$Y = [(Q_p \cdot n) / 1.486 \cdot W \cdot S^{0.5}]^{0.6}$$

  where:

  Y = the depth of flow in feet

  W = the bottom width of the channel (trapezoidal section is assumed)

  Q_p = the peak discharge for the design storm in cfs

  S = the slope of the channel bottom in ft/ft

The cross sectional area of flow can be determined by:

$$A = W \cdot Y$$

The average velocity of flow is found by:

$$V = \frac{Qp}{A}$$

- The channel design should also be checked for larger design events to be sure that sufficient capacity is available and that the channel will not likely erode. For most roadside vegetation associations in Texas, velocities should not exceed 4 ft/sec in sandy soils and 5 ft/sec in more cohesive clays.
- Provide a minimum of 12 in freeboard above the peak design storm.
- Check dams should be designed for safety and ease of mechanical mowing. Reinforced earth or rock check dams that are backfilled and seeded are recommended. Figure 27 provides typical details of grass swale check dams.

Channel length should be at least 200 ft. (60m), or of sufficient length to provide a water residence time of at least 10 minutes. Assuming a minimum residence time of 10 minutes, the required length of swale is calculated by:

$$L_{10} = 600 \cdot \frac{Qp}{A}$$

where:

L_{10} = the length of swale required for a detention time of 10 minutes

Q_p = the peak discharge for the runoff from a 1.50 in rainfall depth over the watershed

A = the cross-sectional area of the channel

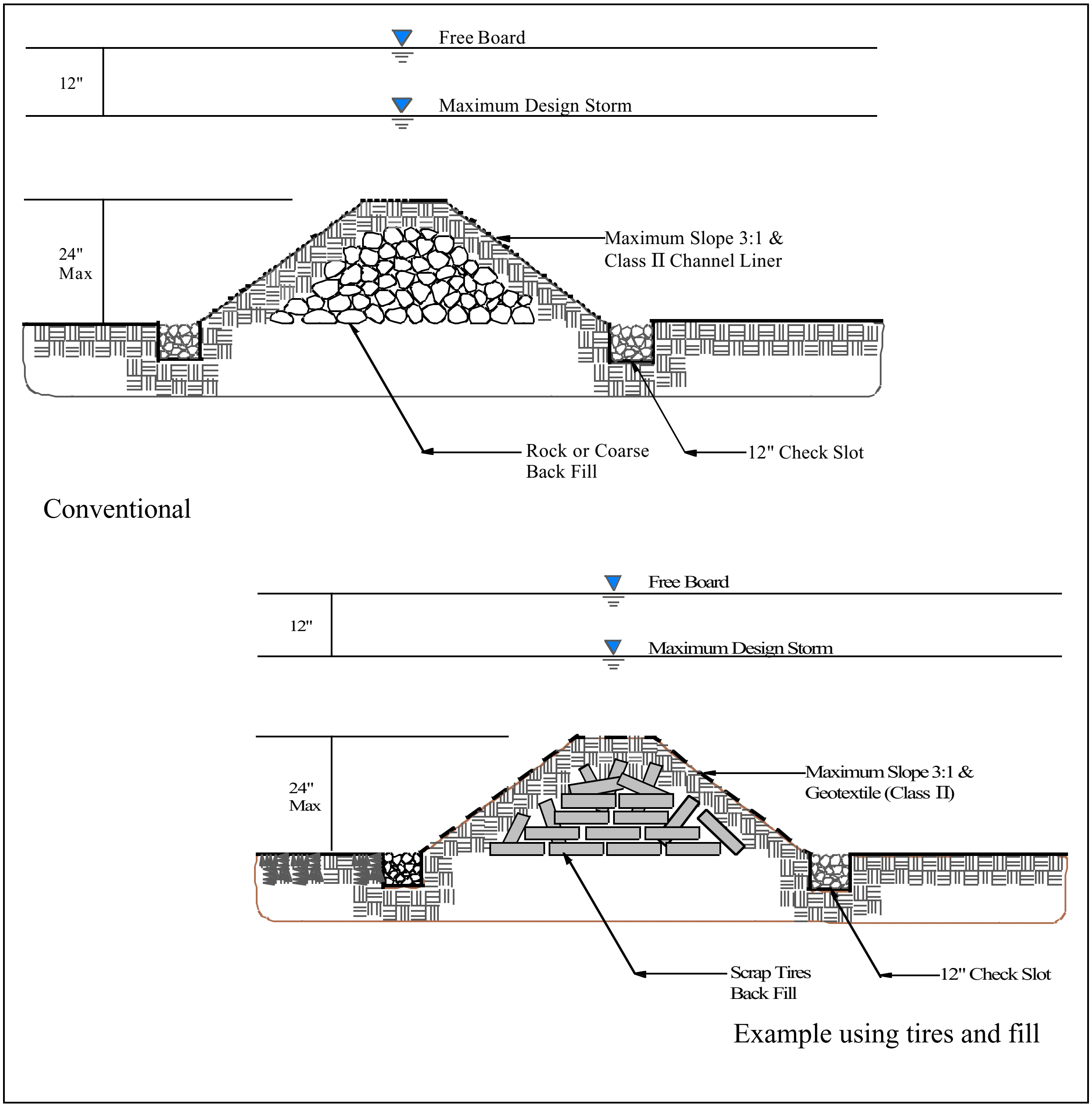

Figure 27. Check Dams for Use in Grass-Lined Channels.

Pollutant Removal Performance

The pollutant removal performance depends on whether or not a grass swale or channel has been designed to specifically provide water quality functions. In general, any channel will that meets the four basic design criteria related to slope, soil type, vegetative cover, and length. The efficiency numbers shown in Table 14 are for water quality swales only.

It is important to remember that vegetated BMPs have variable performance with respect to the removal of nutrients. The primary removal of nutrients will be due to infiltration or detention of the runoff in the swale. Therefore, the use of check dams is very important to overall success where nutrients are concerned. Likewise, a good vegetative cover and mowing heights maintained above 4 inches will further enhance the performance of a grass channel.

Table 14. Pollutant Removal Performance: Water Quality Swales (Percent).

Pollutant	FHWA Evaluation and Management of Highway Runoff Quality [1] 200 ft length	National Pollutant Removal Performance Database [2]	Claytor and Schueler: Controlling Urban Runoff (1996) [3]
TSS	83	81	88
Total Phosphorous	29	34	49
Total Nitrogen	25	84	74
Metals	63 (Pb) 67(Zn)	71(Zn) 51(Cu)	78 (Pb) 79 (Zn)
Oil and Grease	75	N/A	N/A

[1] Young, et al. (1996); [2] Winer (2000); [3] Claytor and Schueler (1996).

Maintenance Requirements

The maintenance requirements of grass channels are minimal beyond normal roadside maintenance consisting of seasonal mowing and trash pickup. Periodically, sediment will have to be removed from behind the check dams, but this can probably be scheduled as a part of regular ditch maintenance. In rapidly urbanizing areas typical of the urban fringe, some rapid sedimentation of roadside channels is very likely. In these cases, provisions will have to be made for more frequent maintenance of ditches and swales.

It is very important to provide for immediate revegetation after ditch cleaning and sediment removal. This is probably the only significant expense that would be beyond normal roadside maintenance.

Costs

Figure 28 summarizes the costs per pound of TSS removed for grass swales.

For small watersheds and for areas with relatively flat terrain the grass swale is an extremely effective water quality BMP. Since the normal rural cross-section of a highway almost always includes a grass-lined channel on at least one side of the right-of-way, a great deal of the Clean Water Act, Section 401 water quality requirement could be met by adding some very simple check dams to the roadside channels. In many cases, rock check dams are used as a part of the Storm Water Pollution Prevention Plan (SW3P) for construction. Properly located and constructed, these dams could be left in place as part of the long range water quality management plan.

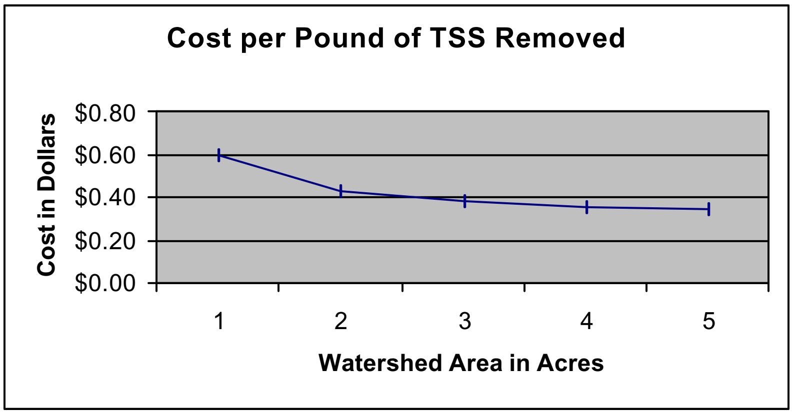

Figure 28. Cost per Pound of TSS Removed for a Grass Swale.

Biofiltration or Biofilters

Description

Biofilters are essentially a combination of natural pollutant removal components that treat stormwater by absorption, decomposition, filtration, and other natural processes. A complete biofiltration facility should contain six components as illustrated in Figure 29.

A biofiltration structure has six primary components:

- a grass filter belt around the primary holding area,
- a ponding basin,
- a sand filtration bed,
- an organic mulch layer,
- a top soil layer, and
- plant materials.

In areas of karst topography or where there is a near surface ground water supply that could be contaminated by infiltration of pollutants, a waterproof line and underdrain system can be used to collect filtered water and direct it to surface channels.

A grass filter belt around the primary holding area provides initial sediment removal and transitions runoff into the holding area. The ponding basin collects and stores runoff for transition to the filter layers below. The sand filtration bed intercepts a portion of the runoff and helps provide aeration to the adjacent top soil bed. The top soil, a loam with good nutrient content, supports vigorous plant growth, and the clay content of the loam helps remove some pollutants by adsorption. The organic mulch layer maintained over the surface is intended to provide some filtration and supports the development of beneficial microorganisms. Plant materials in the basin remove additional pollutants through uptake and assimilation.

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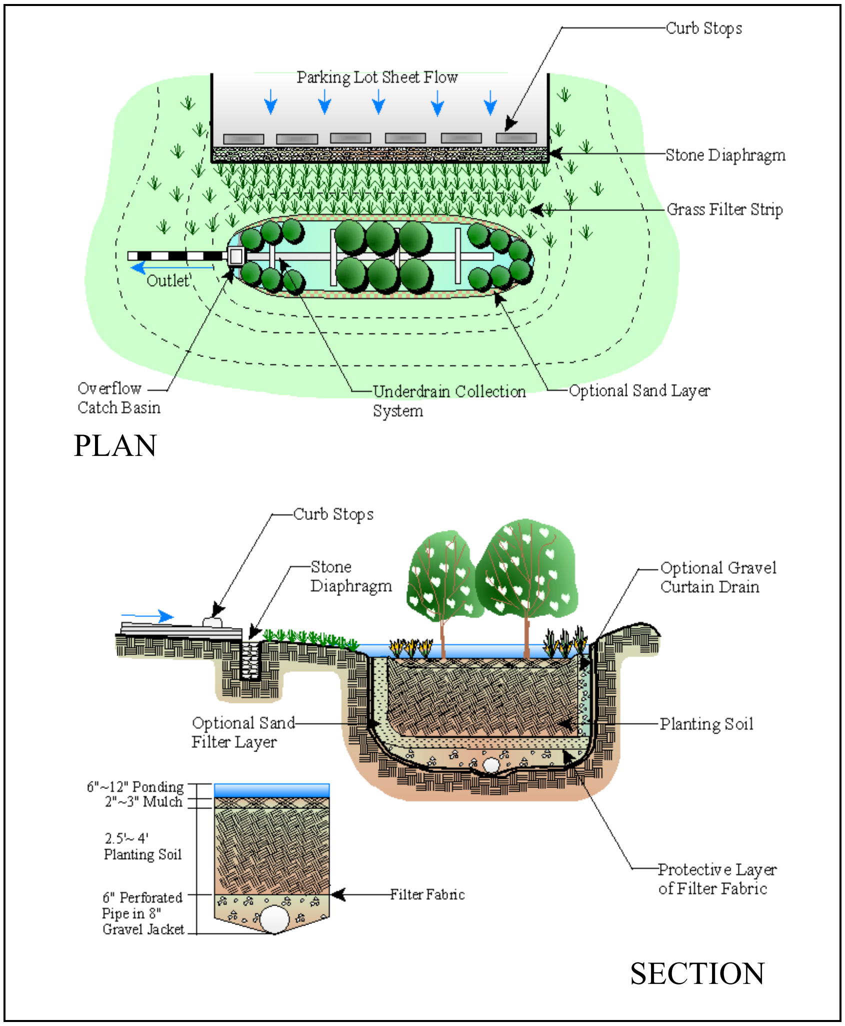

Figure 29. Biofiltration Structure.

Applications and Constraints

The use of biofilters appears to have limited application in transportation practice due to the space required for implementation. Situations where biofiltration may have some application would be on large sites adjacent to paved parking, typical of urban park and ride or transit facilities. Like grass swales, the biofiltration system should be very effective in removing oil and grease.

Design Requirements

Bioretention is a concept that has always been associated with vegetative water quality concepts. However, Claytor and Schueler (1996) indicate that Prince George's County, Maryland, was one of the first agencies to actually codify a bioretention BMP around 1990. These recommendations are adapted from Claytor and Schueler (1996).

For highway applications, a biofiltration structure would be designed to operate offline. A diversion structure would direct a design water quality volume to the biofiltration structure for treatment. The basic design requirements for a biofiltration structure are as follows:

- The intake structure should be designed to reduce velocity and spread the flow onto a vegetated pretreatment filter strip.
- The pretreatment strip should be heavily vegetated and sloped at 1 to 5 percent. Steeper slopes will not provide the desired velocity reduction and treatment. Other features, such as a stone diaphram or sump can be added to reduce velocity and enhance pretreatment. Table 15 shows the recommended sizing of grass pretreatment strips.

Table 15. Recommended Sizing of Grass Pretreament Strips.

Design Element	Paved Areas				Remarks
Max Inflow Approach in Ft (m)	35< (10<)		75> (22>)		
Filter Strip Slope (Percent)	2<	2>	2<	2>	Maximum 6
Minimum Filter Strip Length	10 (3)	15 (4.5)	20 (6)	25 (7.6)	

Adapted from Claytor and Schueler (1996).

- Provide a coarse sand or pea gravel curtain drain adjacent to the main soil bed. This is to supplement infiltration of the water quality volume into the topsoil bed.
- Provide a shallow ponding area of 6 in to 12 in (150 mm to 300 mm).
- An organic mulch layer should be composed of a well-graded bark mulch or organic compost with a neutral to slightly acid pH.
- A planting soil bed 30 in to 48 in deep. The soil can range between a sandy loam to a well-drained clay loam. The pH should be neutral to slightly acid.
- The surface of the topsoil bed must be level to allow ponding and ensure uniform infiltration.
- Plant materials should be a mix of grasses and woody species. Trees with high branching or open habits of growth should be used to avoid shading and loss of the grass cover as the vegetation matures. Good examples are native plants like yaupon (Ilex vomitoria), cedar elm (Ulmus crassifolia), honey locust (Gleditsia tricanthos f. inermis), river birch (Betula nigra), sycamore (Platanus

occidentalis), and loblolly pine (Pinus taeda). Grass mixes should be those appropriate to the region of Texas.

- Claytor and Schueler recommend a sand bed between the topsoil layer and the gravel bed and subdrain. The sand should provide additional polishing of the water and protect the gravel bed from siltation. A filter fabric is not mentioned between the sand and gravel but could be useful depending on the fine content of the sand.
- The under drain system collects the filtered water and conveys it to the receiving channel which may be a ditch, stream, or storm sewer. The depth of the bed should be sufficient to provide a cover of 2 in (50 mm) over the top of perforated pipe.
- An over flow should be provided to convey excess flows.
- The filter surface area can be sized using the method described in the section on sand filters.
- Claytor and Schueler give some minimum sizing guidance for bioretention facilities serving a one acre watershed. These guidelines were included in the Prince George's County, Maryland, Bioretention Design Manual, 1993. They are:
  - minimum width of ponding area 10 ft (3 m),
  - minimum length 15 ft (4.5 m),
  - for width greater than 10 ft (4.5 m) maintain a 2:1 ratio of length to width,
  - minimum ponding depth 6 in (150 mm),
  - minimum depth of top soil bed 4 ft (1.2 m), and
  - sand bed depth 12 in (300 mm).

In general, the complexity of biofiltration will limit the application of this BMP to very special situations where high performance is desired for small watershed areas.

Pollutant Removal Performance

The biofiltration concept is included in practically all recent literature on BMPs, along with the design considerations summarized in the preceding section. However, there are no studies in the literature that document the performance. USEPA's National Pollutant Removal Database, June 2000 publication specifically cites the bioretention BMP as a critical gap in the knowledge base.

So, while it could be assumed that a bioretention structure should combine all the best traits of a grassed swale and a sand or organic filter, there is no data to support this assumption.

Maintenance Requirements

Maintenance of a bioretention structure would be about the same as for a grass swale or infiltration basin. These would include routine activities such as mowing, inspection, annual replenishment of the mulch layer, and trash pickup.

Periodic tasks would include flushing the sand and gravel layers and cleaning the subdrain system. What is not clear is the life cycle of the topsoil layer planting. Since woody materials are used in the primary biofilter area, it would be extremely difficult to rebuild the underlying sand and gravel layers without disturbing or removing the large woody materials. Depending on the location, this could create problems with the public and regulators.

Costs

Biofilters are best suited for small watersheds and fall in the same service group as porous pavements and grass swales. Figure 30 presents cost per pound of TSS removed by a biofilter.

The costs in this case are based on the minimum space and material requirements given by PrinceGeorge's County for biofilters shown earlier. Maintenance includes routine tasks like inspection, trash removal, mowing, and annual replacement of the mulch cover.

It was also assumed that one major reconstruction would be required during the 20 year period. Researchers assumed reconstruction costs to be 1.5 times the initial construction cost.

Given the lack of hard information on the performance and cost of biofilter BMPs, it is difficult to suggest this technique as a viable tool for water quality purposes at this time.

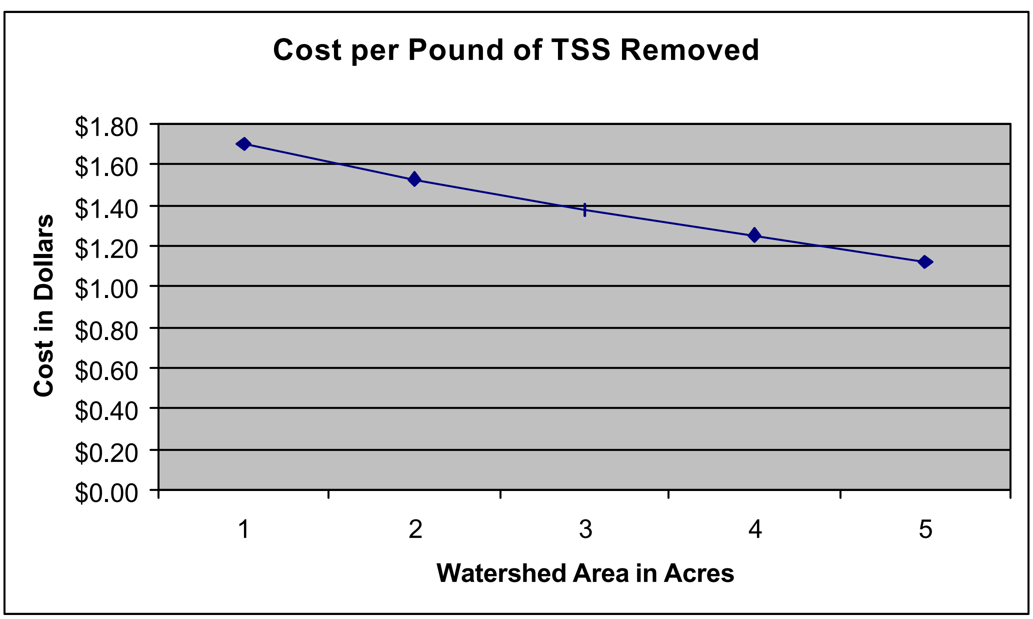

Figure 30. Cost per Pound of TSS Removed: Biofilter.

PERFORMANCE MONITORING

INTRODUCTION

The literature review on stormwater BMPs strongly suggested that there were lower cost options for treating stormwater than those that are employed by TxDOT in the Austin district. Most all the structures in the Austin district are variations of what is known nationally as the Austin Sand Filter. These are two or three chamber structures. The first chamber uses sedimentation to remove heavy solids from runoff. The water is then passed through a perforated stand pipe or a rock gabion dam to a sand filter bed. The water moves through the sand medium and is collected by a subdrain network and discharged into either a wet pond for polishing or directly into a receiving channel or stream.

The sand filter and rock gabion structures are subject to clogging, and several studies show that this can occur quickly depending on the state of upstream development. When a wet pond is incorporated into the structure, it is difficult to maintain a permanent water pool without providing supplemental water because natural rainfall is not sufficient to maintain a permanent pool. In a developing watershed with ongoing construction, these types of BMPs will quickly lose their utility due to heavy sediment loads.

Less expensive stormwater treatment options are infiltration basins, extended detention basins, and water quality swales. Infiltration structures are mentioned because, even though they cannot be used over the Edwards Aquifer due to the potential for polluting the ground water, they would have application in other parts of Texas.

These BMPs are all less expensive to build and maintain than sand filters or wet ponds. And due to their relative simplicity there was some evidence that they maintained their performance better over the lifetime of the facility. It was hypothesized that if this were true, the lifetime performance might be significantly better than the more expensive alternatives.

The primary deficiency in the literature was the lack of side by side comparison tests of the optional BMPs. For this reason researchers conducted a field survey of existing BMPs in the Austin area to see if they could identify a cross-section of BMPs to allow a performance comparison between the high-cost structures used by TxDOT and lower cost alternatives that other entities had installed.

The survey found several different BMP types that ranged from extended detention to some simple interpretations of the sand filter concept. After reviewing this with the Project Advisory Committee, it was agreed that we would proceed with a performance comparison study of a cross-section of in-place stormwater quality BMPs.

METHODS

Site Selection

The study took place in the southwest part of Austin in the vicinity of U.S. 290 West and the southern end of MoPac. There are several TxDOT structures in this area, as well as numerous low-cost BMPs that are under the jurisdiction of the City of Austin (City). TTI contacted the City and they agreed to allow us to monitor several of their structures. City personnel were very cooperative in helping us locate suitable sites. However, clearing all the hurdles and getting final permits for access and installation took about three months. Installation began in late November and was complete around the first of January on most structures.

Numerous sites were reviewed before the final selections were made. The criteria considered when selecting a site included:

- accessibility,
- suitable sites for installation of samplers,
- age of the structure,
- type of BMP,
- size, and
- proximity to other BMPs.

The goal was to identify a group of BMPs of different size, design, and age within a relatively small geographic space. This was intended to minimize the variations in rainfall distribution that could occur and to facilitate the collection of samples. The following sites used in the study are identified by the street address of a residence or a nearby business or highway structure.

503 Mesa Verde Court

57 Narin Dr.

77 Narin Dr.

288 La Siesta Bend

305 Kiva Dr.

232 Ira Ingram Dr.

492 Edwardson Cove

U.S. 290 Academy

MoPac Best Buy

MoPac Best Buy, TxDOT

MoPac, Gaines Creek Bridge

In addition to the neighborhood sites, three roadside sites were selected to see what value the grass shoulder of the road might have in treating runoff. These were located near the terminus of MoPac and designated as Roadside 1 through 3. All sites look similar to pictures below.

MoPac Roadside

Roadside Site
Before Treatment

Roadside Site
After Treatment

Samplers

A composite sample of water was needed for both the influent and effluent sides of each BMP. Because of the number and location of the samplers, they needed to be inexpensive, durable, and relatively vandal resistant. A simple sampler developed by GKY Associates was selected because it met these basic criteria. Figure 31 shows both boxed and non-boxed effluent samplers as well as the influent sampler.

The sampler is an injection molded plastic with five openings that can be closed with simple plugs as a means of calibrating the fill rate of the sampler. Simple float valves attached to the inside top of the sampler case seal the holes when the sampler is full. Since the sampler was new and had not been field tested or calibrated for the particular application intended, several trials were run in the flume at the Texas A&M University Hydraulics Laboratory. The sampler was checked for fill rates at various water depths and velocities as well as for a water tight seal under head.

The sampler demonstrated excellent ability to maintain a tight seal under heads of 14 inches. Fill rates varied depending on the depth of flow and the number of holes open. At depths of between 0.75 in and 0.5 in and velocities less than 1 ft/sec, fill times ranged to just over 16 minutes with one hole open. As depths and velocities increased, fill times increased somewhat.

Samplers were placed in pairs, one at the inlet to the upstream chamber and the other at the discharge point of the BMP. In the upper basins, the samplers were located near the center of the pretreatment basin. Where this was not possible due to the configuration of the BMP, the sampler

Boxed Effluent Sampler.


Non-boxed Effluent Sampler.


Influent Sampler.

Figure 31. Sampler Installations.

was mounted in a frame located to intercept the inflow stream. When samplers could be placed in the pretreatment basin, they were set approximately 1.5 in (50 mm) above the ground elevation to minimize the potential for previously trapped sediments being washed into the sampler during the first part of a storm event. The effluent samplers were placed in a box that straddled the discharge line or in a concrete apron immedately downstream of the discharge line.

Early problems with samplers were related to unanticipated site conditions or unexpected erosion around the sampler in some locations. Adjustments were made as needed to protect the samplers and enhance their function.

At the roadside sites it was found that at rainfall depths of less than about 0.7 in (18 mm) the samplers would not completely fill even with all five openings unplugged. This effectively removed them from the data set.

Sample Collection

Installation was complete in early February after several delays in getting final approval from the City of Austin. While researchers took initial samples in January, fine tuning of the sampler sites and collection procedures was not complete until mid-February. Between January and August of this year there were only 10 measurable rainfall events.

Initially, researchers intended sampling to be a one-step process. That is, the samples were removed and a clean sample container was placed in the sampler. However, with the first soaking rains in February and March there were often residual flows that continued for several days after the main event. To avoid contamination of the samples, it was necessary to leave the samplers plugged after sample collection until all flow stopped. This was usually a period of 72 hours. In one case, flows never stopped, apparently due to interflow.

The sampling procedure that was finally adopted in March was a two-step process. After an event, samples were collected, and the samplers were left plugged and empty. After 72 to 96 hours each site was revisited. The samplers were cleaned, unplugged, and a clean sample container installed.

Each site was fitted with a simple rain gauge to determine the depth of rainfall in the general area. The data suggests that the rainfall was generally uniform over the entire study area for the events sampled.

Sample Handling and Testing

Samples were collected within 24 hours after the end of the rainfall event. Samples were approximately 1.9 quarts (1.8 l). When they were removed from the sampler, they were covered and agitated to resuspend the solids that had settled out. They were then transferred to sample bottles which were prelabeled and prepared with appropriate preservatives. Bottles were immediately sealed and stored in ice. Chain of custody forms were filled out for each set of samples at the site. When all the samples were taken, they were shipped by express bus to Texas

Tech University for laboratory testing. The tests performed include: TSS, TKN, TP, Zn, Pb, and Oil and Grease.

Results

The results of the sampling were, at best, inconclusive for two reasons. First, by the time all the clearances were obtained and the samplers were in place and properly calibrated, there were only a few significant rainfall events. Second, a significant number of the events sampled gave negative readings. That is, the index pollutant in the effluent sample was equal to or greater than the influent water. In some early cases it appeared that this could be attributed to untreated surface drainage sheeting over the surface that contaminated the effluent sample. However, this would not explain all cases.

While several steps were taken to prevent contamination of the effluent samples, the random pattern of negative results continued to occur. Further field review suggests that some of the contamination may be the result of residual sediment deposited by groundwater leaking into the boxed samplers or by wind-blown material collecting in the sampler during dry periods. While all of these could contribute to the observations, there are simply too few observations to explain the negative results with any confidence.

Further review of studies by the City of Austin and Keblin et al. (1997) show that there are some negative observations in their data as well. However, these variations were not of the magnitude observed in this case.

Possibly, a passive sampler may not be discriminating enough for the intended application. Work in the flume showed that fill rates did vary under various flow depths, particularly at low flows. In these conditions, fill rates tended to accelerate rather than extend. This would tend to make the samples less representative of an overall event.

Several refinements were implemented after a good section of data was available from the first few events. At this point, the drought began, and there were no further rainfall events. Because the refinements were never field tested and because the negative values cannot be explained with any confidence, no recommendation was made to extend the time of the study to collect more data.

CONCLUSIONS

Table 16 summarizes the data points where the influent/effluent pairs showed some reduction of the various index pollutants. Almost every situation had instances where the concentration of the index pollutant in the effluent was greater than that in the influent. What is of some interest is that the values do seem to closely parallel published values in other studies.

Overall, it is not possible to draw any conclusion about how well any of the BMPs performed from the data collected. The data points are not sufficient, and the variability among observations cannot be adequately explained. Detailed data for all observations is provided in the appendix materials.

Table 16. Pollutant Removal Observations.

Pollutant Removal Observations[a]						
Location	**TSS**	**P**	**TKN**	**Pb**	**Zn**	**O&G**
Low-Cost Structures						
305 Kiva Dr.	78	55	66	15	65	68
232 Ira Ingram Dr.	81	Neg	Neg	--	--	Neg
492 Edwardson Cove	72	44	77	43	60	50
503 Mesa Verde Court	32	47	20	31	49	73
57 Narin Dr.	84	64	37	21	49	66
77 Narin Dr.	56	52	44	23	52	72
288 La Siesta Bend	72	36	14	5	36	70
TxDOT Structures						
U.S. 290 Academy	89	51	22	39	52	90
MoPac Best Buy	76	66	45	24	58	58
MoPac Bridge	89	55	77	33	63	64

a. The values shown here are simple arithmetic mean values. Some of these are taken from fewer than five observations and some observations may have been negative. No correlation was found or is implied by these values.

CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

The question of BMP performance is one that has no simple answers. It has become increasingly apparent throughout the transportation industry that BMP performance must be measured against the constituents carried in stormwater to be treated, the volume of water to be treated, and the locational constraints for the available BMPs. Changes or variations in any one of these variables can significantly impact actual performance and decisions regarding the most appropriate BMP.

Characterization of runoff is very difficult and will change with seasonal variation, landuse, atmospheric conditions, traffic patterns, and the like. Because of the variability in pollutant sources, characterizations of runoff quality have to be generalized to a point that there is very little chance that they will match actual observations. In growing urban centers it is also reasonable to assume that the constituent composition of stormwater runoff will continue to change as development continues. Therefore, the use of generalized stormwater characterizations will continue to be the norm. Refinement in the current means of predicting stormwater properties will be a function of synthesis efforts such as the National Pollutant Removal Database rather than any single project.

Setting design parameters for stormwater quality design is further complicated by the fact that there is no consensus among the regulators as to what constitutes acceptable water quality, how it is to be measured, and which BMPs will achieve a particular goal. Because of the uncertainty in the regulatory community, questions of BMP design, performance measures, and acceptability are going to become increasingly difficult. This will be particularly true in those districts impacted by aquatic habitat preservation and endangered species issues.

Water quality volume is a second issue for which there is not consensus. In the past, it was generally accepted that the first 0.5 in (13 mm) of runoff carried the majority of the pollutant load and this became a much used standard for determining water quality volume. However, current practice seems to favor designs based on the capture and treatment of all the runoff for a rainfall depth that would represent a certain percentage of all storms likely to occur. In most cases, the depth is set to represent a capture of the runoff from 90 percent of all storms.

Lastly, the final BMP selection must consider the opportunities and constraints of the site. The cost analysis conducted in this study clearly demonstrates that simple earthen structures and grass swales will be the least expensive BMPs so long as land costs or unusual site conditions are not considered. On the other hand, when land costs and construction variations required to meet site conditions are factored in, costs can quickly escalate making some seemingly expensive solutions more cost-effective for a particular situation.

This is the context in which the following conclusions and recommendations are made.

CONCLUSIONS

BMP Technology

There are no new technologies that appear to offer improved performance or cost benefits for treating stormwater. There are several proprietary devices being marketed under trade names for stormwater treatment. For the most part, these devices are some form of separator that operates on gravity or centrifugal principles.

On the other hand, there have been improvements and refinement in the selection criteria, design, and operational characteristics of existing BMP technologies. Where refined application and design knowledge was available, the information was incorporated into the discussion of the individual BMP.

BMP Performance

The ranking of BMP performance is a difficult task. Most rankings are based on a BMP's ability to reduce or remove specific index pollutants. Therefore, the notion of ranking performance differences in pollutant concentration in and out assumes that the concentrations of a particular pollutant will be removed linearly which is not the case. Secondly, there seems to be a desire to have a single BMP that will solve the water quality equation, which is also not possible. The fact is that depending on the characteristics of the stormwater and the water quality goals for that specific situation, more than one BMP may have to be utilized to meet the design goals.

These problems not withstanding, the Clean Water Act, Section 401 regulatory efforts seem to be focused on the most common pollutants found in highway runoff which are: suspended solids, phosphorous, nitrogen, lead, zinc, and oil and grease. In this regard, there is an evolving body of knowledge in the literature that does provide performance values. While these published values have acknowledged weaknesses as noted, they represent the best available information for making selection and design decisions. Given the values in the table, infiltration and detention BMPs exhibit the greatest efficiency when compared to the other alternatives. The one exception seems to be the grass swale which has been reported to have nitrogen removal rates as high as 84 percent. This value must be viewed with some suspicion since many vegetated BMPs such as wetlands and grass filter belts seem to have little or no impact on nitrogen.

Infiltration based BMPs are not viable practices in parts of the state that overlay the karst formations of the Edwards Aquifer or other near-surface groundwater reservoirs. In these areas the stormwater BMP must provide an impervious barrier between the stormwater and the substrate.

It does suggest that detention practices should be investigated further as an alternative to the filtration practices currently in use. Conditions that may mitigate against the use of detention are space availability, land costs, safety considerations, and the potential nuisance of water standing for periods of 48 to 72 hours.

In a significant number of studies, grass swales with improvements to enhance water quality have been demonstrated to be very effective stormwater quality tools. Given the character of the highway roadside and the relatively inexpensive nature of improvements needed to achieve good stormwater quality performance from grass swales, this too seems to be a much overlooked practice.

Cost

Development of a cost to pollutant removal effectiveness index was a primary objective of this study. Clearly, this is one way to evaluate the appropriateness of a BMP to an intended use. However, the difference in the pollutant removal characteristics, spatial requirement, maintenance requirement, and other intangible influences make a simple comparison difficult.

The method employed to evaluate cost in this study utilized a prototype concept in order to eliminate the cost differences that can be induced by specific site conditions. It also looked at cost differences that result from differences in the size of the watershed served by a particular BMP. Land costs or availability were not considered. The extreme variability in land costs and the availability of the space required for a particular BMP would essentially make any comparison invalid.

By using a uniform prototype for each BMP and avoiding the variability of land cost which cannot be reliably predicted, it was possible to develop base costs that could be used for initial comparisons. Then the variable costs can be applied as a final measure of cost-effectiveness for site specific conditions.

Index Pollutant

TSS was used as the index pollutant for measuring the overall pollutant removal effectiveness of a BMP. While TSS is not always a good indicator of how well other pollutants will be removed, it does seem to be a better gauge than any of the other common pollutants.

Cost-effectiveness Index

The cost-effectiveness developed for each BMP is based on the cost of removing one pound of TSS. The large, basin type BMPs are most effective at capturing and treating runoff from watersheds of 10 or more acres. Therefore, the comparison was based on watersheds of 10 to 50 acres in 10 acre increments. Three values were calculated for each BMP type based on the increased use of concrete in the construction of treatment chambers. These values are reflected in Figures 32, 33, and 34.

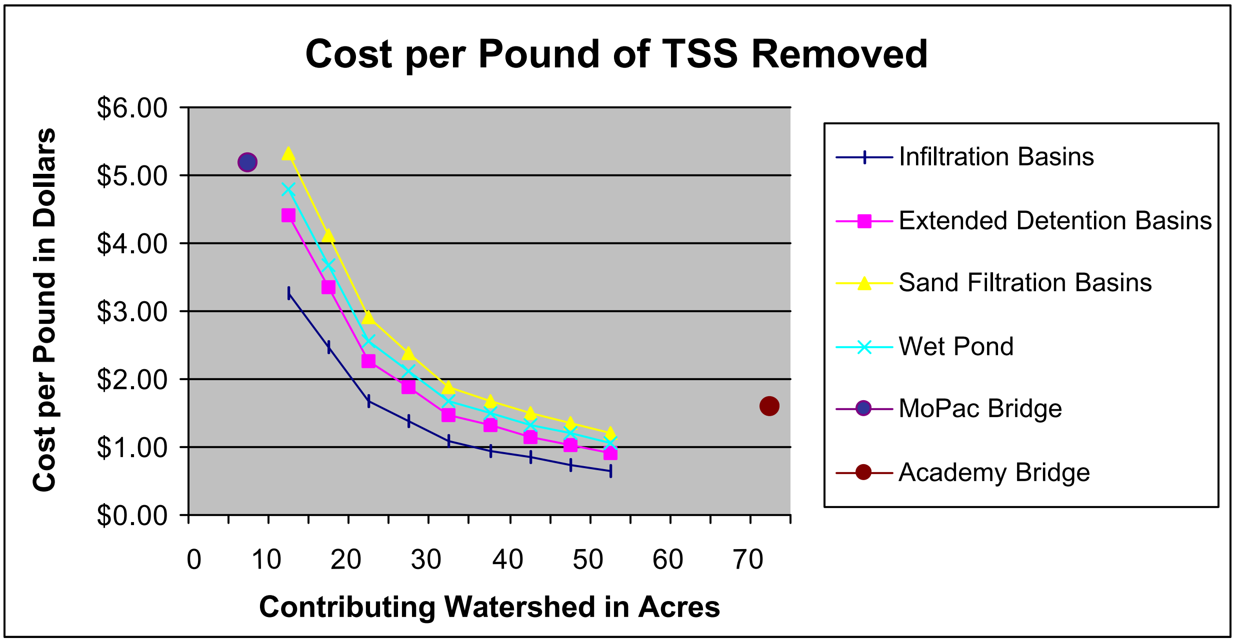

Figure 32. Cost per Pound of TSS Removed: Concrete Construction.

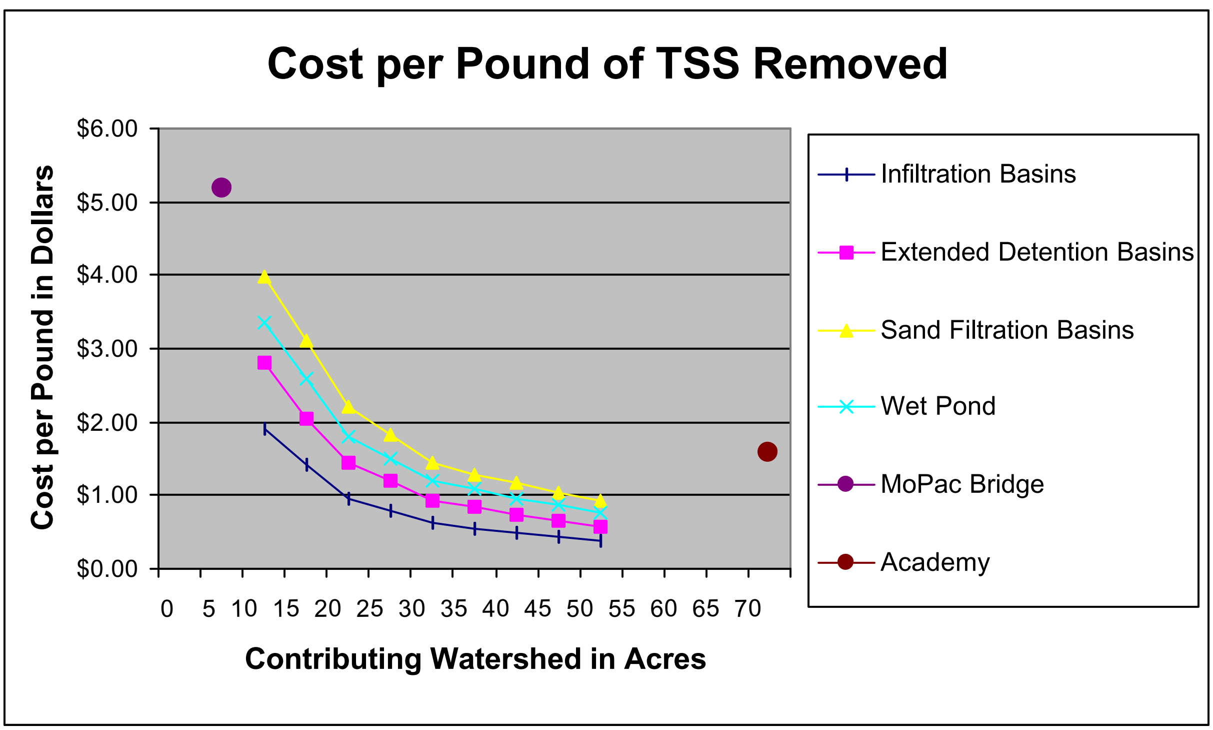

Figure 33. Cost per Pound of TSS Removed: Partial Concrete Construction.

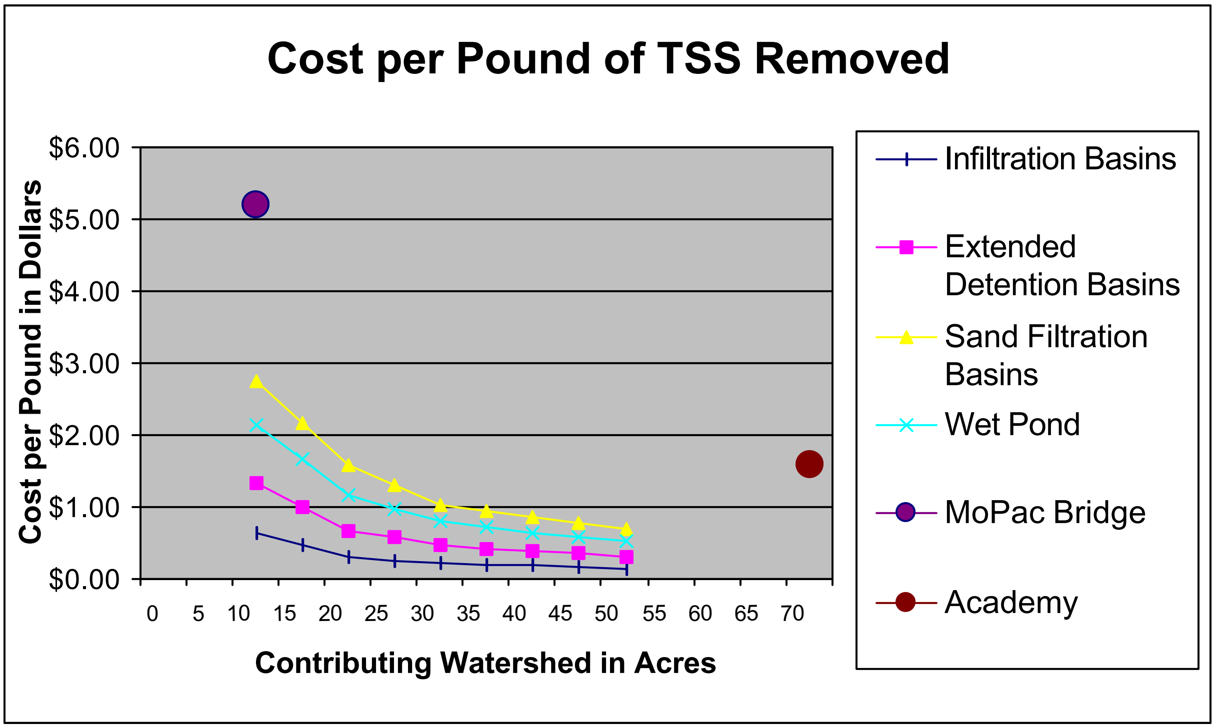

Figure 34. Cost per Pound of TSS Removed: Earthen Construction.

For BMPs that serve smaller drainage areas, it was not necessary to account for different material types since construction materials are generally uniform within a particular BMP type. Figure 35 shows the cost per pound of TSS removed for small drainage basins.

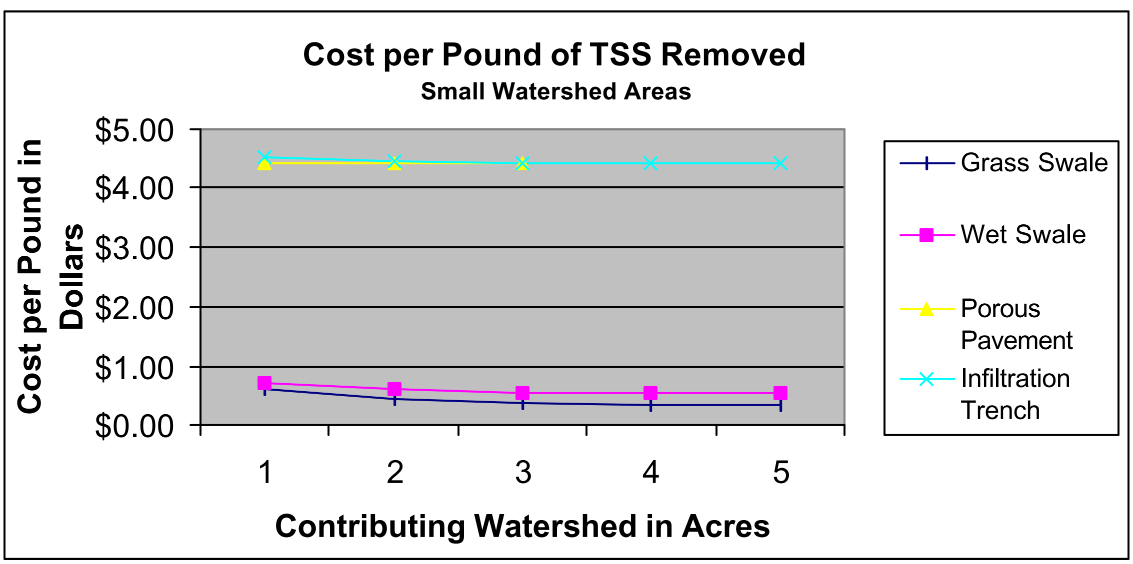

Figure 35. Cost per Pound of TSS Removed: BMPs for Small Drainage Basins.

RECOMMENDATIONS

Upon review of the current literature and contemporary transportation practice, it is clear that the question of the most cost-effective BMP does not have a simple answer. The fact remains that the best and most cost-effective BMP is going to the be the one that fits the site and meets the regulatory performance requirements.

Two issues will continue to make water quality a difficult issue that will have to be addressed on a project by project basis. First, the rules defining acceptable water quality continue to change. The overlapping authorities' differences in mission of the individual regulators will continue to make water quality a difficult issue to address in the project development process. Secondly, the actual performance of various BMPs is not well understood or documented. There is a national effort in progress to establish a database that will eventually answer many of the performance questions. However, until the database is sufficiently populated to statistically characterize performance levels, design of BMPs to specific performance levels will be difficult.

Given the difficulty of predicting the actual performance of a particular water quality BMP, it is recommended that TxDOT adopt procedures for selection and design of stormwater quality BMPs that will satisfy regulatory requirements for most situations. Demonstrating that procedures are in place to address water quality issues is probably the best means of avoiding conflicts over water quality measures. Specific measures that should be incorporated into the stormwater quality design procedures follow.

- Consider the Need for Water Quality Facilities Early in the Planning Process

  Early consideration of right-of-way needs should consider the likelihood of the need for stormwater quality treatment in the proximity of natural water courses. The cost analysis in this study and other national studies has demonstrated the reduced cost benefits that can be accrued by building single large stormwater quality facilities rather than numerous smaller structures.

- Utilize the 90 Percent Rule as the Basis for Determining Size

  The current trend seems to support the use of the 90 percent rule for determining the water quality volume of a BMP. The 90 percent rule is the basis for most current regulations and is currently being used by LCRA and the City of Austin.

  Table 17 shows the values recommended for use by TxDOT. The values shown have been compiled from the studies and references cited in the references section. Reference materials that demonstrated the greatest rigor in the evaluation of performance data were given the greatest weight. The values in the table assume watershed areas appropriate to the specific BMP and that appropriate selection and design guidelines are followed. As a rule, more conservative values have been used.

Table 17. Recommended Performance Values for Design and Selection of Stormwater BMPs.

Percent Pollutant Removal of Stormwater BMPs[a]						
	TSS	TP	TN	Pb	Zn	O&G[b]
Detention Ponds[c]	90 (47)	50 (19)	50 (25)	50	90 (26)	70
Wet Ponds	80	51	33	45	66	N/A
Infiltration Ponds	90	70	50	55	90	75%
Filters	85	59	40	45	85	N/A
Water Quality Swales	80	35	75	75	75	65
Stormwater Wetlands	75	50	30	50	60	N/A

a. Values reflect average values that the literature suggests can be reasonably expected over time. Single observations may demonstrate substantial variation from these values.
b. Oil and grease removal was not reported frequently enough to suggest a value for many BMPs.
c. The values indicated are for detention times of 48 hrs or greater. The values in parenthesis are for detention times of 24 hours.

- Utilize the Vegetated Roadside and Medians

  For highway segments with grass shoulders and medians, add improvements that will allow them to function as water quality swales. Utilize the design procedures given in the section on grass swales. It may be necessary to consider whether growth is likely to require the addition of travel lanes that could eventually require additional right-of-way or the use of a more expensive BMP at a later date.

  Table 17 shows the values recommended for use by TxDOT. The values shown have been compiled from the studies and references cited in the references section. Reference materials that demonstrated the greatest rigor in the evaluation of performance data were given the greatest weight. The values in the table assume watershed areas appropriate to the specific BMP and that appropriate selection and design guidelines are followed. As a rule, more conservative values have been used.

- Consider Detention or Infiltration Instead of Filtration for Large Watersheds

  Of all the large basin type structures, detention and infiltration basins have demonstrated the greatest pollutant removal efficiencies. The primary deterrent to using a detention or infiltration structure for water quality is the basin size needed to detain the full water quality volume for 48 hours in order to achieve the highest level of pollutant removal. On the other hand, when space is available, infiltration and detention structures offer the best overall performance for all common pollutants, and they are the least expensive to build and maintain. The primary difference in cost between an infiltration structure and a detention structure is the outlet control structure and the impervious liner requirement. The weakness in detention structures appears to be removal of soluble pollutants. If soluble pollutants are a problem, addition of a permanent pool in the structure can significantly improve removal of soluble pollutants.

NEED FOR FURTHER RESEARCH

BMP Performance

The effort to develop the National Pollutant Removal Performance Database has the potential to answer many of the lingering question about BMP performance. In order to be effective, there is a need for well documented data sets to be included in this data set. TxDOT has monitoring data from several different studies that may be of value to this effort, and the EPA has some modest funding available to compile, screen, and submit data to the database.

Proprietary and Underground Stormwater Quality BMPs

The focus of this study was on permanent surface stormwater quality structures. However, new Phase II NPDES rules are going to require the installation of water quality improvements in many urban areas where land availability is very limited, and land costs restrict the use of traditional basin type structures. As part of this project, some information was collected on proprietary systems and some underground installations that are being used. No source was found that provides comparative performance data on the proprietary systems. Likewise, no cost information was found that allowed any meaningful comparison.

In the future, a better understanding of the performance characteristics, installation, and operational costs of underground and small footprint BMPs will be needed to meet stormwater quality requirements in developed urban centers of the state.

Implementation

The conclusions and recommendations outlined in the research report provide a framework of tools for the selection and design of structural water quality BMPs needed to meet EPA Section 401, Texas Pollutant Discharge Elimination System (TPDES), and Edwards Aquifer requirements. The design methods provided are simple tools that can be used by planners and designers to evaluate water quality requirements and to develop final design recommendations. In addition to being simple and cost-effective, the design procedures recommended have achieved wide acceptance and use in Texas and many other parts of the country.

Specific steps recommended for implementation include:

1. Include the design procedures, found in the detailed discussion of BMPs, in the appropriate on-line design manual.

2. Prepare training modules that can be used as self-learning tools or as formal training modules in the selection and design of stormwater quality BMPs. Training modules should include units on:

   - TPDES and Section 401 water quality requirements;
   - BMP selection covering site constraints, runoff characteristics, performance requirements, available BMPs, and cost;
   - BMP design using accepted methods. This section should stress the use of these methods for the means of meeting Section 401 permitting requirements; and
   - develop example problems and cases to support the training modules.

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APPENDIX A

Monitored Sites Pollutant Removal Data

Low-Cost Sites: Total Suspended Solids

Detection Limit: 4-20,000 (mg/l)

	Sample Date	Precip (in)	Influent (mg/l)	Effluent (mg/l)	Efficiency (%)
305 Kiva Drive					
Not boxed	1/28/00		22	2.5	88.6
			9	1.5	83.3
	2/24/00		111.5	38	65.9
	3/18/00		35	3.5	90.0
	3/30/00	0.25	116.5	8	93.1
	4/14/00	0.70	110.5	39	64.7
	5/3/00	3.50	111	46	58.6
	5/22/00	0.70	56.5	0.5	99.1
	6/6/00	1.00	69.5	38	45.3
	6/20/00	1.00	217.5	8	96.3
	7/24/00	0.30	12	13	***NMV***
	8/1/00	0.40	30	30	***NMV***
		Mean:	***75.1***	***19.0***	***78.5***
		Std:	***61.1***	***17.6***	
232 Ira Ingram Drive					
Boxed	1/28/00		195	10.5	94.6
	2/24/00		34.5	304.5	***NMV***
	3/18/00		119	10	91.6
	6/6/00	1.00	18.5	415	***NMV***
		Mean:	***91.8***	***185.0***	***81.3***
		Std:	***81.7***	***206.8***	
492 Edwardson Cove					
Boxed			808	78	90.3
	3/30/00	0.25	243	212	12.8
	4/14/00	0.70	505	41	91.9
	5/5/00	3.50	2.5	12	***NMV***
	5/22/00	0.70	573	93.5	83.7
	6/6/00	1.00	48.5	67	***NMV***
	8/1/00	0.40	80	165	***NMV***
		Mean:	***322.9***	***95.5***	***72.0***
		Std:	***309.4***	***70.1***	

Low-Cost Sites: Total Suspended Solids, cont.

	Sample Date	Precip (in)	Influent (mg/l)	Effluent (mg/l)	Efficiencv (%)
503 Mesa Verde Court					
Boxed			28	10.5	62.5
	2/24/00		841	634	24.6
	3/18/00		16.5	117.5	***NMV***
	3/30/00	0.25	56.5	121	***NMV***
	4/14/00	0.70	121	122	***NMV***
	5/5/00	3.50	75.5	70	7.3
	5/22/00	0.70	30	41.5	***NMV***
	6/20/00	1.00	39	102.5	***NMV***
	7/24/00	0.30	27	86	***NMV***
	8/1/00	0.40	15	10	33.3
		Mean:	***125.0***	***131.5***	***31.9***
		Std:	***253.7***	***181.7***	
57 Nairn Dr.					
Not boxed			23.5	5	78.7
	2/24/00		530.5	13.5	97.5
	3/18/00		108	5	95.4
	3/30/00	0.25	111.5	8	92.8
	4/14/00	0.70	139	248.5	***NMV***
	5/3/00	3.50	382	20.5	94.6
	5/22/00	0.70	66.5	122	***NMV***
	6/6/00	1.00	17	9	47.1
	6/20/00	1.00	14	33.5	***NMV***
	7/24/00	0.30	146.5	24.5	83.3
	8/1/00	0.40	15	15	***NMV***
		Mean:	***141.2***	***45.9***	***84.2***
		Std:	***166.9***	***75.0***	
77 Nairn Dr.					
Not boxed	1/28/00		50.5	73	***NMV***
	2/24/00		200.5	281	***NMV***
	3/18/00		5.5	12.5	***NMV***
	3/30/00	0.25	90	15.5	82.8
	4/14/00	0.70	113.5	76.5	32.6
	5/3/00	3.50	256.5	158	38.4
	5/22/00	0.70	73	34.5	52.7
	6/6/00	1.00	33	21.5	34.8
	6/20/00	1.00	12.5	109.5	***NMV***
	7/24/00	0.30	19	97.5	***NMV***
	8/1/00	0.40	40	1	97.5
		Mean:	***81.3***	***80.0***	***56.5***
		Std:	***80.9***	***82.6***	

Low-Cost Sites: Total Suspended Solids, cont.

	Sample Date	Precip (in)	Influent (mg/l)	Effluent (mg/l)	Efficiencv (%)
288 La Siesta Bend					
Boxed			32	46	***NMV***
	3/18/00		51	20.5	59.8
	3/30/00	0.25	80	85.5	***NMV***
	4/14/00	0.70	99	4.5	95.5
	5/5/00	3.50	28	15.5	44.6
	5/22/00	0.70	88	18	79.5
		Mean:	***63.0***	***31.7***	***72.2***
		Std:	***30.1***	***29.7***	
Road Side # 1					***NMV***
	5/3/00	3.50	44	2	***NMV***
	5/22/00	0.70	9	39.5	93.8
	6/6/00	1.00	4.5	72	***74.2***
	6/20/00	1.00	56	3.5	
		Mean:	***28.4***	***29.3***	
		Std:	***25.5***	***33.4***	***NMV***
Road Side # 2					***NMV***
	5/3/00	3.50	131	382	***NMV***
	5/22/00	0.70	0.5	110.5	***NMV***
	6/6/00	1.00	15.5	27.5	
	6/20/00	1.00	10	22	
		Mean:	***39.3***	***135.5***	***84.0***
		Std:	***61.5***	***169.2***	
Road Side # 3					***NMV***
	5/3/00	3.50	33	9.5	***NMV***
	5/22/00	0.70	6	10	8.0
	6/6/00	1.00	1	18	
	6/20/00	1.00	12.5	11.5	
		Mean:	***13.1***	***12.3***	***46.0***
		Std:	***14.1***	***3.9***	

Low-Cost Sites: Total Kejldahl's Nitrogen

Detection Limits: 0 -150mg/l
TKN

	Sample Date	Precip (in)	Influent (mg/l)	Effluent (mg/l)	Efficiencv (%)
305 Kiva Drive					
Not boxed	1/28/00		1	0	100.0
			13	8	38.5
	2/24/00		8	0	100.0
	3/18/00		18	0	100.0
	3/30/00	0.25	22	10	54.5
	5/3/00	3.50	35	36	***NMV***
	5/22/00	0.70	7	8	***NMV***
	6/6/00	1.00	13	16	***NMV***
	7/24/00	0.30	4	12	***NMV***
	8/1/00	0.40	13	12	7.7
		Mean:	***13.4***	***10.2***	***66.8***
		Std:	***9.9***	***10.7***	
232 Ira Ingram Drive					
Boxed	1/28/00		1	3	***NMV***
	2/24/00		4	5	***NMV***
	6/6/00	1.00	8	46	***NMV***
		Mean:	***4.3***	***18.0***	
		Std:	***3.5***	***24.3***	
492 Edwardson Cove					
Boxed			15	0	100.0
	4/14/00	0.70	11	13	***NMV***
	5/5/00	3.50	51	23	54.9
	5/22/00	0.70	8	10	***NMV***
	6/6/00	1.00	8	12	***NMV***
	8/1/00	0.40	16	93	***NMV***
		Mean:	***18.2***	***25.2***	***77.5***
		Std:	***16.4***	***34.0***	

Low-Cost Sites: Total Kejldahl's Nitrogen, cont.

	Sample Date	Precip (in)	Influent (mg/l)	Effluent (mg/l)	Efficiencv (%)
503 Mesa Verde Court					
Boxed			0	12	***NMV***
	2/24/00		5	6	***NMV***
	3/18/00		8	9	***NMV***
	3/30/00	0.25	10	14	***NMV***
	4/14/00	0.70	6	10	***NMV***
	5/5/00	3.50	19	14	26.3
	5/22/00	0.70	8	7	12.5
	6/6/00	1.00	6	9	***NMV***
	7/24/00	0.30	12	17	***NMV***
	8/1/00	0.40	14	11	21.4
		Mean:	***8.8***	***10.9***	***20.1***
		Std:	***5.3***	***3.4***	
57 Nairn Dr.					
Not boxed			0	0	***NMV***
			0	10	***NMV***
	2/24/00		7	6	14.3
	3/18/00		20	16	20.0
	3/30/00	0.25	21	6	71.4
	4/14/00	0.70	11	6	45.5
	5/3/00	3.50	21	17	19.0
	5/22/00	0.70	15	7	53.3
	6/6/00	1.00	13	15	***NMV***
	7/24/00	0.30	10	20	***NMV***
	8/1/00	0.40	6	12	***NMV***
		Mean:	***11.3***	***10.5***	***37.3***
		Std:	***7.6***	***6.1***	
77 Nairn Dr.					
Not boxed	1/28/00		0	0	***NMV***
	2/24/00		7	8	***NMV***
	3/18/00		14	24	***NMV***
	4/14/00	0.70	20	14	30.0
	5/3/00	3.50	9	7	22.2
	5/22/00	0.70	37	9	75.7
	6/6/00	1.00	10	5	50.0
	7/24/00	0.30	14	14	***NMV***
	8/1/00	0.40	9	9	***NMV***
		Mean:	***13.3***	***10.0***	***44.5***
		Std:	***10.4***	***6.8***	

Low-Cost Sites: Total Kejldahl's Nitrogen, cont.

	Sample Date	Precip (in)	Influent (mg/l)	Effluent (mg/l)	Efficiencv (%)
288 La Siesta Bend					
Boxed			9	8	11.1
	3/18/00		9	15	***NMV***
	3/30/00	0.25	15	12	20.0
	4/14/00	0.70	10	13	***NMV***
	5/5/00	3.50	20	36	***NMV***
	5/22/00	0.70	9	8	11.1
	8/1/00	0.40	7	10	***NMV***
		Mean:	***11.3***	***14.6***	***14.1***
		Std:	***4.6***	***9.8***	
Road Side # 1					
	5/3/00	3.50	20	38	***NMV***
	6/6/00	1.00	18	11	38.9
		Mean:	***19.0***	***24.5***	***38.9***
		Std:	***1.4***	***19.1***	
Road Side # 2					
	5/3/00	3.50	15	36	***NMV***
	6/6/00	1.00	12	7	41.7
		Mean:	***13.5***	***21.5***	***41.7***
		Std:	***2.1***	***20.5***	
Road Side # 3					
	5/3/00	3.50	70	8	88.6
	5/22/00	0.70	13	14	***NMV***
	6/6/00	1.00	16	7	56.3
		Mean:	***33.00***	***9.67***	***72.41***
		Std:	***32.08***	***3.79***	

Low-Cost Sites: Total Phosphorus

Detection Limit: 0-2.5 mg/l

	Sample Date	Precip (in)	Influent (mg/l)	Effluent (mg/l)	Efficiency (%)
305 Kiva Drive					
Not Boxed	1/28/00		0.50	0.57	***NMV***
			0.39	0.39	***NMV***
	2/24/00		0.68	0.21	69.1
	3/18/00		0.37	0.19	48.6
	3/30/00	0.25	0.06	0.19	***NMV***
	5/3/00	0.70	0.20	0.14	30.0
	5/22/00	3.50	0.17	0.04	76.5
	6/6/00	0.70	0.06	0.01	83.3
	6/20/00	1.00	1.70	0.88	48.2
	7/24/00	0.30	0.06	0.51	***NMV***
	8/1/00	0.40	1.60	1.06	33.8
		Mean:	***0.53***	***0.38***	***55.65***
		Std:	***0.59***	***0.34***	***20.91***
232 Ira Ingram Drive					
Boxed	1/28/00		0.50	0.70	***NMV***
	2/24/00		0.00	0.21	***NMV***
	5/22/00		0.11	2.33	***NMV***
		Mean:	***0.20***	***1.08***	
		Std:	***0.26***	***1.11***	
492 Edwardson Cove					
Boxed					
	3/30/00	0.25	0.73	1.80	***NMV***
	4/14/00	0.70	0.47	0.28	40.4
	5/5/00	3.50	1.41	1.40	0.7
	5/22/00	0.70	1.36	0.09	93.4
	6/6/00	1.00	0.20	1.11	***NMV***
	8/1/00	0.40	0.80	2.75	***NMV***
		Mean:	***0.83***	***1.24***	***44.8***
		Std:	***0.48***	***0.99***	

Low-Cost Sites: Total Phosphorus, cont.

	Sample Date	Precip (in)	Influent (mg/l)	Effluent (mg/l)	Efficiencv (%)
503 Mesa Verde Court					
Boxed			0.47	0.35	25.5
	2/24/00		0.58	0.50	13.8
	3/18/00		0.38	0.11	71.1
	3/30/00	0.70	0.14	0.18	***NMV***
	4/14/00	3.50	0.40	0.21	47.5
	5/5/00	0.70	1.27	0.15	88.2
	5/22/00		0.06	0.03	50.0
	6/6/00		0.08	0.82	***NMV***
	6/20/00	1.00	2.46	1.12	54.5
	7/24/00	0.30	0.43	1.06	***NMV***
	8/1/00	0.40	1.12	0.75	33.0
		Mean:	***0.67***	***0.48***	***47.9***
		Std:	***0.71***	***0.40***	
57 Nairn Dr.					
Not Boxed	1/28/00		0.50	0.57	***NMV***
			0.39	0.39	NMV
	2/24/00		0.68	0.21	69.1
	3/18/00		0.37	0.19	48.6
	3/30/00	0.25	0.06	0.19	***NMV***
	4/14/00	0.70	0.20	0.14	30.0
	5/3/00		0.17	0.04	76.5
	5/22/00	0.70	0.06	0.01	83.3
	6/6/00		0.01	0.46	***NMV***
	6/20/00	1.00	0.37	0.50	***NMV***
	7/24/00	0.30	2.75	0.63	77.1
	8/1/00	0.40	1.16	2.75	***NMV***
		Mean:	***0.56***	***0.51***	***64.11***
		Std:	***0.76***	***0.74***	***20.58***
77 Nairn Dr.					
Not Boxed			0.44	0.46	***NMV***
	2/24/00		0.67	0.32	52.2
	3/18/00		0.21	0.23	***NMV***
	3/30/00	0.25	0.28	0.25	10.7
	4/14/00	0.70	0.09	0.10	***NMV***
	5/3/00	3.50	0.06	0.03	50.0
	5/22/00	0.70	0.02	0.57	***NMV***
	6/20/00	1.00	0.13	1.07	***NMV***
	7/24/00	0.30	2.59	0.34	86.9
	8/1/00	0.40	1.78	0.70	60.7
		Mean:	***0.63***	***0.41***	***52.10***
		Std:	***0.87***	***0.31***	***27.39***

Low-Cost Sites: Total Phosphorus, cont.

	Sample Date	Precip (in)	Influent (mg/l)	Effluent (mg/l)	Efficiencv (%)
288 La Siesta Bend					
Boxed			0.35	1.14	***NMV***
	3/18/00		0.61	0.20	67.2
	3/30/00	0.25	0.44	0.36	18.2
	4/14/00	0.70	0.41	0.31	24.4
	5/22/00	0.70	0.02	0.49	***NMV***
	6/6/00	1.00	0.04	0.05	***NMV***
	8/1/00	0.40	0.03	1.06	***NMV***
		Mean:	***0.27***	***0.52***	***36.60***
		Std:	***0.24***	***0.42***	***26.70***
Road Side # 1					
	5/3/00	3.50	0.20	0.01	95.0
	6/6/00	1.00	0.03	0.63	***NMV***
	6/20/00	1.00	0.35	0.49	***NMV***
		Mean:	***0.19***	***0.38***	***95.00***
		Std:	***0.16***	***0.33***	***NMV***
Road Side # 2					
	5/3/00	3.50	0.04	0.29	***NMV***
	6/6/00	1.00	0.13	0.08	38.5
	6/20/00	1.00	0.23	0.32	***NMV***
		Mean:	***0.13***	***0.23***	***38.46***
		Std:	***0.10***	***0.13***	***NMV***
Road Side # 3					
	5/3/00	3.50	0.09	0.09	***NMV***
	5/22/00	0.70	0.01	0.03	***NMV***
	6/6/00	1.00	0.09	0.10	***NMV***
	6/20/00	1.00	0.74	0.85	***NMV***
		Mean:	***0.23***	***0.27***	***NMV***
		Std:	***0.34***	***0.39***	***NMV***

Low-Cost Sites: Pb & Zn

Pb Detection Limits: 0.0 - 0.1mg/l

Zn Detection Limits: 0.005 - 1mg/

	Sample Date	Precip (in)	Pb Influent (mg/l)	Pb Effluent (mg/l)	Pb Efficiencv (%)	Zn Influent (mg/l)	Zn Effluent (mg/l)	Zn Efficiencv (%)
305 Kiva Drive								
Not Boxed	1/28/00		0.013	0.012	7.7	0.082	0.036	56.1
			0.019	0.022	***NMV***	0.048	0.042	12.5
	2/24/00		0.034	0.027	20.6	0.333	0.040	88.0
	3/18/00		0.025	0.041	***NMV***	0.170	0.060	64.7
	3/30/00	0.25	0.033	0.045	***NMV***	0.160	0.060	62.5
	4/14/00	0.7	0.042	0.042	***NMV***	0.070	0.100	***NMV***
	5/30/00	3.5	0.006	0.070	***NMV***	0.180	0.040	77.8
	5/22/00	0.7	0.030	0.032	***NMV***	0.110	0.160	***NMV***
	6/6/00	1	0.006	0.006	***NMV***	0.170	0.030	82.4
	6/20/00	1	0.016	0.013	18.8	0.240	0.040	83.3
	7/24/00	0.3	0.007	0.019	***NMV***	0.080	0.090	***NMV***
	8/1/00	0.4	0.001	0.002	***NMV***	0.060	0.020	66.7
		Mean:	***0.019***	***0.028***	***15.677***	***0.142***	***0.060***	***65.991***
		Std:	***0.013***	***0.020***		***0.085***	***0.039***	
232 Ira Inqram Drive								
Boxed	1/28/00		0.013	0.013	***NMV***	0.014	0.167	***NMV***
	3/18/00		0.026	0.025	3.8	0.120	0.060	50.0
		Mean:	***0.020***	***0.019***		***0.067***	***0.114***	
		Std:	***0.009***	***0.008***		***0.075***	***0.076***	
492 Edwardson Cove								
Boxed			0.028	0.021	25.0	0.326	0.081	75.2
	3/30/00	0.25	0.027	0.030	***NMV***	0.090	0.110	***NMV***
	4/14/00	0.7	0.040	0.040	***NMV***	0.110	0.120	***NMV***
	5/5/00	3.5	0.029	0.018	37.9	0.360	0.110	69.4
	5/22/00	0.7	0.035	0.024	31.4	0.180	0.080	55.6
	6/6/00	1	0.018	0.004	77.8	0.310	0.180	41.9
			0.003	0.003	***NMV***	0.130	0.050	61.5
		Mean:	***0.026***	***0.020***	***43.034***	***0.215***	***0.104***	***60.725***
		Std:	***0.012***	***0.013***		***0.114***	***0.041***	

Low-Cost Sites: Pb & Zn, cont.

	Sample Date	Precip (in)	Pb Influent (mg/l)	Pb Effluent (mg/l)	Pb Efficiency (%)	Zn Influent (mg/l)	Zn Effluent (mg/l)	Zn Efficiencv (%)
503 Mesa Verde Court								
Boxed			0.017	0.023	***NMV***	0.130	0.076	41.5
	2/24/00		0.046	0.030	34.8	0.180	0.315	***NMV***
	3/18/00		0.032	0.023	28.1	0.080	0.090	***NMV***
	4/14/00	0.7	0.038	0.040	***NMV***	0.080	0.070	12.5
	5/5/00	3.5	0.017	0.020	***NMV***	0.130	0.170	***NMV***
	5/22/00	0.7	0.024	0.025	***NMV***	0.060	0.040	33.3
	6/6/00	1	0.004	0.006	***NMV***	0.080	0.060	25.0
	6/20/00	1	0.014	0.014	***NMV***	0.210	0.060	71.4
	7/24/00	0.3	0.001	0.002	***NMV***	0.050	0.030	40.0
	8/1/00	0.4	0.001	0.001	***NMV***	0.060	0.020	66.7
		Mean:	***0.019***	***0.018***	***31.454***	***0.106***	***0.093***	***41.495***
		Std:	***0.016***	***0.013***		***0.055***	***0.088***	
57 Nairn Dr.	1/28/00		0.012	0.010	16.7	0.074	0.047	36.5
Not Boxed			0.019	0.018	5.3	0.063	0.030	52.4
	2/24/00		0.023	0.025	***NMV***	0.165	0.053	67.9
	3/18/00		0.021	0.015	28.6	0.100	0.070	30.0
	3/30/00	0.25	0.039	0.035	10.3	0.120	0.050	58.3
	4/14/00	0.7	0.041	0.038	7.3	0.060	0.050	16.7
	5/3/00	3.5	0.005	0.006	***NMV***	0.110	0.030	72.7
	5/22/00	0.7	0.035	0.012	65.7	0.120	0.060	50.0
	6/6/00	1	0.004	0.005	***NMV***	0.070	0.060	14.3
	6/20/00	1	0.016	0.013	18.8	0.240	0.040	83.3
	7/24/00	0.3	0.007	0.019	***NMV***	0.080	0.090	***NMV***
	8/1/00	0.4	0.001	0.002	***NMV***	0.060	0.020	66.7
		Mean:	***0.019***	***0.017***	***21.791***	***0.105***	***0.050***	***49.887***
		Std:	***0.014***	***0.011***		***0.053***	***0.019***	
77 Nairn Dr.								
Not Boxed			0.018	0.021	***NMV***	0.078	0.028	64.1
	2/24/00		0.029	0.014	51.7	0.183	0.055	69.9
	3/18/00		0.018	0.017	5.6	0.070	0.050	28.6
	3/30/00	0.25	0.040	0.030	25.0	0.030	0.060	***NMV***
	4/14/00	0.7	0.039	0.043	***NMV***	0.130	0.080	38.5
	5/3/00	3.5	0.006	0.006	***NMV***	0.210	0.060	71.4
	5/22/00	0.7	0.036	0.038	***NMV***	0.130	0.040	69.2
	6/6/00	1	0.008	0.007	12.5	0.030	0.100	***NMV***
	6/20/00	1	0.013	0.017	***NMV***	0.040	0.050	***NMV***
	7/24/00	0.3	0.002	0.002	***NMV***	0.120	0.070	41.7
	8/1/00	0.4	0.001	0.002	***NMV***	0.050	0.030	40.0
		Mean:	***0.019***	***0.018***	***23.695***	***0.097***	***0.057***	***52.926***
		Std:	***0.015***	***0.014***		***0.062***	***0.021***	

Low-Cost Sites: Pb & Zn, cont.

	Sample Date	Precip (in)	Pb Influent (mg/l)	Pb Effluent (mg/l)	Pb Efficiency (%)	Zn Influent (mg/l)	Zn Effluent (mg/l)	Zn Efficiency (%)
288 La Siesta Bend								
Boxed			0.024	0.022	8.3	0.069	0.065	5.8
	3/18/00		0.017	0.022	***NMV***	0.110	0.060	45.5
	3/30/00	0.25	0.038	0.041	***NMV***	0.140	0.160	***NMV***
	4/14/00	0.7	0.041	0.040	2.4	0.060	0.600	***NMV***
	5/22/00	0.7	0.031	0.034	***NMV***	0.110	0.060	45.5
	8/1/00	0.4	0.000	0.002	***NMV***	0.040	0.020	50.0
		Mean:	***0.025***	***0.027***	***5.386***	***0.088***	***0.161***	***36.677***
		Std:	***0.015***	***0.015***		***0.038***	***0.220***	
Road Side # 1								
	5/3/00	3.5	0.007	0.005	28.6	0.200	0.050	75.0
	6/6/00	1	0.012	0.007	41.7	0.190	0.020	89.5
	6/20/00	1	0.022	0.020	9.1	0.200	0.060	70.0
		Mean:	***0.014***	***0.011***	***26.443***	***0.197***	***0.043***	***78.158***
		Std:	***0.008***	***0.008***		***0.006***	***0.021***	
Road Side # 2	5/3/00	3.5	0.007	0.060	***NMV***	0.140	0.060	57.1
	6/6/00	1	0.010	0.009	10.0	0.090	0.050	44.4
	6/20/00	1	0.024	0.023	4.2	0.150	0.050	66.7
		Mean:	***0.014***	***0.031***	***7.083***	***0.120***	***0.053***	***56.085***
		Std:	***0.009***	***0.026***		***0.032***	***0.006***	
Road Side # 3	5/3/00	3.5	0.013	0.005	61.5	0.340	0.050	85.3
	5/22/00	0.7	0.009	0.001	88.9	0.090	0.040	55.6
	6/6/00	1	0.008	0.007	12.5	0.090	0.050	44.4
	6/20/00	1	0.025	0.025	***NMV***	0.200	0.050	75.0
		Mean:	***0.014***	***0.010***	***50.694***	***0.180***	***0.048***	***58.333***
		Std:	***0.008***	***0.011***		***0.119***	***0.005***	

Low-Cost Sites: Oil and Grease

Detection Limit: 1.4 mg/l, range is 5 - 1,000 mg/l

	Sample Date	Precip (in)	Influent (mg/l)	Effluent (mg/l)	Efficiency (%)
305 Kiva Drive					
Not Boxed	1/28/00		178.9	40.7	77.2
			40.4	43.2	***NMV***
	2/24/00		430.7	30.2	93.0
	3/18/00		28.5	0	100.0
	3/30/00	0.25	72.2	18.6	74.2
	5/3/00	0.70	142.2	9.4	93.4
	5/22/00	3.50	434.4	159.5	63.3
	6/6/00	0.70	47.7	92.3	***NMV***
	6/20/00	1.00	38.8	0.4	99.0
	7/24/00	0.30	262.3	261.8	0.2
	8/1/00	0.40	20.9	17.10	18.2
		Mean:	***154.27***	***61.20***	***68.72***
		Std:	***156.62***	***81.52***	
232 Ira Ingram Drive					
Boxed	1/28/00		18.9	298.9	***NMV***
	2/24/00		266.7	0	100.0
	5/22/00		6.8	70.3	***NMV***
		Mean:	***97.47***	***123.07***	***100.00***
		Std:	***146.69***	***156.28***	
492 Edwardson Cove					
Boxed					
	3/30/00	0.25	46.8	336.5	***NMV***
	4/14/00	0.70	33.8	32.8	3.0
	5/5/00	3.50	3.1	19.3	***NMV***
	5/22/00	0.70	94.1	95.5	***NMV***
	6/6/00	1.00	91.2	177.1	***NMV***
	8/1/00	0.40	67.6	0.9	98.7
		Mean:	***56.10***	***110.35***	***50.81***
		Std:	***35.22***	***128.14***	

Low-Cost Sites: Oil and Grease, cont.

	Sample Date	Precip (in)	Influent (mg/l)	Effluent (mg/l)	Efficiencv (%)
503 Mesa Verde Court					
Boxed			123.8	3.6	97.1
	2/24/00		361.3	711.4	***NMV***
	3/18/00		605.8	184.1	69.6
	3/30/00	0.70	44.9	409.5	***NMV***
	4/14/00	3.50	69.4	19	72.6
	5/5/00	0.70	62.2	2	96.8
	5/22/00		99.4	13.48	86.4
	6/6/00		49.9	54.3	***NMV***
	6/20/00	1.00	10.9	35.4	***NMV***
	7/24/00	0.30	23.71	19.09	19.5
	8/1/00	0.40	21.41	22.48	***NMV***
		Mean:	***133.88***	***134.03***	***73.67***
		Std:	***184.36***	***227.09***	
57 Nairn Dr.	1/28/00		41.1	25	39.2
Not Boxed			0	1.9	***NMV***
	2/24/00		628.9	927.3	***NMV***
	3/18/00		53.9	362.6	***NMV***
	3/30/00	0.25	73.3	77	***NMV***
	4/14/00	0.70	348.8	47.3	86.4
	5/3/00		158.5	82.5	47.9
	5/22/00	0.70	184.5	35.9	80.5
	6/6/00		92.2	17	81.6
	6/20/00	1.00	1.1	18.3	***NMV***
	7/24/00	0.30	53.2	157.2	***NMV***
	8/1/00	0.40	201.5	75.7	62.4
		Mean:	***153.08***	***152.31***	***66.35***
		Std:	***180.16***	***263.02***	
77 Nairn Dr.					
Not Boxed			31.4	0	100.0
	2/24/00		305.7	471.4	***NMV***
	3/18/00		40.5	42.7	***NMV***
	3/30/00	0.25	392.3	30.2	92.3
	4/14/00	0.70	4.2	20	***NMV***
	5/3/00	3.50	26.7	1.1	95.9
	5/22/00	0.70	47.2	196.8	***NMV***
	6/20/00	1.00	62.1	18.9	69.6
	7/24/00	0.30	223.7	118.5	47.0
	8/1/00	0.40	190.3	137.9	27.5
		Mean:	***132.41***	***103.75***	***72.05***
		Std:	***136.51***	***145.24***	

Low-Cost Sites: Oil and Grease, cont.

	Sample Date	Precip (in)	Influent (mg/l)	Effluent (mg/l)	Efficiencv (%)
288 La Siesta Bend					
Boxed			41.3	6.7	83.8
	3/18/00		315.4	665.7	***NMV***
	3/30/00	0.25	47.1	0	100.0
	4/14/00	0.70	51.3	81.8	***NMV***
	5/22/00	0.70	36	632.5	***NMV***
	6/6/00	1.00	0	131.2	***NMV***
	8/1/00	0.40	71.1	51.8	27.1
		Mean:	***80.31***	***224.24***	***70.31***
		Std:	***105.85***	***293.78***	
Road Side # 1					
	5/3/00	3.50	7.8	0.2	97.4
	6/6/00	1.00	74.9	16.6	77.8
	6/20/00	1.00	6.4	216.5	***NMV***
		Mean:	***29.70***	***77.77***	***87.64***
		Std:	***39.15***	***120.43***	
Road Side # 2					
	5/3/00	3.50	86.4	565.7	***NMV***
	6/6/00	1.00	135.9	14.8	89.1
	6/20/00	1.00	51.8	6.2	88.0
		Mean:	***91.37***	***195.57***	***88.57***
		Std:	***42.27***	***320.57***	
Road Side # 3					
	5/3/00	3.50	363.3	108.7	70.1
	5/22/00	0.70	57.6	65.9	***NMV***
	6/6/00	1.00	12.1	159.4	***NMV***
	6/20/00	1.00	4.1	33.9	***NMV***
		Mean:	***109.28***	***91.98***	***70.08***
		Std:	***170.98***	***54.40***	

TxDOT Sites: Total Suspended Solids

Detection Limit: 4-20,000 (mg/l)

	Sample Date	Precip (in)	Sample Number	Influent (mg/l)	Sample Number	Effluent (mg/l)	Efficiency (%)	Influent (sorted)	Effluent (sorted)	Efficiency sorted (%)	Aggregated Site Data Influent (sorted)	Aggregated Site Data Effluent (sorted)
2N (Academy)												
	3/30/00	0.25	7535	46	7536	9	80.4	570	15	97.4	382.0	191.5
	7/24/00	0.30	8298	570	8299	5.5	99.0	46	9	80.4		
	8/1/00	0.40	8379	8	8380	15	NMV	8	5.5	31.3		
			Mean:	**208.0**		**9.8**	**89.7**				350.5	108.5
			StD:	**314.1**		**4.8**					316	80.0
											307.0	30.0
4N (Best Buy)											211.5	26.0
	3/30/00	0.25	7537	74.5	7538	30	59.7	350.5	539	NMV	188.5	22.5
	4/14/00	0.50	7624	350.5	7625	108.5	69.0	255.5	191.5	25.0	140.5	18.5
	5/3/00	4.50	7766	140.5	7767	191.5	NMV	188.5	108.5	42.4	128	9.5
	5/22/00	0.50	7915	188.5	7916	9.5	95.0	140.5	50	64.4	74.5	9.0
	6/20/00	0.30	8139	128	8140	22.5	82.4	128	30	76.6	46.0	7.0
	7/24/00	0.30	8300	255.5	8301	539	NMV	74.5	22.5	69.8		
	8/1/00	0.40	8375	35	8376	50	NMV	35	9.5	72.9		
			Mean:	**167.5**		**135.9**	**76.5**					
			StD:	**108.1**		**188.8**						
5N (Bridge)												
	4/14/00	0.50	7622	307	7623	7	97.7	382	80	79.1		
	5/3/00	4.50	7764	382	7765	80	79.1	316	26	91.8		
	5/22/00	0.50	7917	211.5	7918	26	87.7	307	18.5	94.0		
	8/1/00	1.00	8141	316	8142	18.5	94.1	211.5	7	96.7		
			Mean:	**304.1**		**32.9**	**89.7**					
			StD:	**70.2**		**32.4**						

Nitrogen

Detection Limits: 0 -150mg/l TKN

	Sample Date	Influent (mg/l)	Effluent (mg/l)	Efficiency (%)
Academy	3/30/00	0	5	NMV
	5/22/00	7	5	28.6
	6/6/00	18	10	44.4
	7/24/00	26	10	61.5
	8/1/00	24	7	70.8
	Mean:	**15.00**	**7.40**	**51.35**
	Std:	**11.18**	**2.51**	**18.71**
Best Buy				
	3/30/00	3	15	NMV
	4/14/00	10	0	100.0
	5/3/00	26	15	42.3
	5/22/00	8	19	NMV
	6/6/00	10	34	NMV
	6/20/00	16	7	56.3
	7/24/00	21	42	NMV
	8/1/00	9	15	NMV
	Mean:	**12.88**	**18.38**	**66.19**
	Std:	**7.57**	**13.65**	**30.10**
Bridge				
	4/14/00	18	6	66.7
	5/3/00	27	12	55.6
	5/22/00	11	5	54.5
	6/6/00	11	6	45.5
	6/20/00	11	5	54.5
	8/1/00	8	9	NMV
	Mean:	**14.33**	**7.17**	**55.35**
	Std:	**7.03**	**2.79**	**7.54**

Lead

Detection Limit: Pb-- 0.0--0.1 (mg/l)

	Sample Date	Pb Influent (mg/l)	Pb Effluent (mg/l)	Pb Efficiency (%)
Academy				
	3/30/00	0.037	0.029	21.6
	5/22/00	0.024	0.021	12.5
	7/24/00	0.007	0.001	85.7
	8/1/00	0.002	0.004	NMV
	Mean:	**0.018**	**0.014**	**39.9**
	Std:	**0.016**	**0.013**	
Best Buy				
	3/18/00	0.041	0.033	19.5
	3/30/00	0.033	0.038	NMV
	4/14/00	0.051	0.039	23.5
	5/3/00	0.01	0.006	40.0
	5/22/00	0.032	0.028	12.5
	6/6/00	0.015	0.01	33.3
	6/20/00	0.024	0.02	16.7
	7/24/00	0.004	0.008	NMV
	8/1/00	0.003	0.003	NMV
	Mean:	**0.024**	**0.021**	**24.3**
	Std:	**0.017**	**0.014**	
Bridge				
	3/18/00	0.017	0.036	NMV
	4/14/00	0.047	0.037	21.3
	5/3/00	0.023	0.011	52.2
	5/22/00	0.032	0.029	9.4
	6/6/00	0.014	0.007	50.0
	7/24/00	0.023	0.021	8.7
	8/1/00	0.005	0.002	60.0
	Mean:	**0.023**	**0.020**	**33.6**
	Std:	**0.014**	**0.014**	

Phosphorous

Detection Limit: 0-2.5 mg/l po43-

	Sample Date	Influent (mg/l)	Effluent (mg/l)	Efficiency (%)
2N (Academy)	3/30/00	0.30	0.01	96.7
	5/22/00	0.05	0.01	80.0
	6/6/00	0.02	0.10	NMV
	7/24/00	0.22	0.58	NMV
	8/1/00	0.12	0.40	NMV
	Mean:	**0.14**	**0.22**	**88.33**
	Std:	**0.12**	**0.26**	**11.79**
4N (Best Buy)				
	3/30/00	0.30	0.40	NMV
	4/14/00	0.49	0.28	42.9
	5/3/00	0.24	0.22	8.3
	5/22/00	0.03	0.01	66.7
	6/6/00	0.01	0.53	NMV
	6/20/00	0.82	0.29	64.6
	7/24/00	0.74	0.39	47.3
	8/1/00	0.05	0.07	NMV
	Mean:	**0.34**	**0.27**	**45.96**
	Std:	**0.32**	**0.17**	**23.48**
5N (Bridge)				
	4/14/00	0.36	0.11	69.4
	5/3/00	0.10	1.05	NMV
	5/22/00	0.41	0.05	87.8
	6/6/00	0.24	0.31	NMV
	6/20/00	1.03	0.27	73.8
	8/1/00	0.13	0.33	NMV
	Mean:	**0.38**	**0.35**	**77.01**
	Std:	**0.34**	**0.36**	**9.60**

Zinc

Detection Limit: Zn-- 0.005--1 (mg/l)

	Sample Date	Zn Influent (mg/l)	Zn Effluent (mg/l)	Zn Efficiency (%)
Academy				
	3/30/00	0.22	0.05	77.3
	5/22/00	0.24	0.05	79.2
	7/24/00	0.41	0.04	90.2
	8/1/00	0.03	0.29	NMV
	Mean:	**0.225**	**0.108**	**52.2**
	Std:	**0.155**	**0.122**	
Best Buy				
	3/18/00	0.27	0.33	NMV
	3/30/00	0.2	0.03	85.0
	4/14/00	0.36	0.13	63.9
	5/3/00	0.27	0.07	74.1
	5/22/00	0.23	0.09	60.9
	6/6/00	0.52	0.34	34.6
	6/20/00	0.27	0.15	44.4
	7/24/00	0.21	0.45	NMV
	8/1/00	0.13	0.07	46.2
	Mean:	**0.273**	**0.184**	**58.4**
	Std:	**0.112**	**0.150**	
Bridge				
	3/18/00	0.11	0.03	72.7
	4/14/00	0.35	0.18	48.6
	5/3/00	0.53	0.32	39.6
	5/22/00	0.4	0.1	75.0
	6/6/00	0.6	0.15	75.0
	7/24/00	0.32	0.16	50.0
	8/1/00	0.31	0.05	83.9
	Mean:	**0.374**	**0.141**	**63.5**
	Std:	**0.160**	**0.097**	

Oil and Grease

Detection Limit: 1.4 mg/l, range is 5 - 1,000 mg/l

	Sample Date	Influent (mg/l)	Effluent (mg/l)	Efficiency (%)
Academy				
	3/30/00	92.6	685.8	NMV
	5/22/00	1.3	93.6	NMV
	6/6/00	314.4	31.6	89.9
	7/24/00	764.6	73.4	90.4
	8/1/00	0.6	79.3	NMV
	Mean:	**234.70**	**192.74**	**90.17**
	Std:	**322.73**	**276.59**	**0.32**
Best Buy				
	3/30/00	33.8	32.8	3.0
	4/14/00	37.3	0	100.0
	5/3/00	0	982.2	NMV
	5/22/00	48.3	131.2	NMV
	6/6/00	71.8	19.1	73.4
	6/20/00	25.4	29.7	NMV
	7/24/00	63.4	82	NMV
	8/1/00	18.9	160.8	NMV
	Mean:	**37.36**	**179.73**	**58.79**
	Std:	**23.53**	**329.16**	**50.14**
Bridge				
	4/14/00	336.4	381.1	NMV
	5/3/00	2.7	5.6	NMV
	5/22/00	31	163	NMV
	6/6/00	140.6	24.3	82.7
	6/20/00	15.3	8.3	45.8
	8/1/00	9.7	115.6	NMV
	Mean:	**89.28**	**116.32**	**64.23**
	Std:	**131.45**	**144.69**	**26.14**

APPENDIX B

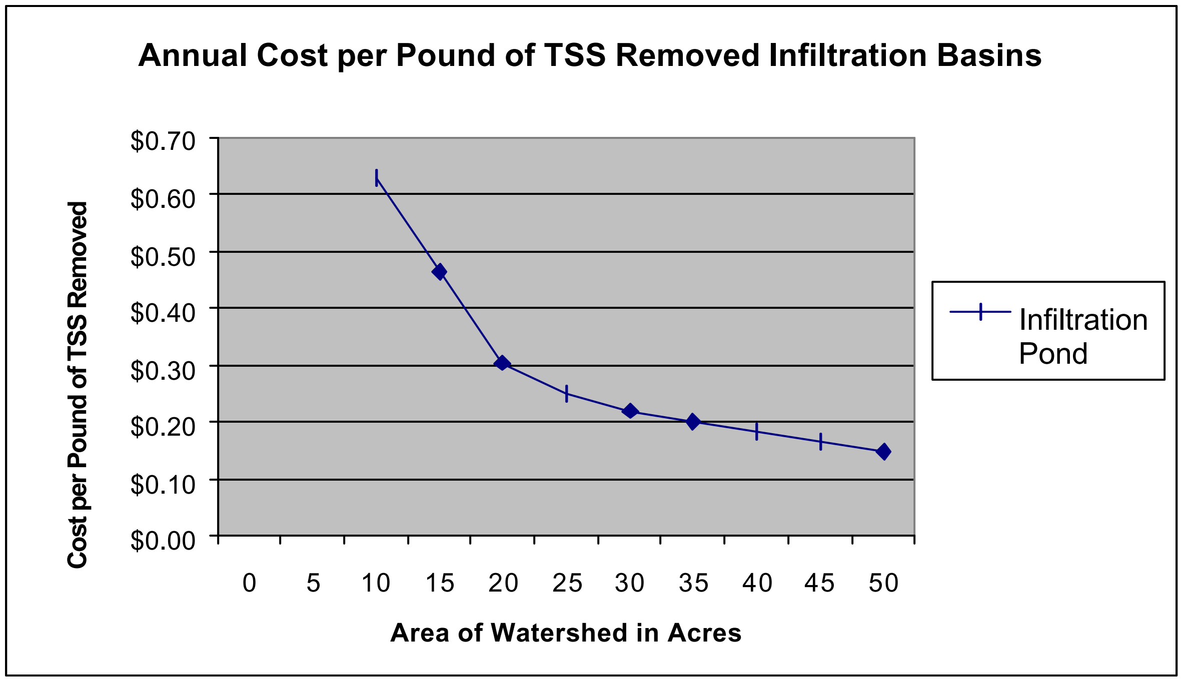
Stormwater Quality BMPs Final Estimates and Cost Index Composite

Infiltration Basins with Pretreatment

Item	Units	Price	Cycles/ Year	Quant. 10 Acre WS	Total	Quant. 20 Acre WS	Total	Quant. 30 Acre WS	Total	Quant. 40 Acre WS	Total	Quant. 50 Acre WS	Total
Site Size in Acres				1.44		2.34		3.16		4.01		4.75	
Storage Volume CF				69000		137000		204190		272250		340350	
Permanent Pool CF				0		0		0		0		0	
Grading	SY	$2.00		7000	$14,000	11340	$22,680	15300	$30,600	19500	$39,000	23100	$46,200
Embankment	CY	$16.00		478	$7,648	840	$13,440	1560	$24,960	1986	$31,776	2311	$36,976
Stone Riprap, Inlet	CY	$80.00		2.5	$200	2.8	$224	3	$240	4	$320	7	$560
Stone Riprap, Flume	CY	$80.00		2.5	$200	2.8	$224	3	$240	4	$320	7	$560
Stone Riprap, Spillway	CY	$80.00		3	$240	4	$320	4	$320	6	$480	10	$800
Concrete Riprap, Spillway	CY	$98.00		2.4	$235	3	$294	3	$294	8	$784	5	$490
Concrete Riprap, Flume	CY	$98.00		3	$294	4	$392	4	$392	4	$392	7	$686
Soil Stabilization	SY	$9.00		340	$3,060	450	$4,050	450	$4,050	500	$4,500	500	$4,500
Seeding	SY	$0.05		7000	$350	11340	$567	15300	$765	19500	$975	23100	$1,155
End Wall 3'	EA	$109.00		1	$109		$0		$0		$0		$0
End Wall 4'	EA	$204.00			$0	1	$204		$0		$0		$0
End Wall 5'	EA	$940.00			$0		$0	1	$940	1	$940		$0
End Wall 6'	EA	$950.00			$0		$0		$0		$0	1	$950
Total Construction Cost					**$26,336**		**$42,395**		**$62,801**		**$79,487**		**$92,877**
Construction Costs Amortized for 20 Years					**$1,317**		**$2,120**		**$3,140**		**$3,974**		**$4,644**
Annual Maintenance Expense													
Mowing	AC	$37.00	4	1.44	$213	2.34	$346	3.16	$468	4.01	$593	4.75	$703
Trash and Cleaning	AC	$36.00	4	1.44	$207	2.34	$337	3.16	$455	4.01	$577	4.75	$684
Inspection	MH	$20.00	20		$400	20	$400	20	$400	20	$400	20	$400
Reconstruction	AC	$500.00	0.33	1.44	$238	2.34	$386	3.16	$521	4.01	$662	4.75	$784
Total Annual Maintenance Expense					**$1,058**		**$1,469**		**$1,844**		**$2,233**		**$2,571**

Annual Cost Summary Infiltration Basins								
Watershed in Acres	**TSS #/CF**	**TSS #/Year**	**TSS Removed #/Year at 70 Percent Efficiency**	**Construction Cost (20 yr Amortization)**	**Annual Maintenance Cost**	**Total Annual Cost**	**Cost $/# Removed**	**Watershed in Acres**
10	0.005	5,401	3,781	$1,317	$1,058	$2,375	$0.63	**10**
20	0.0078	16,852	11,796	$2,120	$1,469	$3,589	$0.30	**20**
30	0.01	32,408	22,686	$3,140	$1,844	$4,984	$0.22	**30**
40	0.0112	48,396	33,877	$3,974	$2,233	$6,207	$0.18	**40**
50	0.0128	69,137	48,396	$4,644	$2,571	$7,215	$0.15	**50**

Values X	Values Y
0	
5	
10	$0.63
15	0.465
20	$0.30
25	$0.25
30	$0.22
35	$0.20
40	$0.18
45	$0.17
50	$0.15



Note: Intermediate values for five acre increments are interpolated.

Infiltration Basins, Hybrid

Item	Units	Price	Cycles/ Year	Quant. 10 Acre WS	Total	Quant. 20 Acre WS	Total	Quant. 30 Acre WS	Total	Quant. 40 Acre WS	Total	Quant. 50 Acre WS	Total
Site Size in Acres				1.44		2.34		3.16		4.01		4.75	
Storage Volume CF				69000		137000		204190		272250		340350	
Permanent Pool CF				0		0		0		0		0	
Grading	SY	$2.00		7000	$14,000	11340	$22,680	15300	$30,600	19500	$39,000	23100	$46,200
Dam	CY	$382.00		272	$103,904	443	$169,226	540	$206,280	625	$238,750	693	$264,726
Stone Riprap, Inlet	CY	$80.00		2.5	$200	2.8	$224	3	$240	4	$320	7	$560
Stone Riprap, Flume	CY	$80.00		2.5	$200	2.8	$224	3	$240	4	$320	7	$560
Stone Riprap, Spillway	CY	$80.00		3	$240	4	$320	4	$320	6	$480	10	$800
Concrete Riprap, Spillway	CY	$98.00		2.4	$235	3	$294	3	$294	8	$784	5	$490
Concrete Riprap, Flume	CY	$98.00		3	$294	4	$392	4	$392	4	$392	7	$686
Soil Stabilization	SY	$9.00		340	$3,060	450	$4,050	450	$4,050	500	$4,500	500	$4,500
Seeding	SY	$0.05		7000	$350	11340	$567	15300	$765	19500	$975	23100	$1,155
End Wall 3'	EA	$109.00		1	$109		$0		$0		$0		$0
End Wall 4'	EA	$204.00			$0	1	$204		$0		$0		$0
End Wall 5'	EA	$940.00			$0		$0	1	$940	1	$940		$0
End Wall 6'	EA	$950.00			$0		$0		$0		$0	1	$950
Total Construction Cost					**$122,592**		**$198,181**		**$244,121**		**$286,461**		**$320,627**
Construction Costs Amortized for 20 Years					**$6,130**		**$9,909**		**$12,206**		**$14,323**		**$16,031**

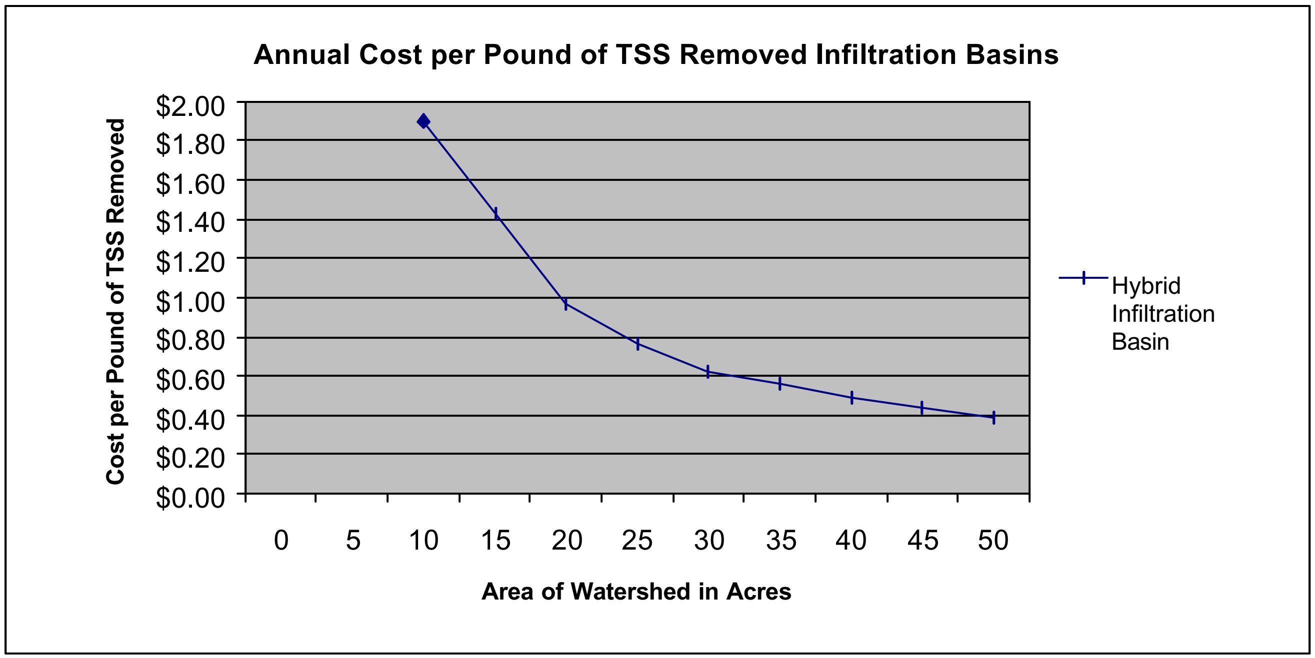
Annual Maintenance Expense

Item	Units	Price	Cycles/ Year	Quant. 10 Acre WS	Total	Quant. 20 Acre WS	Total	Quant. 30 Acre WS	Total	Quant. 40 Acre WS	Total	Quant. 50 Acre WS	Total
Mowing	AC	$37.00	4	1.44	$213	2.34	$346	3.16	$468	4.01	$593	4.75	$703
Trash and Cleaning	AC	$36.00	4	1.44	$207	2.34	$337	3.16	$455	4.01	$577	4.75	$684
Inspection	MH	$20.00	20		$400	20	$400	20	$400	20	$400	20	$400
Reconstruction	AC	$500.00	0.33	1.44	$238	2.34	$386	3.16	$521	4.01	$662	4.75	$784
Total Annual Maintenance Expense					**$1,058**		**$1,469**		**$1,844**		**$2,233**		**$2,571**

Annual Cost Summary Infiltration Basins, Hybrid

Watershed in Acres	TSS #/CF	TSS #/Year	TSS Removed #/Year at 70 Percent Efficiency	Construction Cost (20 yr Amortization)	Annual Maintenance Cost	Total Annual Cost	Cost $/# Removed	Watershed in Acres
10	0.005	5,401	3,781	$6,130	$1,058	$7,188	$1.90	**10**
20	0.0078	16,852	11,796	$9,909	$1,469	$11,378	$0.96	**20**
30	0.01	32,408	22,686	$12,206	$1,844	$14,050	$0.62	**30**
40	0.0112	48,396	33,877	$14,323	$2,233	$16,556	$0.49	**40**
50	0.0128	69,137	48,396	$16,031	$2,571	$18,602	$0.38	**50**

Values X	Values Y
0	
5	
10	$1.90
15	$1.43
20	$0.96
25	$0.76
30	$0.62
35	$0.56
40	$0.49
45	$0.44
50	$0.38

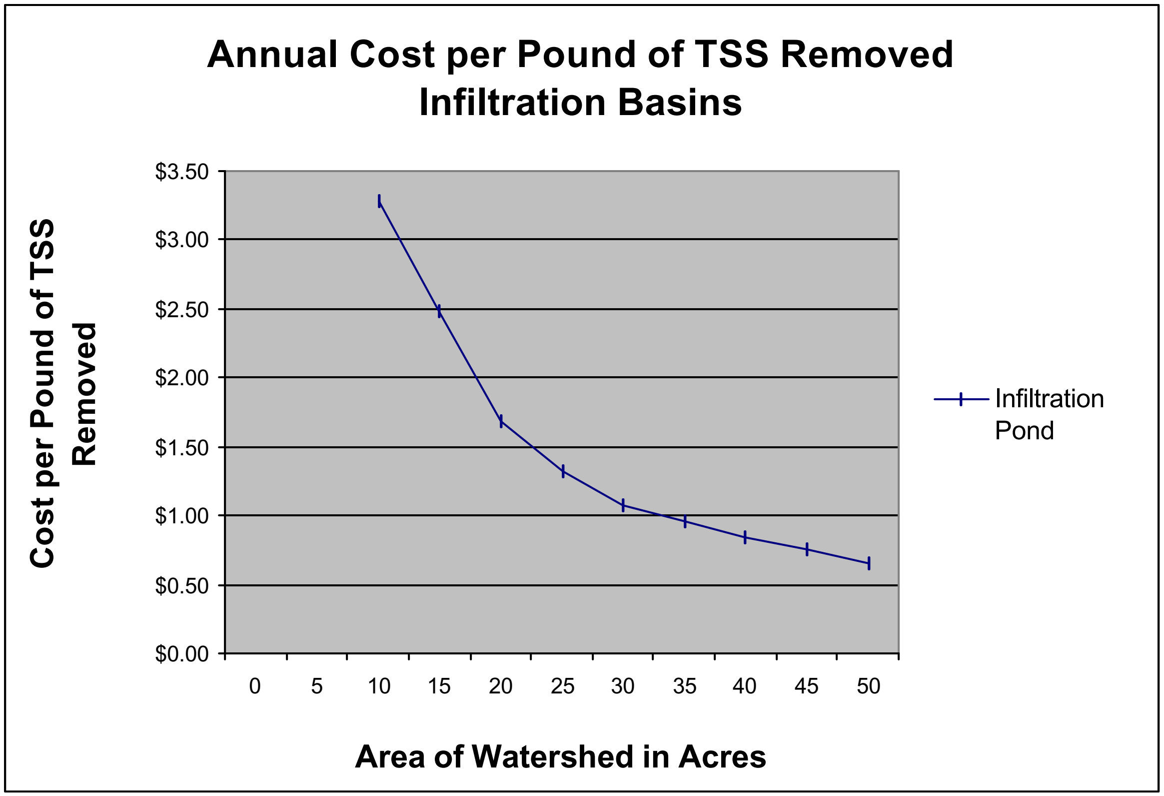


Note: Intermediate values for five acre increments are interpolated.

Infiltration Basins, Concrete													
Site Size in Acres				1.44		2.34		3.16		4.01		4.75	
Storage Volume CF				69000		137000		204190		272250		340350	
Permanent Pool CF				0		0		0		0		0	
Item	**Units**	**Price**	**Cycles/ Year**	**Quant. 10 Acre WS**	**Total**	**Quant. 20 Acre WS**	**Total**	**Quant. 30 Acre WS**	**Total**	**Quant. 40 Acre WS**	**Total**	**Quant. 50 Acre WS**	**Total**
Grading	SY	$2.00		7000	$14,000	11340	$22,680	15300	$30,600	19500	$39,000	23100	$46,200
Dam	CY	$382.00		544	$207,808	886	$338,452	1080	$412,560	1250	$477,500	1386	$529,452
Stone Riprap, Inlet	CY	$80.00		2.5	$200	2.8	$224	3	$240	4	$320	7	$560
Stone Riprap, Flume	CY	$80.00		2.5	$200	2.8	$224	3	$240	4	$320	7	$560
Stone Riprap, Spillway	CY	$80.00		3	$240	4	$320	4	$320	6	$480	10	$800
Concrete Riprap, Spillway	CY	$98.00		2.4	$235	3	$294	3	$294	8	$784	5	$490
Concrete Riprap, Flume	CY	$98.00		3	$294	4	$392	4	$392	4	$392	7	$686
Soil Stabilization	SY	$9.00		340	$3,060	450	$4,050	450	$4,050	500	$4,500	500	$4,500
Seeding	SY	$0.05		7000	$350	11340	$567	15300	$765	19500	$975	23100	$1,155
End Wall 3'	EA	$109.00		1	$109		$0		$0		$0		$0
End Wall 4'	EA	$204.00			$0	1	$204		$0		$0		$0
End Wall 5'	EA	$940.00			$0		$0	1	$940	1	$940		$0
End Wall 6'	EA	$950.00			$0		$0		$0		$0	1	$950
Total Construction Cost					**$226,496**		**$367,407**		**$450,401**		**$525,211**		**$585,353**
Construction Costs Amortized for 20 Years					**$11,325**		**$18,370**		**$22,520**		**$26,261**		**$29,268**
Annual Maintenance Expense													
Mowing	AC	$37.00	4	1.44	$213	2.34	$346	3.16	$468	4.01	$593	4.75	$703
Trash and Cleaning	AC	$36.00	4	1.44	$207	2.34	$337	3.16	$455	4.01	$577	4.75	$684
Inspection	MH	$20.00	20		$400	20	$400	20	$400	20	$400	20	$400
Reconstruction	AC	$500.00	0.33	1.44	$238	2.34	$386	3.16	$521	4.01	$662	4.75	$784
Total Annual Maintenance Expense					**$1,058**		**$1,469**		**$1,844**		**$2,233**		**$2,571**

Annual Cost Summary Infiltration Basins, Concrete								
Watershed in Acres	**TSS #/CF**	**TSS #/Year**	**TSS Removed #/Year at 70 Percent Efficiency**	**Construction Cost (20 yr Amortization)**	**Annual Maintenance Cost**	**Total Annual Cost**	**Cost $/# Removed**	**Watershed in Acres**
10	0.005	5,4 01	3,781	$11,325	$1,058	$12,383	$3.28	**10**
20	0.0078	16,852	11,796	$18,370	$1,469	$19,840	$1.68	**20**
30	0.01	32,408	22,686	$22,520	$1,844	$24,364	$1.07	**30**
40	0.0112	48,396	33,877	$26,261	$2,233	$28,493	$0.84	**40**
50	0.0128	69,137	48,396	$29,268	$2,571	$31,838	$0.66	**50**

Values X	Values Y
0	
5	
10	$3.28
15	2.48
20	$1.68
25	$1.32
30	$1.07
35	$0.96
40	$0.84
45	$0.75
50	$0.66



Note: Intermediate values for five acre increments are interpolated.

Detention Basins, Concrete

Item	Units	Price	Cycles/ Year	Quant. 10 Acre WS	Total	Quant. 20 Acre WS	Total	Quant. 30 Acre WS	Total	Quant. 40 Acre WS	Total	Quant. 50 Acre WS	Total
Site Size in Acres				1.44		2.34		3.16		4.01		4.75	
Storage Volume CF				69,000		137,000		204,190		272,250		340,350	
Permanent Pool CF				0		0		0		0		0	
Grading	SY	$2.00		7000	$14,000	11340	$22,680	15300	$30,600	19500	$39,000	23100	$46,200
Dam	CY	$382.00		544	$207,808	886	$338,452	1080	$412,560	1250	$477,500	1386	$529,452
Stone Riprap, Inlet	CY	$80.00		2.5	$200	2.8	$224	3	$240	4	$320	7	$560
Stone Riprap, Flume	CY	$80.00		2.5	$200	2.8	$224	3	$240	4	$320	7	$560
Stone Riprap, Spillway	CY	$80.00		3	$240	4	$320	4	$320	6	$480	10	$800
Concrete Riprap, Spillway	CY	$98.00		2.4	$235	3	$294	3	$294	8	$784	5	$490
Concrete Riprap, Flume	CY	$98.00		3	$294	4	$392	4	$392	4	$392	7	$686
Stone Riprap Pretreat Outfall	CY	$80.00		2.5	$200	2.8	$224	3	$240	4	$320	7	$560
Stone Riprap Outfall	CY	$80.00		2.5	$200	2.8	$224	3	$240	4	$320	7	$560
Soil Stabilization	SY	$9.00		340	$3,060	450	$4,050	450	$4,050	500	$4,500	500	$4,500
Seeding	SY	$0.05		7000	$350	11340	$567	15300	$765	19500	$975	23100	$1,155
End Wall 3'	EA	$1,240.00		3	$3,720		$0		$0		$0		$0
End Wall 4'	EA	$1,430.00			$0	3	$4,290		$0		$0		$0
End Wall 5'	EA	$1,940.00			$0		$0	3	$5,820	3	$5,820		$0
End Wall 6'	EA	$2,200.00			$0		$0		$0		$0	3	$6,600
Stand Pipe 8" PVC	LF	$8.75			$0		$0		$0		$0		$0
Stand Pipe 30" RCP	LF	$56.00		10	$560		$0		$0		$0		$0
Stand Pipe 36" RCP	LF	$80.00			$0	10	$800	10	$800		$0		$0
Stand Pipe 48" RCP	LF	$175.00			$0		$0		$0	10	$1,750	10	$1,750
8" PVC Pipe	LF	$6.75		60	$2,283	80	$3,044	120	$4,566	180	$6,849	200	$1,350
Reinforced Concrete Pipe 12"	LF	$28.00		35	$1,332		$0		$0		$0		$0

Detention Basins, Concrete (cont.)

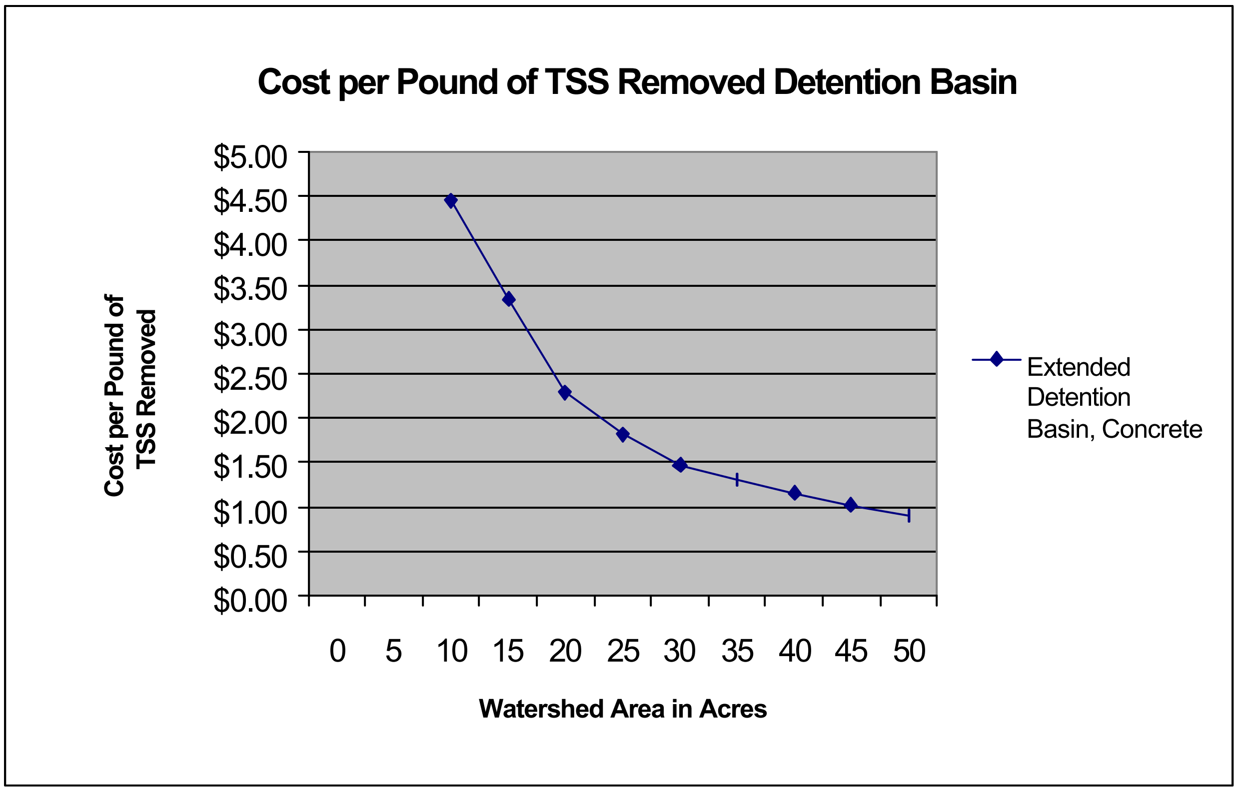
Reinforced Concrete Pipe 15"	LF	$38.05			$0	35	$1,046		$0		$0		$0
Reinforced Concrete Pipe 18"	LF	$29.88			$0		$0	45	$1,575		$0		$0
Reinforced Concrete Pipe 24"	LF	$35.00			$0		$0		$0	55	$2,197		$0
Reinforced Concrete Pipe 30"	LF	$39.94			$0		$0		$0		$0	65	$2,596
Reinforced Concrete Pipe 36"	LF	$60.78			$0		$0		$0		$0		$0
Poly Pipe Underdrain, 4"	LF	$2.50		0	$0	0	$0	0	$0	0	$0	0	$0
Sand Backfill	CY	$18.00		0	$0	0	$0	0	$0	0	$0	0	$0
Clay Liner	SY	$8.30		2,800	$23,240	5,600	$46,480	7,000	$58,100	8,500	$70,550	10,000	$83,000
Manhole and Valve	EA	Varies		1	$1,200	1	$1,600	1	$2,000	1	$2,600	1	$3,000
Total Construction Cost					**$257,922**		**$423,311**		**$520,802**		**$612,077**		**$680,819**
Construction Costs Amortized for 20 Years					**$12,896**		**$21,166**		**$26,040**		**$30,604**		**$34,041**

Annual Maintenance Expense

Mowing	AC	$37.00	4	1.44	$213	2.34	$346	3.16	$468	4.01	$593	4.75	$703
Trash and Cleaning	AC	$36.00	4	1.44	$207	2.34	$337	3.16	$455	4.01	$577	4.75	$684
Inspection	MH	$20.00	20		$400	20	$400	20	$400	20	$400	20	$400
Silt Removal	AC	$500.00	1	1	$720	1.8	$900	2.6	$1,300	2.9	$1,450	3.2	$1,600
Total Annual Maintenance Expense					**$1,540**		**$1,983**		**$2,623**		**$3,021**		**$3,387**

Annual Cost Summary Detention Basins								
Watershed in Acres	**TSS #/CF**	**TSS #/Year**	**TSS Removed #/Year at 60 Percent Efficiency**	**Construction Cost (20 yr Amortization)**	**Annual Maintenance Cost**	**Total Annual Cost**	**Cost $/# Removed**	**Watershed in Acres**
10	0.005	5,401	3,241	$12,896	$1,540	$14,437	$4.45	**10**
20	0.0078	16,852	10,111	$21,166	$1,983	$23,149	$2.29	**20**
30	0.01	32,408	19,445	$26,040	$2,623	$28,663	$1.47	**30**
40	0.0112	48,396	29,038	$30,604	$3,021	$33,625	$1.16	**40**
50	0.0128	69,137	41,482	$34,041	$3,387	$37,428	$0.90	**50**

Values X	Values Y
0	
5	
10	$4.45
15	3.34
20	$2.29
25	$1.82
30	$1.47
35	$1.31
40	$1.16
45	$1.03
50	$0.90



Note: Intermediate values for five acre increments are interpolated.

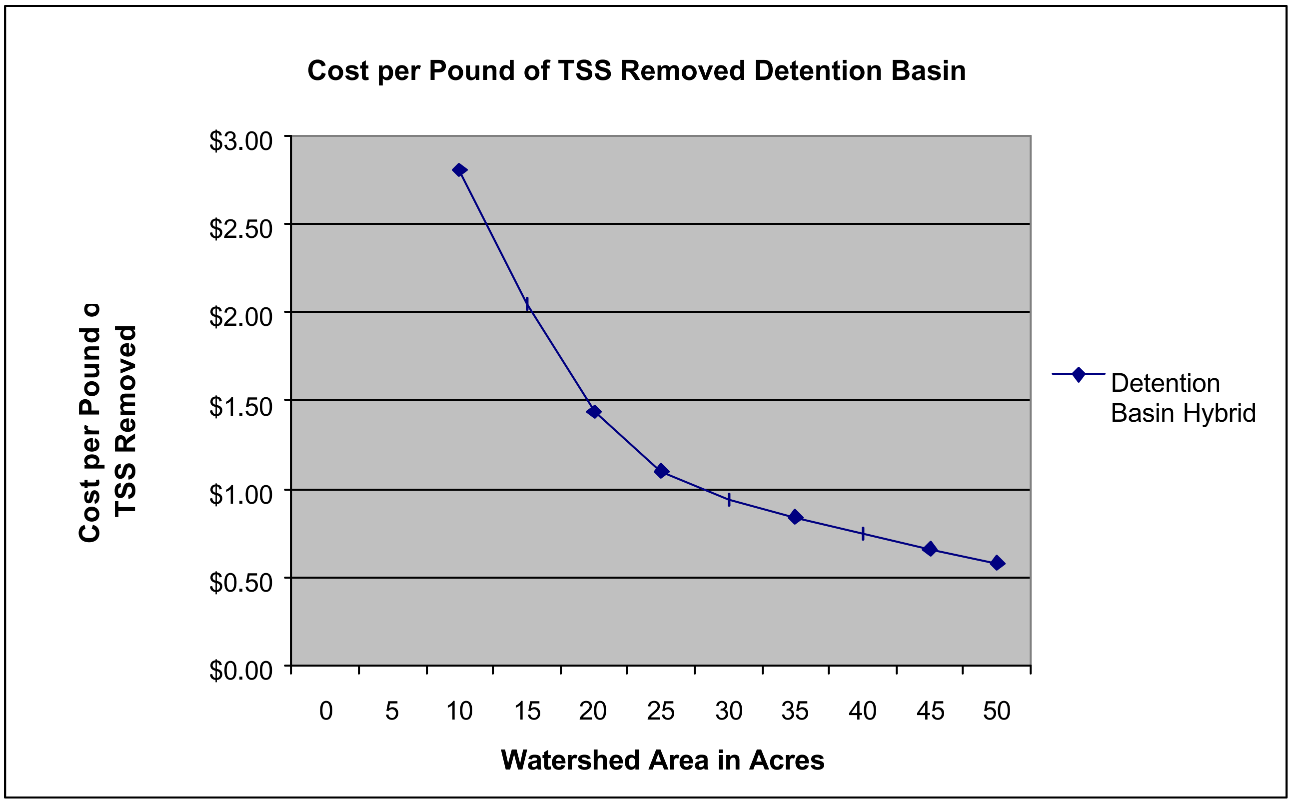
Detention Basins, Hybrid

Item	Units	Price	Cycles/ Year	Quant. 10 Acre WS	Total	Quant. 20 Acre WS	Total	Quant. 30 Acre WS	Total	Quant. 40 Acre WS	Total	Quant. 50 Acre WS	Total
Site Size in Acres				1.44		2.34		3.16		4.01		4.75	
Storage Volume CF				69000		137000		204190		272250		340350	
Permanent Pool CF				0		0		0		0		0	
Grading	SY	$2.00		7000	$14,000	11340	$22,680	15300	$30,600	19500	$39,000	23100	$46,200
Dam	CY	$382.00		272	$103,904	443	$169,226	540	$206,280	625	$238,750	693	$264,726
Stone Riprap, Inlet	CY	$80.00		2.5	$200	2.8	$224	3	$240	4	$320	7	$560
Stone Riprap, Flume	CY	$80.00		2.5	$200	2.8	$224	3	$240	4	$320	7	$560
Stone Riprap, Spillway	CY	$80.00		3	$240	4	$320	4	$320	6	$480	10	$800
Concrete Riprap, Spillway	CY	$98.00		2.4	$235	3	$294	3	$294	8	$784	5	$490
Concrete Riprap, Flume	CY	$98.00		3	$294	4	$392	4	$392	4	$392	7	$686
Stone Riprap Pretreat Outfall	CY	$80.00		2.5	$200	2.8	$224	3	$240	4	$320	7	$560
Stone Riprap Outfall	CY	$80.00		2.5	$200	2.8	$224	3	$240	4	$320	7	$560
Soil Stabilization	SY	$9.00		340	$3,060	450	$4,050	450	$4,050	500	$4,500	500	$4,500
Seeding	SY	$0.05		7000	$350	11340	$567	15300	$765	19500	$975	23100	$1,155
End Wall 3'	EA	$1,240.00		3	$3,720		$0		$0		$0		$0
End Wall 4'	EA	$1,430.00			$0	3	$4,290		$0		$0		$0
End Wall 5'	EA	$1,940.00			$0		$0	3	$5,820	3	$5,820		$0
End Wall 6'	EA	$2,200.00			$0		$0		$0		$0	3	$6,600
Stand Pipe 8" PVC	LF	$8.75			$0		$0		$0		$0		$0
Stand Pipe 30" RCP	LF	$56.00		10	$560		$0		$0		$0		$0
Stand Pipe 36" RCP	LF	$80.00			$0	10	$800	10	$800		$0		$0
Stand Pipe 48" RCP	LF	$175.00			$0		$0		$0	10	$1,750	10	$1,750
8" PVC Pipe	LF	$6.75		60	$2,283	80	$3,044	120	$4,566	180	$6,849	200	$1,350

Detention Basins, Hybrid (cont.)													
Reinforced Concrete Pipe 12"	LF	$28.00		35	$1,332		$0		$0		$0		$0
Reinforced Concrete Pipe 15"	LF	$38.05			$0	35	$1,046		$0		$0		$0
Reinforced Concrete Pipe 18"	LF	$29.88			$0		$0	45	$1,575		$0		$0
Reinforced Concrete Pipe 24"	LF	$35.00			$0		$0		$0	55	$2,197		$0
Reinforced Concrete Pipe 30"	LF	$39.94			$0		$0		$0		$0	65	$2,596
Reinforced Concrete Pipe 36"	LF	$60.78			$0		$0		$0		$0		$0
Poly Pipe Underdrain, 4"	LF	$2.50		0	$0	0	$0	0	$0	0	$0	0	$0
Sand Backfill	CY	$18.00		0	$0	0	$0	0	$0	0	$0	0	$0
Clay Liner	SY	$8.30		2,800	$23,240	5,600	$46,480	7,000	$58,100	8,500	$70,550	10,000	$83,000
Manhole and Valve	EA	Varies		1	$1,200	1	$1,600	1	$2,000	1	$2,600	1	$3,000
Total Construction Cost					**$154,018**		**$254,085**		**$314,522**		**$373,327**		**$416,093**
Construction Costs Amortized for 20 Years					**$7,701**		**$12,704**		**$15,726**		**$18,666**		**$20,805**
Annual Maintenance Expense													
Mowing	AC	$37.00	4	1.44	$213	2.34	$346	3.16	$468	4.01	$593	4.75	$703
Trash and Cleaning	AC	$36.00	4	1.44	$207	2.34	$337	3.16	$455	4.01	$577	4.75	$684
Inspection	MH	$20.00	20		$400	20	$400	20	$400	20	$400	20	$400
Silt Removal	AC	$500.00	1	1	$720	1.8	$900	2.6	$1,300	2.9	$1,450	3.2	$1,600
Total Annual Maintenance Expense					**$1,540**		**$1,983**		**$2,623**		**$3,021**		**$3,387**

Annual Cost Summary Detention Basins								
Watershed in Acres	**TSS #/CF**	**TSS #/Year**	**TSS Removed #/Year at 60 Percent Efficiency**	**Construction Cost (20 yr Amortization)**	**Annual Maintenance Cost**	**Total Annual Cost**	**Cost $/# Removed**	**Watershed in Acres**
10	0.005	5,401	3,241	$7,701	$1,540	$9,241	$2.85	**10**
20	0.0078	16,852	10,111	$12,704	$1,983	$14,688	$1.45	**20**
30	0.01	32,408	19,445	$15,726	$2,623	$18,349	$0.94	**30**
40	0.0112	48,396	29,038	$18,666	$3,021	$21,687	$0.75	**40**
50	0.0128	69,137	41,482	$20,805	$3,387	$24,192	$0.58	**50**

Values X	Values Y
0	
5	
10	$2.81
15	$2.05
20	$1.44
25	$1.10
30	$0.94
35	$0.84
40	$0.74
45	$0.66
50	$0.58



Note: Intermediate values for five acre increments are interpolated.

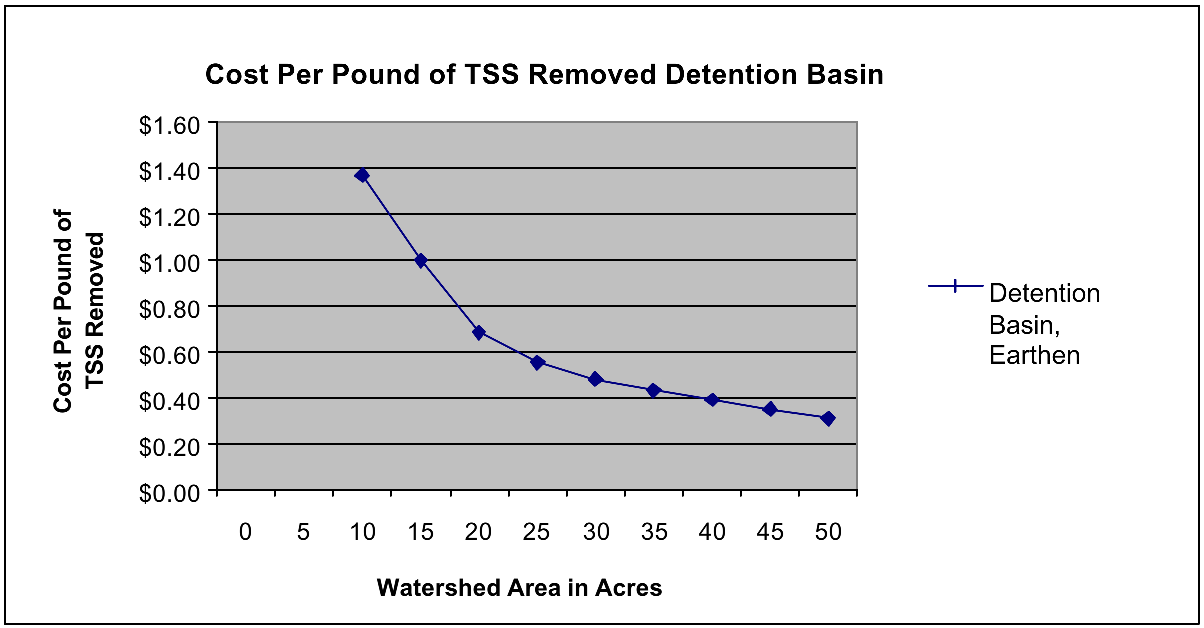
Detention Basins with Pretreatment

Item	Units	Price	Cycles/ Year	Quant. 10 Acre WS	Total	Quant. 20 Acre WS	Total	Quant. 30 Acre WS	Total	Quant. 40 Acre WS	Total	Quant. 50 Acre WS	Total
Site Size in Acres				1.44		2.34		3.16		4.01		4.75	
Storage Volume CF				69000		137000		204190		272250		340350	
Permanent Pool CF				0		0		0		0		0	
Grading	SY	$2.00		7000	$14,000	11340	$22,680	15300	$30,600	19500	$39,000	23100	$46,200
Dam	CY	$16.00		478	$7,648	840	$13,440	1560	$24,960	1986	$31,776	2311	$36,976
Stone Riprap, Inlet	CY	$80.00		2.5	$200	2.8	$224	3	$240	4	$320	7	$560
Stone Riprap, Flume	CY	$80.00		2.5	$200	2.8	$224	3	$240	4	$320	7	$560
Stone Riprap, Spillway	CY	$80.00		3	$240	4	$320	4	$320	6	$480	10	$800
Concrete Riprap, Spillway	CY	$98.00		2.4	$235	3	$294	3	$294	8	$784	5	$490
Concrete Riprap, Flume	CY	$98.00		3	$294	4	$392	4	$392	4	$392	7	$686
Stone Riprap Pretreat Outfall	CY	$80.00		2.5	$200	2.8	$224	3	$240	4	$320	7	$560
Stone Riprap Outfall	CY	$80.00		2.5	$200	2.8	$224	3	$240	4	$320	7	$560
Soil Stabilization	SY	$9.00		340	$3,060	450	$4,050	450	$4,050	500	$4,500	500	$4,500
Seeding	SY	$0.05		7000	$350	11340	$567	15300	$765	19500	$975	23100	$1,155
End Wall 3'	EA	$1,240.00		3	$3,720		$0		$0		$0		$0
End Wall 4'	EA	$1,430.00			$0	3	$4,290		$0		$0		$0
End Wall 5'	EA	$1,940.00			$0		$0	3	$5,820	3	$5,820		$0
End Wall 6'	EA	$2,200.00			$0		$0		$0		$0	3	$6,600
Stand Pipe 8" PVC	LF	$8.75			$0		$0		$0		$0		$0
Stand Pipe 30" RCP	LF	$56.00		10	$560		$0		$0		$0		$0
Stand Pipe 36" RCP	LF	$80.00			$0	10	$800	10	$800		$0		$0
Stand Pipe 48" RCP	LF	$175.00			$0		$0		$0	10	$1,750	10	$1,750
8" PVC Pipe	LF	$6.75		60	$2,283	80	$3,044	120	$4,566	180	$6,849	200	$1,350

Detention Basins with Pretreatment (cont.)													
Reinforced Concrete Pipe 12"	LF	$28.00		35	$1,332		$0		$0		$0		$0
Reinforced Concrete Pipe 15"	LF	$38.05			$0	35	$1,046		$0		$0		$0
Reinforced Concrete Pipe 18"	LF	$29.88			$0		$0	45	$1,575		$0		$0
Reinforced Concrete Pipe 24"	LF	$35.00			$0		$0		$0	55	$2,197		$0
Reinforced Concrete Pipe 30"	LF	$39.94			$0		$0		$0		$0	65	$2,596
Reinforced Concrete Pipe 36"	LF	$60.78			$0		$0		$0		$0		$0
Poly Pipe Underdrain, 4"	LF	$2.50		0	$0	0	$0	0	$0	0	$0	0	$0
Sand Backfill	CY	$18.00		0	$0	0	$0	0	$0	0	$0	0	$0
Clay Liner	SY	$8.30		2,800	$23,240	5,600	$46,480	7,000	$58,100	8,500	$70,550	10,000	$83,000
Manhole and Valve	EA	Varies		1	$1,200	1	$1,600	1	$2,000	1	$2,600	1	$3,000
Total Construction Cost					**$57,762**		**$98,299**		**$133,202**		**$166,353**		**$188,343**
Construction Costs Amortized for 20 Years					**$2,888**		**$4,915**		**$6,660**		**$8,318**		**$9,417**
Annual Maintenance Expense													
Mowing	AC	$37.00	4	1.44	$213	2.34	$346	3.16	$468	4.01	$593	4.75	$703
Trash and Cleaning	AC	$36.00	4	1.44	$207	2.34	$337	3.16	$455	4.01	$577	4.75	$684
Inspection	MH	$20.00	20		$400	20	$400	20	$400	20	$400	20	$400
Silt Removal	AC	$500.00	1	1	$720	1.8	$900	2.6	$1,300	2.9	$1,450	3.2	$1,600
Total Annual Maintenance Expense					**$1,540**		**$1,983**		**$2,623**		**$3,021**		**$3,387**

Annual Cost Summary Detention Basins								
Watershed in Acres	**TSS #/CF**	**TSS #/Year**	**TSS Removed #/Year at 60 Percent Efficiency**	**Construction Cost (20 yr Amortization)**	**Annual Maintenance Cost**	**Total Annual Cost**	**Cost $/# Removed**	**Watershed in Acres**
10	0.005	5,401	3,241	$2,888	$1,540	$4,429	$1.37	**10**
20	0.0078	16,852	10,111	$4,915	$1,983	$6,898	$0.68	**20**
30	0.01	32,408	19,445	$6,660	$2,623	$9,283	$0.48	**30**
40	0.0112	48,396	29,038	$8,318	$3,021	$11,339	$0.39	**40**
50	0.0128	69,137	41,482	$9,417	$3,387	$12,804	$0.31	**50**

Values X	Values Y
0	
5	
10	$1.37
15	$1.00
20	$0.68
25	$0.55
30	$0.48
35	$0.43
40	$0.39
45	$0.35
50	$0.31



Note: Intermediate values for five acre increments are interpolated.

Sand Filter Hybrid with Pretreatment

Site Size in Acres				1.44		2.34		3.16		4.01		4.75	
Storage Volume CF				69000		137000		204190		272250		340350	
Permanent Pool CF				0		0		0		0		0	
Item	**Units**	**Price**	**Cycles/ Year**	**Quant. 10 Acre WS**	**Total**	**Quant. 20 Acre WS**	**Total**	**Quant. 30 Acre WS**	**Total**	**Quant. 40 Acre WS**	**Total**	**Quant. 50 Acre WS**	**Total**
Grading	SY	$2.00		7000	$14,000	11340	$22,680	15300	$30,600	19500	$39,000	23100	$46,200
Dam	CY	$382.00		272	$103,904	443	$169,226	540	$206,280	625	$238,750	693	$264,726
Stone Riprap, Inlet	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Stone Riprap, Flume	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Stone Riprap, Spillway	CY	$26.00		3	$78	4	$104	4	$104	6	$156	10	$260
Concrete Riprap, Spillway	CY	$27.00		2.4	$65	3	$81	3	$81	8	$216	5	$135
Concrete Riprap, Flume	CY	$27.00		3	$81	4	$108	4	$108	4	$108	7	$189
Stone Riprap Pretreat Outfall	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Stone Riprap Outfall	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Soil Stabilization	SY	$9.00		340	$3,060	450	$4,050	450	$4,050	480	$4,320	500	$4,500
Seeding	SY	$0.05		7000	$350	11340	$567	15300	$765	19500	$975	23100	$1,155
End Wall 3'	EA	$1,240.00		3	$3,720		$0		$0		$0		$0
End Wall 4'	EA	$1,430.00			$0	3	$4,290		$0		$0		$0
End Wall 5'	EA	$1,940.00			$0		$0	3	$5,820	3	$5,820		$0
End Wall 6'	EA	$2,200.00			$0		$0		$0		$0	3	$6,600
Stand Pipe 8" PVC	LF	$8.75			$0		$0		$0		$0		$0
Stand Pipe 30" RCP	LF	$56.00		10	$560		$0		$0		$0		$0
Stand Pipe 36" RCP	LF	$80.00			$0	10	$800	10	$800		$0		$0
Stand Pipe 48" RCP	LF	$175.00			$0		$0		$0	10	$1,750	10	$1,750
8" PVC Pipe	LF	$6.75			$0		$0		$0		$0		$0

Sand Filter Hybrid with Pretreatment (cont.)

Reinforced Concrete Pipe 12"	LF	$28.00		35	$1,332		$0		$0		$0		$0
Reinforced Concrete Pipe 15"	LF	$38.05			$0	35	$1,046		$0		$0		$0
Reinforced Concrete Pipe 18"	LF	$29.88			$0		$0	45	$1,575		$0		$0
Reinforced Concrete Pipe 24"	LF	$35.00			$0		$0		$0	55	$2,197		$0
Reinforced Concrete Pipe 30"	LF	$39.94			$0		$0		$0		$0	65	$2,596
Reinforced Concrete Pipe 36"	LF	$60.78			$0		$0		$0		$0		$0
Poly Pipe Underdrain, 4"	LF	$2.50		1,156	$9,595	2,256	$18,725	3,321	$8,303	3,906	$9,765	4,225	$10,563
Sand Backfill	CY	$18.00		685	$12,330	1,337	$24,066	1,728	$31,104	2,315	$41,670	2,504	$45,072
Clay Liner	SY	$8.30		2,800	$23,240	5,600	$46,480	7,000	$58,100	8,500	$70,550	10,000	$83,000
Manhole and Valve	EA	Varies		1	$1,200	1	$1,600	1	$2,000	1	$2,400	1	$3,000
Total Construction Cost					**$173,774**		**$294,114**		**$350,002**		**$418,093**		**$470,474**
Construction Costs Amortized for 20 Years					**$8,689**		**$14,706**		**$17,500**		**$20,905**		**$23,524**

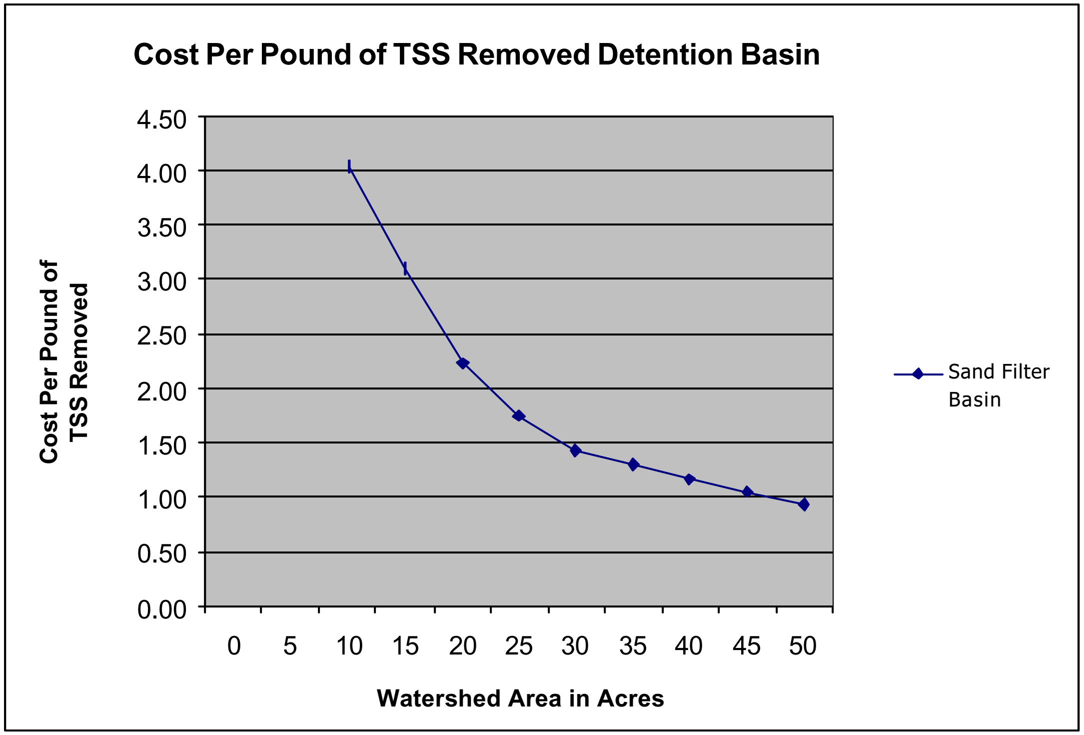
Annual Maintenance Expense

Mowing	AC	$37.00	4	1.44	$213	2.34	$346	3.16	$468	4.01	$593	4.75	$703
Trash and Cleaning	AC	$36.00	4	1.44	$207	2.34	$337	3.16	$455	4.01	$577	4.75	$684
Inspection	MH	$20.00	20		$400	20	$400	20	$400	20	$400	20	$400
Silt Removal	AC	$500.00	1	1	$720	1.8	$900	2.6	$1,300	2.9	$1,450	3.2	$1,600
Rennovation Cost	SY	$26.00	0.1	2085	$5,421	4000	$10,400	5184	$13,478	6432	$16,723	7500	$19,500
Total Annual Maintenance Expense					**$6,961**		**$12,383**		**$16,101**		**$19,744**		**$22,887**

Annual Cost Summary Sand Filter Hybrid

Watershed in Acres	TSS #/CF	TSS #/Year	TSS Removed #/Year at 80 Percent Efficiency	Construction Cost (20 yr Amortization)	Annual Maintenance Cost	Total Annual Cost	Cost $/# Removed	Watershed in Acres
10	0.005	4,860	3,888	$8,689	$6,961	$15,650	$4.03	**10**
20	0.0078	15,167	12,134	$14,706	$12,383	$27,089	$2.23	**20**
30	0.01	29,186	23,349	$17,500	$16,101	$33,601	$1.44	**30**
40	0.0112	43,557	34,846	$20,905	$19,744	$40,649	$1.17	**40**
50	0.0128	62,224	49,779	$23,524	$22,887	$46,411	$0.93	**50**

Values X	Values Y
0	
5	
10	$4.03
15	$3.11
20	$2.23
25	$1.75
30	$1.44
35	$1.30
40	$1.17
45	$1.05
50	$0.93



Note: Intermediate values for five acre increments are interpolated.

Sand Filter Concrete with Pretreatment

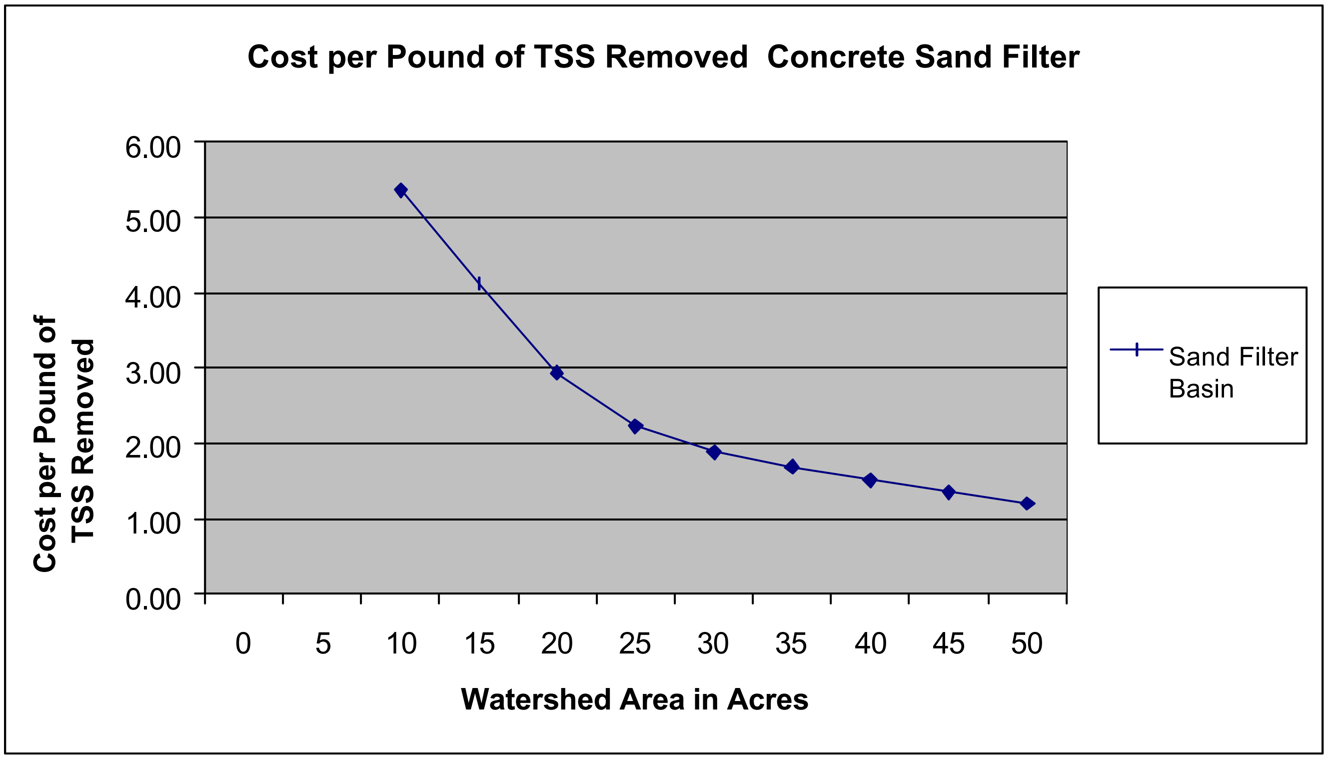
Item	Units	Price	Cycles/ Year	Quant. 10 Acre WS	Total	Quant. 20 Acre WS	Total	Quant. 30 Acre WS	Total	Quant. 40 Acre WS	Total	Quant. 50 Acre WS	Total
Site Size in Acres				**1.44**		**2.34**		**3.16**		**4.01**		**4.75**	
Storage Volume CF				**69000**		**137000**		**204190**		**272250**		**340350**	
Permanent Pool CF				**0**		**0**		**0**		**0**		**0**	
Grading	SY	$2.00		7000	$14,000	11340	$22,680	15300	$30,600	19500	$39,000	23100	$46,200
Dam and Basin Walls	CY	$382.00		544	$207,808	886	$338,452	1080	$412,560	1250	$477,500	1386	$529,452
Stone Riprap, Inlet	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Stone Riprap, Flume	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Stone Riprap, Spillway	CY	$26.00		3	$78	4	$104	4	$104	6	$156	10	$260
Concrete Riprap, Spillway	CY	$27.00		2.4	$65	3	$81	3	$81	8	$216	5	$135
Concrete Riprap, Flume	CY	$27.00		3	$81	4	$108	4	$108	4	$108	7	$189
Stone Riprap Pretreat Outfall	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Stone Riprap Outfall	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Soil Stabilization	SY	$9.00		340	$3,060	450	$4,050	450	$4,050	480	$4,320	500	$4,500
Seeding	SY	$0.05		7000	$350	11340	$567	15300	$765	19500	$975	23100	$1,155
End Wall 3'	EA	$1,240.00		3	$3,720		$0		$0		$0		$0
End Wall 4'	EA	$1,430.00			$0	3	$4,290		$0		$0		$0
End Wall 5'	EA	$1,940.00			$0		$0	3	$5,820	3	$5,820		$0
End Wall 6'	EA	$2,200.00			$0		$0		$0		$0	3	$6,600
Stand Pipe 8" PVC	LF	$8.75			$0		$0		$0		$0		$0
Stand Pipe 30" RCP	LF	$56.00		10	$560		$0		$0		$0		$0
Stand Pipe 36" RCP	LF	$80.00			$0	10	$800	10	$800		$0		$0
Stand Pipe 48" RCP	LF	$175.00			$0		$0		$0	10	$1,750	10	$1,750
8" PVC Pipe	LF	$6.75			$0		$0		$0		$0		$0

Sand Filter Concrete with Pretreatment (cont.)

Reinforced Concrete Pipe 12"	LF	$28.00		35	$1,332		$0		$0		$0		$0
Reinforced Concrete Pipe 15"	LF	$38.05			$0	35	$1,046		$0		$0		$0
Reinforced Concrete Pipe 18"	LF	$29.88			$0		$0	45	$1,575		$0		$0
Reinforced Concrete Pipe 24"	LF	$35.00			$0		$0		$0	55	$2,197		$0
Reinforced Concrete Pipe 30"	LF	$39.94			$0		$0		$0		$0	65	$2,596
Reinforced Concrete Pipe 36"	LF	$60.78			$0		$0		$0		$0		$0
Poly Pipe Underdrain, 4"	LF	$2.50		1,156	$9,595	2,256	$18,725	3,321	$8,303	3,906	$9,765	4,225	$10,563
Sand Backfill	CY	$18.00		685	$12,330	1,337	$24,066	1,728	$31,104	2,315	$41,670	2,504	$45,072
Clay Liner	SY	$8.30		2,800	$23,240	5,600	$46,480	7,000	$58,100	8,500	$70,550	10,000	$83,000
Manhole and Valve	EA	Varies		1	$1,200	1	$1,600	1	$2,000	1	$2,400	1	$3,000
Total Construction Cost					**$277,678**		**$463,340**		**$556,282**		**$656,843**		**$735,200**
Construction Costs Amortized for 20 Years					**$13,884**		**$23,167**		**$27,814**		**$32,842**		**$36,760**
Annual Maintenance Expense													
Mowing	AC	$37.00	4	1.44	$213	2.34	$346	3.16	$468	4.01	$593	4.75	$703
Trash and Cleaning	AC	$36.00	4	1.44	$207	2.34	$337	3.16	$455	4.01	$577	4.75	$684
Inspection	MH	$20.00	20		$400	20	$400	20	$400	20	$400	20	$400
Silt Removal	AC	$500.00	1	1	$720	1.8	$900	2.6	$1,300	2.9	$1,450	3.2	$1,600
Renovation Cost	SY	$26.00	0.1	2085	$5,421	4000	$10,400	5184	$13,478	6432	$16,723	7500	$19,500
Total Annual Maintenance Expense					**$6,961**		**$12,383**		**$16,101**		**$19,744**		**$22,887**

Annual Cost Summary Sand Filter Concrete								
Watershed in Acres	TSS #/CF	TSS #/Year	TSS Removed #/Year at 80 Percent Efficiency	Construction Cost (20 yr Amortization)	Annual Maintenance Cost	Total Annual Cost	Cost $/# Removed	Watershed in Acres
10	0.005	4,860	3,888	$13,884	$6,961	$20,845	$5.36	**10**
20	0.0078	15,167	12,134	$23,167	$12,383	$35,550	$2.93	**20**
30	0.01	29,186	23,349	$27,814	$16,101	$43,915	$1.88	**30**
40	0.0112	43,557	34,846	$32,842	$19,744	$52,586	$1.51	**40**
50	0.0128	62,224	49,779	$36,760	$22,887	$59,647	$1.20	**50**

Values X	Values Y
0	
5	
10	$5.36
15	4.12
20	$2.93
25	$2.23
30	$1.88
35	$1.69
40	$1.51
45	$1.35
50	$1.20



Note: Intermediate values for five acre increments are interpolated.

Sand Filter Basin with Pretreatment

Item	Units	Price	Cycles/ Year	Quant. 10 Acre WS	Total	Quant. 20 Acre WS	Total	Quant. 30 Acre WS	Total	Quant. 40 Acre WS	Total	Quant. 50 Acre WS	Total
Site Size in Acres				1.44		2.34		3.16		4.01		4.75	
Storage Volume CF				69000		137000		204190		272250		340350	
Permanent Pool CF				0		0		0		0		0	
Grading	SY	$2.00		7000	$14,000	11340	$22,680	15300	$30,600	19500	$39,000	23100	$46,200
Dam and Basin Walls	CY	$16.00		544	$7,648	840	$13,440	1560	$24,960	1986	$31,776	2311	$36,976
Stone Riprap, Inlet	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Stone Riprap, Flume	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Stone Riprap, Spillway	CY	$26.00		3	$78	4	$104	4	$104	6	$156	10	$260
Concrete Riprap, Spillway	CY	$27.00		2.4	$65	3	$81	3	$81	8	$216	5	$135
Concrete Riprap, Flume	CY	$27.00		3	$81	4	$108	4	$108	4	$108	7	$189
Stone Riprap Pretreat Outfall	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Stone Riprap Outfall	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Soil Stabilization	SY	$9.00		340	$3,060	450	$4,050	450	$4,050	480	$4,320	500	$4,500
Seeding	SY	$0.05		7000	$350	11340	$567	15300	$765	19500	$975	23100	$1,155
End Wall 3'	EA	$1,240.00		3	$3,720		$0		$0		$0		$0
End Wall 4'	EA	$1,430.00			$0	3	$4,290		$0		$0		$0
End Wall 5'	EA	$1,940.00			$0		$0	3	$5,820	3	$5,820		$0
End Wall 6'	EA	$2,200.00			$0		$0		$0		$0	3	$6,600
Stand Pipe 8" PVC	LF	$8.75			$0		$0		$0		$0		$0
Stand Pipe 30" RCP	LF	$56.00		10	$560		$0		$0		$0		$0
Stand Pipe 36" RCP	LF	$80.00			$0	10	$800	10	$800		$0		$0
Stand Pipe 48" RCP	LF	$175.00			$0		$0		$0	10	$1,750	10	$1,750
8" PVC Pipe	LF	$6.75			$0		$0		$0		$0		$0

Sand Filter Basin with Pretreatment (cont.)

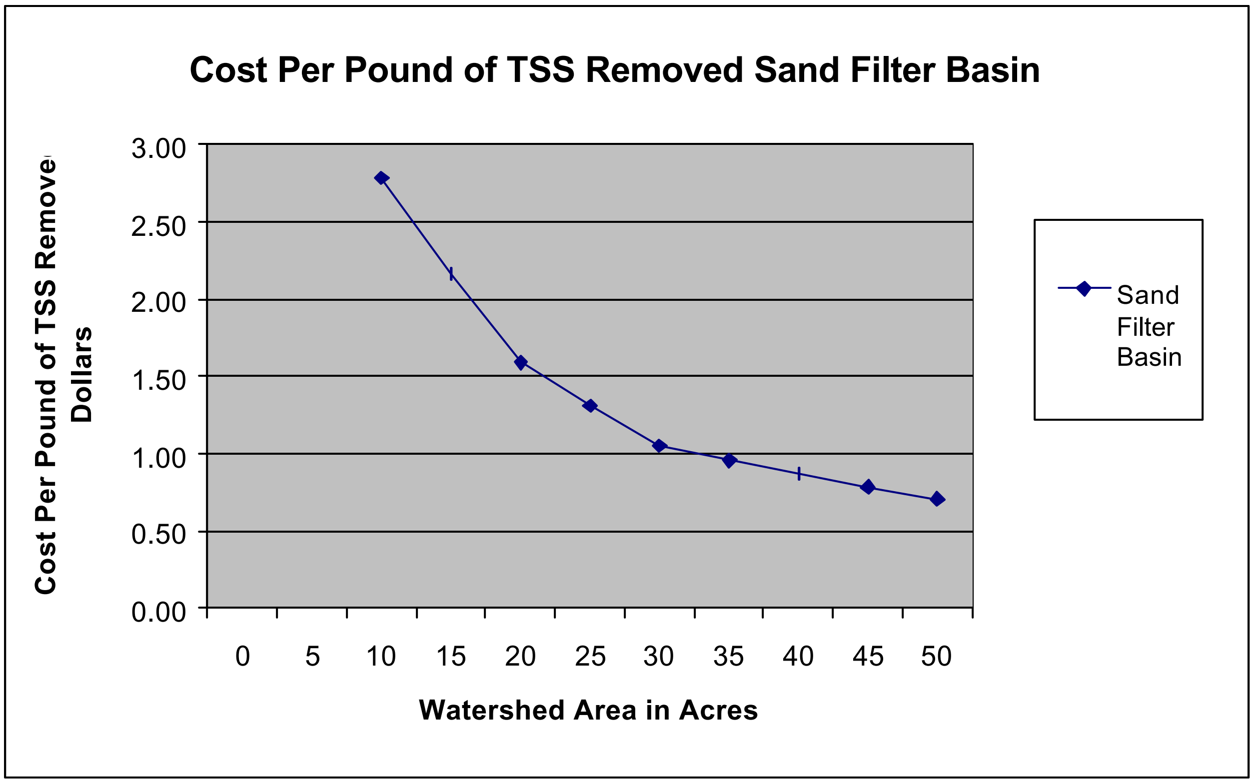
Reinforced Concrete Pipe 12"		$28.00		35	$13,32		$0		$0		$0		$0
Reinforced Concrete Pipe 15"	LF	$38.05			$0	35	$1,046		$0		$0		$0
Reinforced Concrete Pipe 18"	LF	$29.88			$0		$0	45	$1,575		$0		$0
Reinforced Concrete Pipe 24"	LF	$35.00			$0		$0		$0	55	$2,197		$0
Reinforced Concrete Pipe 30"	LF	$39.94			$0		$0		$0		$0	65	$2,596
Reinforced Concrete Pipe 36"	LF	$60.78			$0		$0		$0		$0		$0
Poly Pipe Underdrain, 4"	LF	$2.50		1,156	$9,595	2,256	$18,725	3,321	$8,303	3,906	$9,765	4,225	$10,563
Sand Backfill	CY	$18.00		685	$12,330	1,337	$24,066	1,728	$31,104	2,315	$41,670	2,504	$45,072
Clay Liner	SY	$8.30		2,800	$23,240	5,600	$46,480	7,000	$58,100	8,500	$70,550	10,000	$83,000
Manhole and Valve	EA	Varies		1	$1,200	1	$1,600	1	$2,000	1	$2,400	1	$3,000
Total Construction Cost					**$77,518**		**$138,328**		**$168,682**		**$211,119**		**$242,724**
Construction Costs Amortized for 20 Years					**$3,876**		**$6,916**		**$8,434**		**$10,556**		**$12,136**

Annual Maintenance Expense

Mowing	AC	$37.00	4	1.44	$213	2.34	$346	3.16	$468	4.01	$593	4.75	$703
Trash and Cleaning	AC	$36.00	4	1.44	$207	2.34	$337	3.16	$455	4.01	$577	4.75	$684
Inspection	MH	$20.00	20		$400	20	$400	20	$400	20	$400	20	$400
Silt Removal	AC	$500.00	1	1	$720	1.8	$900	2.6	$1,300	2.9	$1,450	3.2	$1,600
Rennovation Cost	SY	$26.00	0.1	2085	$5,421	4000	$10,400	5184	$13,478	6432	$16,723	7500	$19,500
Total Annual Maintenance Expense					**$6,961**		**$12,383**		**$16,101**		**$19,744**		**$22,887**

Annual Cost Summary Sand Filter Basin								
Watershed in Acres	**TSS #/CF**	**TSS #/Year**	**TSS Removed #/Year at 80 Percent Efficiency**	**Construction Cost (20 yr Amortization)**	**Annual Maintenance Cost**	**Total Annual Cost**	**Cost $/# Removed**	**Watershed in Acres**
10	0.005	4,860	3,888	$3,876	$6,961	$10,837	$2.79	**10**
20	0.0078	15,167	12,134	$6,916	$12,383	$19,300	$1.59	**20**
30	0.01	29,186	23,349	$8,434	$16,101	$24,535	$1.05	**30**
40	0.0112	43,557	34,846	$10,556	$19,744	$30,300	$0.87	**40**
50	0.0128	62,224	49,779	$12,136	$22,887	$35,023	$0.70	**50**

Values X	Values Y
0	
5	
10	$2.79
15	$2.17
20	$1.59
25	$1.31
30	$1.05
35	$0.96
40	$0.87
45	$0.79
50	$0.70



Note: Intermediate values for five acre increments are interpolated.

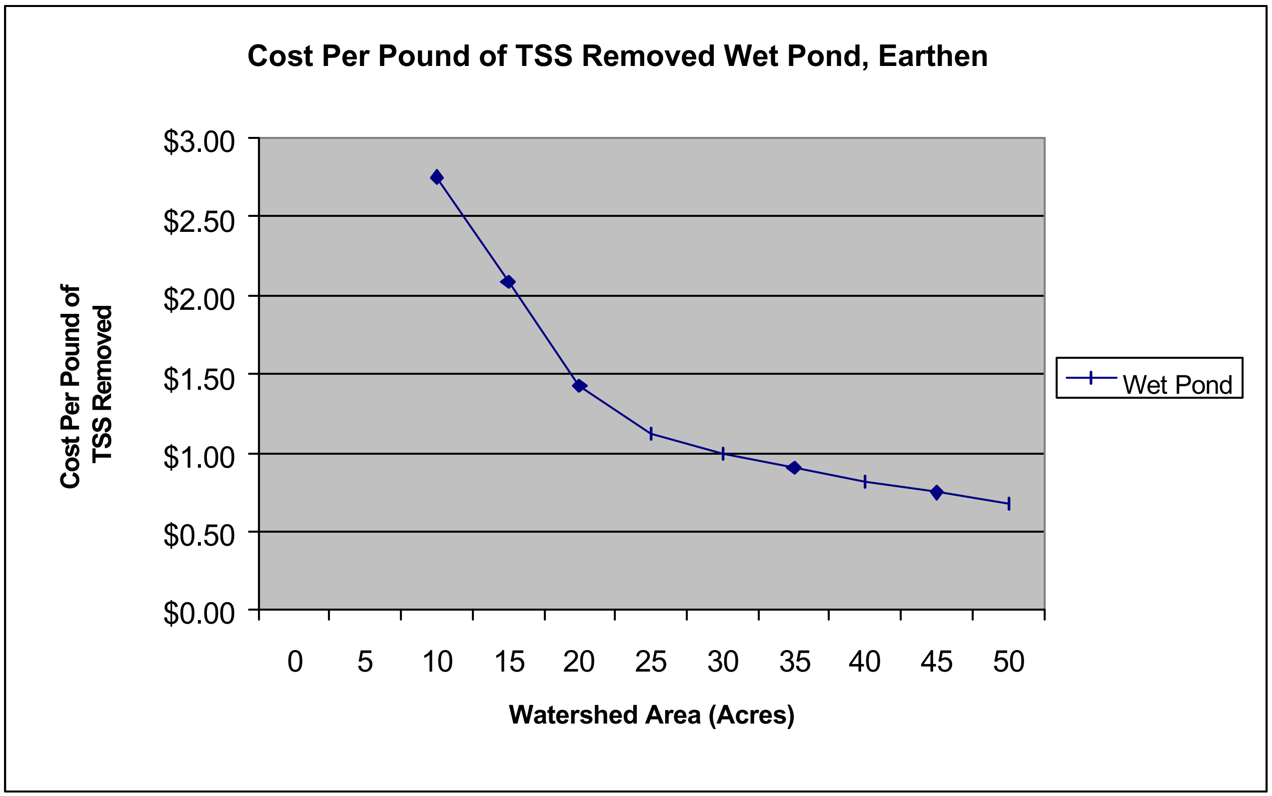
Wet Pond, Earthen, with Permanent Pool at 2.5 Times Mean Runoff Event (0.42 in)

Item	Units	Price	Cycles/ Year	Quant. 10 Acre WS	Total	Quant. 20 Acre WS	Total	Quant. 30 Acre WS	Total	Quant. 40 Acre WS	Total	Quant. 50 Acre WS	Total
Site Size in Acres				1.73		2.92		4.03		5.17		6.2	
Storage Volume CF				69,000		137,000		204,190		272,250		340,350	
Permanent Pool CF				38,110		76,200		114,330		152,440		190,550	
Grading	SY	$2.00		8750	$17,500	14420	$28,840	18245	$36,490	23120	$46,240	28895	$57,790
Excavation	CY	$3.00		2805	$8,415	5666	$16,998	10396	$31,188	15145	$45,435	18075	$54,225
Embankment	CY	$16.00		957	$15,312	1337	$21,392	1900	$30,400	2138	$34,208	2542	$40,672
Stone Riprap, Inlet	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Stone Riprap, Flume	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Stone Riprap, Spillway	CY	$26.00		3	$78	4	$104	4	$104	6	$156	10	$260
Concrete Riprap, Spillway	CY	$27.00		2.4	$65	3	$81	3	$81	8	$216	5	$135
Concrete Riprap, Flume	CY	$27.00		3	$81	4	$108	4	$108	4	$108	7	$189
Stone Riprap Pretreat Outfall	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Stone Riprap Outfall	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Soil Stabilization	SY	$9.00		3500	$31,500	5500	$49,500	7200	$64,800	8000	$72,000	9500	$85,500
Seeding	SY	$0.05		8750	$438	14420	$721	18245	$912	23120	$1,156	28895	$1,445
End Wall 3'	EA	$1,240.00		3	$3,720		$0		$0		$0		$0
End Wall 4'	EA	$1,430.00			$0	3	$4,290		$0		$0		$0
End Wall 5'	EA	$1,940.00			$0		$0	3	$5,820	3	$5,820		$0
End Wall 6'	EA	$2,200.00			$0		$0		$0		$0	3	$6,600
Stand Pipe 8" PVC	LF	$8.75			$0		$0		$0		$0		$0
Stand Pipe 30" RCP	LF	$56.00		10	$560		$0		$0		$0		$0
Stand Pipe 36" RCP	LF	$80.00			$0	10	$800	10	$800		$0		$0
Stand Pipe 48" RCP	LF	$175.00			$0		$0		$0	10	$1,750	10	$1,750
8" PVC Pipe	LF	$6.75			$0		$0		$0		$0		$0

Wet Pond, Earthen, with Permanent Pool at 2.5 Times Mean Runoff Event (0.42 in) (cont.)													
Reinforced Concrete Pipe 12"	LF	$28.00		35	$1,332		$0		$0		$0		$0
Reinforced Concrete Pipe 15"	LF	$38.05			$0	35	$1,046		$0		$0		$0
Reinforced Concrete Pipe 18"	LF	$29.88			$0		$0	45	$1,575		$0		$0
Reinforced Concrete Pipe 24"	LF	$35.00			$0		$0		$0	55	$2,197		$0
Reinforced Concrete Pipe 30"	LF	$39.94			$0		$0		$0		$0	65	$2,596
Reinforced Concrete Pipe 36"	LF	$60.78			$0		$0		$0		$0		$0
Poly Pipe Underdrain, 4"	LF	$2.50		0	$0	0	$0	0	$0	0	$0	0	$0
Sand Backfill	CY	$18.00		0	$0	0	$0	0	$0	0	$0	0	$0
Clay Liner	SY	$8.30		3,500	$29,050	7,000	$58,100	8,750	$72,625	10,625	$88,188	13,125	$108,938
Drain Valve w/Manhole	EA	Varies		1	$1,200	1	$1,600	1	$1,800	1	$2,600	1	$3,000
Chain Link Fence	LF	$12.50		1,098	$13,725	1,426	$17,825	1,675	$20,938	$1,898	$23,725	2,078	$25,975
Total Construction Cost					**$108,310**		**$182,271**		**$245,215**		**$297,889**		**$363,827**
Construction Costs Amortized for 20 Years					**$5,416**		**$9,114**		**$12,261**		**$14,894**		**$18,191**
Annual Maintenance Expense													
Mowing	AC	$37.00	4	1.5	$222	2.5	$370	3	$444	4	$592	5	$740
Trash and Cleaning	AC	$250.00	4	1.73	$1,500	2.92	$2,920	4.03	$4,030	5.17	$5,170	6.2	$6,200
Inspection	MH	$20.00	20		$400	20	$400	20	$400	20	$400	20	$400
Silt Removal	AC	$1,000.00	1	1.2	$1,500	2.1	$2,100	3.1	$3,100	3.8	$3,800	4	$4,000
Draining	EA	Varies	1		$1,000	1	$1,300	1	$1,500	1	$1,800	1	$2,000
Total Annual Maintenance Expense					**$4,622**		**$7,090**		**$9,474**		**$11,762**		**$13,340**

Annual Cost Summary Wet Ponds								
Watershed in Acres	**TSS #/CF**	**TSS #/Year**	**TSS Removed #/Year at 80 Percent Efficiency**	**Construction Cost (20 yr Amortization)**	**Annual Maintenance Cost**	**Total Annual Cost**	**Cost $/# Removed**	**Watershed in Acres**
10	0.005	4,860		$5,416	$4,622	$10,038	$2.75	**10**
20	0.0078	15,167	11,375	$9,114	$7,090	$16,204	$1.42	**20**
30	0.01	29,186	21,890	$12,261	$9,474	$21,735	$0.99	**30**
40	0.0112	43,557	32,668	$14,894	$11,762	$26,656	$0.82	**40**
50	0.0128	62,224	46,668	$18,191	$13,340	$31,531	$0.68	**50**

Values X	Values Y
0	
5	
10	$2.75
15	$2.09
20	$1.42
25	$1.12
30	$0.99
35	$0.90
40	$0.82
45	$0.75
50	$0.68



Note: Intermediate values for five acre increments are interpolated.

Wet Pond, Hybrid, with Permanent Pool at 2.5 Times Mean Runoff Event (0.42 in)

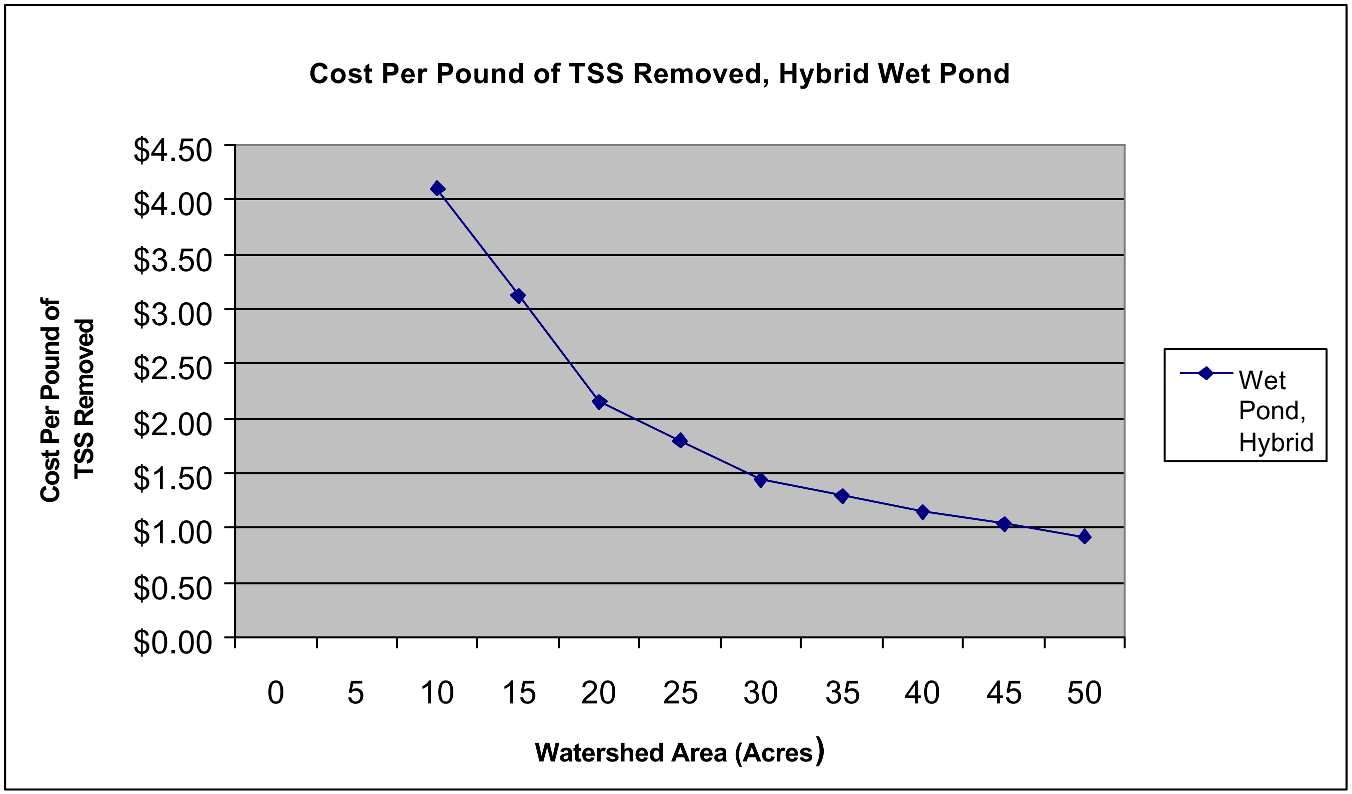
Site Size in Acres				1.73		2.92		4.03		5.17		6.2	
Storage Volume CF				69,000		137,000		204,190		272,250		340,350	
Permanent Pool CF				38,110		76,200		114,330		152,440		190,550	
Item	**Units**	**Price**	**Cycles/ Year**	**Quant. 10 Acre WS**	**Total**	**Quant. 20 Acre WS**	**Total**	**Quant. 30 Acre WS**	**Total**	**Quant. 40 Acre WS**	**Total**	**Quant. 50 Acre WS**	**Total**
Grading	SY	$2.00		8750	$17,500	14420	$28,840	18245	$36,490	23120	$46,240	28895	$57,790
Excavation	CY	$3.00		2805	$8,415	5666	$16,998	10396	$31,188	15145	$45,435	18075	$54,225
Embankment	CY	$382.00		297	$113,454	487	$186,034	594	$226,908	656	$250,592	725	$276,950
Stone Riprap, Inlet	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Stone Riprap, Flume	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Stone Riprap, Spillway	CY	$26.00		3	$78	4	$104	4	$104	6	$156	10	$260
Concrete Riprap, Spillway	CY	$27.00		2.4	$65	3	$81	3	$81	8	$216	5	$135
Concrete Riprap, Flume	CY	$27.00		3	$81	4	$108	4	$108	4	$108	7	$189
Stone Riprap Pretreat Outfall	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Stone Riprap Outfall	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Soil Stabilization	SY	$9.00		3500	$31,500	5500	$49,500	7200	$64,800	8000	$72,000	9500	$85,500
Seeding	SY	$0.05		8750	$438	14420	$721	18245	$912	23120	$1,156	28895	$1,445
End Wall 3'	EA	$1,240.00		3	$3,720		$0		$0		$0		$0
End Wall 4'	EA	$1,430.00			$0	3	$4,290		$0		$0		$0
End Wall 5'	EA	$1,940.00			$0		$0	3	$5,820	3	$5,820		$0
End Wall 6'	EA	$2,200.00			$0		$0		$0		$0	3	$6,600
Stand Pipe 8" PVC	LF	$8.75			$0		$0		$0		$0		$0
Stand Pipe 30" RCP	LF	$56.00		10	$560		$0		$0		$0		$0
Stand Pipe 36" RCP	LF	$80.00			$0	10	$800	10	$800		$0		$0
Stand Pipe 48" RCP	LF	$175.00			$0		$0		$0	10	$1,750	10	$1,750
8" PVC Pipe	LF	$6.75			$0		$0		$0		$0		$0

Wet Pond, Hybrid, with Permanent Pool at 2.5 Times Mean Runoff Event (0.42 in) (cont.)

Reinforced Concrete Pipe 12"	LF	$28.00		35	$1,332		$0		$0		$0		$0
Reinforced Concrete Pipe 15"	LF	$38.05			$0	35	$1,046		$0		$0		$0
Reinforced Concrete Pipe 18"	LF	$29.88			$0		$0	45	$1,575		$0		$0
Reinforced Concrete Pipe 24"	LF	$35.00			$0		$0		$0	55	$2,197		$0
Reinforced Concrete Pipe 30"	LF	$39.94			$0		$0		$0		$0	65	$2,596
Reinforced Concrete Pipe 36"	LF	$60.78			$0		$0		$0		$0		$0
Poly Pipe Underdrain, 4"	LF	$2.50		0	$0	0	$0	0	$0	0	$0	0	$0
Sand Backfill	CY	$18.00		0	$0	0	$0	0	$0	0	$0	0	$0
Clay Liner	SY	$8.30		3,500	$29,050	7,000	$58,100	8,750	$72,625	10,625	$88,188	13,125	$108,938
Drain Valve w/Manhole	EA	Varies		1	$1,200	1	$1,600	1	$1,800	1	$2,600	1	$3,000
Chain Link Fence	LF	$12.50		1,098	$13,725	1,426	$17,825	$1,676	$20,950	$1,898	$23,725	2,078	$25,975
Total Construction Cost					**$206,452**		**$346,913**		**$441,723**		**$514,273**		**$600,105**
Construction Costs Amortized for 20 Years					**$10,323**		**$17,346**		**$22,086**		**$25,714**		**$30,005**
Annual Maintenance Expense													
Mowing	AC	$37.00	4	1.5	$222	2.5	$370	3	$444	4	$592	5	$740
Trash and Cleaning	AC	$250.00	4	1.73	$1,500	2.92	$2,920	4.03	$4,030	5.17	$5,170	6.2	$6,020
Inspection	MH	$20.00	20	20	$400	20	$400	20	$400	20	$400	20	$400
Silt Removal	AC	$1,000.00	1	1.2	$1,500	2.1	$2,100	3.1	$3,100	3.8	$3,800	4	$4,000
Draining	EA	Varies	1	1	$1,000	1	$1,300	1	$1,500	1	$1,800	1	$2,000
Total Annual Maintenance Expense					**$4,622**		**$7,090**		**$9,474**		**$11,762**		**$13,160**

Annual Cost Summary Wet Ponds								
Watershed in Acres	**TSS #/CF**	**TSS #/Year**	**TSS Removed #/Year at 80 Percent Efficiency**	**Construction Cost (20 yr Amortization)**	**Annual Maintenance Cost**	**Total Annual Cost**	**Cost $/# Removed**	**Watershed in Acres**
10	0.005	4,860	3,645	$10,323	$4,622	$14,945	$4.10	**10**
20	0.0078	15,167	11,375	$17,346	$7,090	$24,436	$2.15	**20**
30	0.01	29,186	21,890	$22,086	$9,474	$31,560	$1.44	**30**
40	0.0112	43,557	32,668	$25,714	$11,762	$37,476	$1.15	**40**
50	0.0128	62,224	46,668	$30,005	$13,160	$43,165	$0.92	**50**

Values X	Values Y
0	
5	
10	$4.10
15	$3.12
20	$2.15
25	$1.79
30	$1.44
35	$1.29
40	$1.15
45	$1.04
50	$0.92



Note: Intermediate values for five acre increments are interpolated.

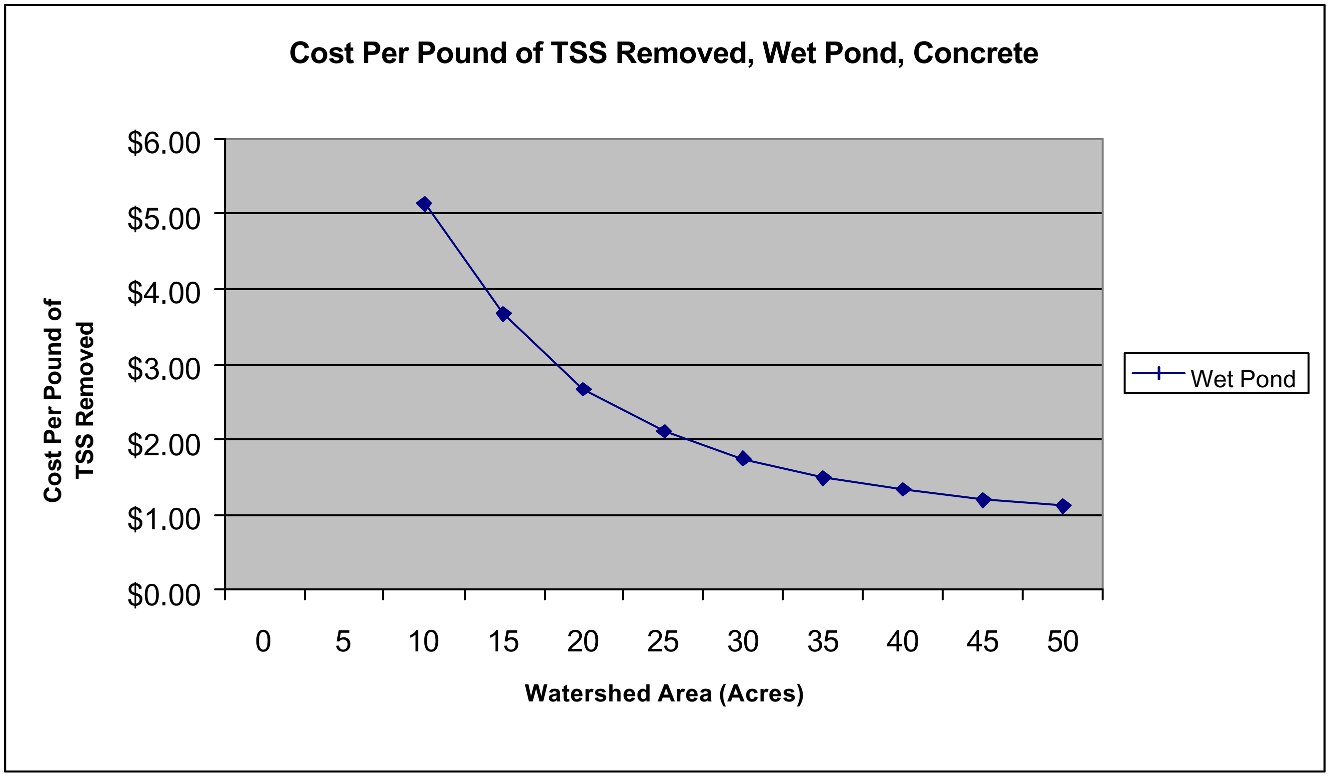
Wet Pond, Concrete

Item	Units	Price	Cycles/ Year	Quant. 10 Acre WS	Total	Quant. 20 Acre WS	Total	Quant. 30 Acre WS	Total	Quant. 40 Acre WS	Total	Quant. 50 Acre WS	Total
Site Size in Acres				1.73		2.92		4.03		5.17		6.2	
Storage Volume CF				69,000		137,000		204,190		272,250		340,350	
Permanent Pool CF				38,110		76,200		114,330		152,440		190,550	
Grading	SY	$2.00		8750	$17,500	14420	$28,840	18245	$36,490	2500	$5,000	28895	$57,790
Excavation	CY	$3.00		1394	$4,182	2844	$8,532	4200	$12,600	9500	$28,500	11000	$33,000
Embankment	CY	$382.00		544	$207,808	886	$338,452	1080	$412,560	1250	$477,500	1386	$529,452
Stone Riprap, Inlet	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Stone Riprap, Flume	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Stone Riprap, Spillway	CY	$26.00		3	$78	4	$104	4	$104	6	$156	10	$260
Concrete Riprap, Spillway	CY	$27.00		2.4	$65	3	$81	3	$81	8	$216	5	$135
Concrete Riprap, Flume	CY	$27.00		3	$81	4	$108	4	$108	4	$108	7	$189
Stone Riprap Pretreat Outfall	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Stone Riprap Outfall	CY	$26.00		2.5	$65	2.8	$73	3	$78	4	$104	7	$182
Soil Stabilization	SY	$9.00		3500	$31,500	5500	$49,500	7200	$64,800	8000	$72,000	9500	$85,500
Seeding	SY	$0.05		8750	$438	14420	$721	18425	$921	2500	$125	28895	$1,445
End Wall 3'	EA	$1,240.00		3	$3,720		$0		$0		$0		$0
End Wall 4'	EA	$1,430.00			$0	3	$4,290		$0		$0		$0
End Wall 5'	EA	$1,940.00			$0		$0	3	$5,820	3	$5,820		$0
End Wall 6'	EA	$2,200.00			$0		$0		$0		$0	3	$6,600
Stand Pipe 8" PVC	LF	$8.75			$0		$0		$0		$0		$0
Stand Pipe 30" RCP	LF	$56.00		10	$560		$0		$0		$0		$0
Stand Pipe 36" RCP	LF	$80.00			$0	10	$800	10	$800		$0		$0
Stand Pipe 48" RCP	LF	$175.00			$0		$0		$0	10	$1,750	10	$1,750
8" PVC Pipe	LF	$6.75			$0		$0		$0		$0		$0

Wet Pond, Concrete (cont.)													
Reinforced Concrete Pipe 12"	LF	$28.00		35	$1,332		$0		$0		$0		$0
Reinforced Concrete Pipe 15"	LF	$38.05			$0	35	$1,046		$0		$0		$0
Reinforced Concrete Pipe 18"	LF	$29.88			$0		$0	45	$1,575		$0		$0
Reinforced Concrete Pipe 24"	LF	$35.00			$0		$0		$0	55	$2,197		$0
Reinforced Concrete Pipe 30"	LF	$39.94			$0		$0		$0		$0	65	$2,596
Reinforced Concrete Pipe 36"	LF	$60.78			$0		$0		$0		$0		$0
Poly Pipe Underdrain, 4"	LF	$2.50		0	$0	0	$0	0	$0	0	$0	0	$0
Sand Backfill	CY	$18.00		0	$0	0	$0	0	$0	0	$0	0	$0
Clay Liner	SY	$8.30		2,800	$23,240	5,600	$46,480	7,000	$58,100	8,500	$70,550	10,000	$83,000
Drain Valve w/Manhole	EA	Varies		1	$1,200	1	$1,600	1	$1,800	1	$2,600	1	$3,000
Chain Link Fence	LF	$12.50		1,098	$13,725	1,426	$17,825	$1,675	$20,938	$1,898	$23,725	2,078	$25,975
Total Construction Cost					**$290,763**		**$479,245**		**$594,271**		**$664,338**		**$805,445**
Construction Costs Amortized for 20 Years					**$14,538**		**$23,962**		**$29,714**		**$33,217**		**$40,272**
Annual Maintenance Expense													
Mowing	AC	$37.00	4	1.5	$222	2.5	$370	3	$444	4	$592	5	$740
Trash and Cleaning	AC	$250.00	4	1.73	$1,500	2.92	$2,920	4.03	$4,030	5.17	$5,170	6.2	$6,200
Inspection	MH	$20.00	20	20	$400	20	$400	20	$400	20	$400	20	$400
Silt Removal	AC	$700.00	1	1.2	$1,050	2.1	$1,470	3.1	$2,170	3.8	$2,660	4	$2,800
Draining	EA	Varies	1	1	$1,000	1	$1,300	1	$1,500	1	$1,800	1	$2,000
Total Annual Maintenance Expense					**$4,172**		**$6,460**		**$8,544**		**$10,622**		**$12,140**

Annual Cost Summary Wet Ponds								
Watershed in Acres	**TSS #/CF**	**TSS #/Year**	**TSS Removed #/Year at 80 Percent Efficiency**	**Construction Cost (20 yr Amortization)**	**Annual Maintenance Cost**	**Total Annual Cost**	**Cost $/# Removed**	**Watershed in Acres**
10	0.005	4,860	3,645	$14,538	$4,172	$18,710	$5.13	**10**
20	0.0078	15,167	11,375	$23,962	$6,460	$30,422	$2.67	**20**
30	0.01	29,186	21,890	$29,714	$8,544	$38,258	$1.75	**30**
40	0.0112	43,557	32,668	$33,217	$10,622	$43,839	$1.34	**40**
50	0.0128	62,224	46,668	$40,272	$12,140	$52,412	$1.12	**50**

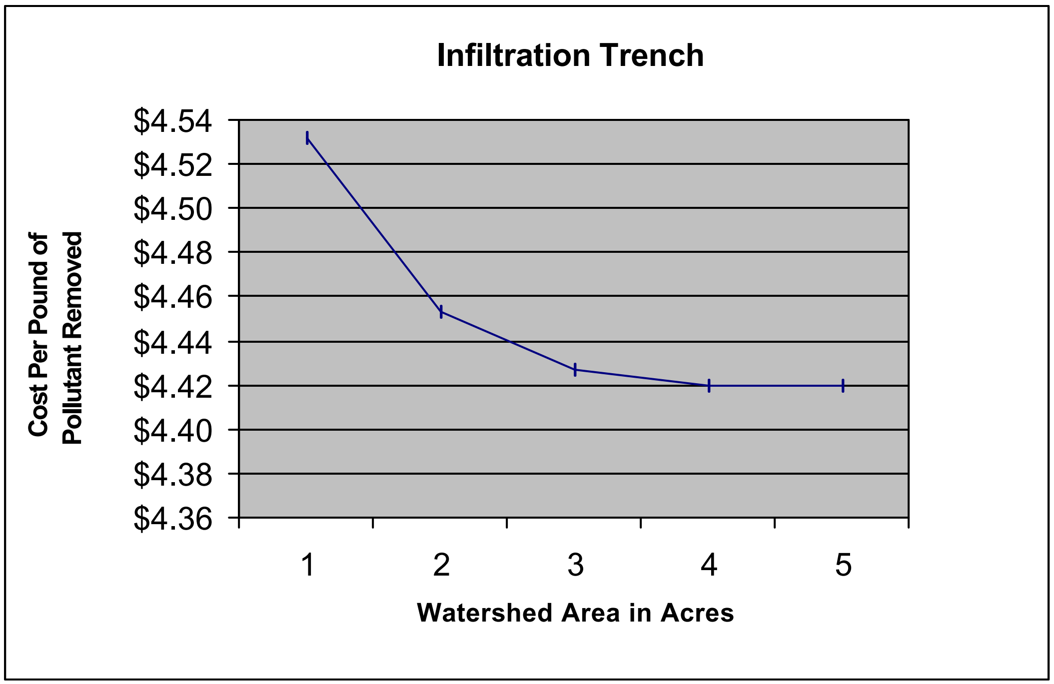
Values X	Values Y
0	
5	
10	$5.13
15	3.67
20	$2.67
25	$2.11
30	$1.75
35	$1.50
40	$1.34
45	$1.20
50	$1.12



Note: Intermediate values for five acre increments are interpolated.

Infiltration Trench													
Item	**Units**	**Price**	**Cycles/ Year**	**Quant. 1 Acre WS**	**Total**	**Quant. 2 Acre WS**	**Total**	**Quant. 3 Acre WS**	**Total**	**Quant. 4 Acre WS**	**Total**	**Quant. 5 Acre WS**	**Total**
Grading	SY	$2.00		105	$210	211	$422	282	$564	376	$752	470	$940
Excavation	CY	$3.60		140	$504	281	$1,012	423	$1,523	564	$2,030	705	$2,538
Filter Fabric	SY	$1.15		494	$568	986	$1,134	1060	$1,219	1411	$1,623	1766	$2,031
Stone Fill	CY	$11.00		140	$1,540	281	$3,091	423	$4,653	564	$6,204	705	$7,755
Sight Well	EA	$300.00		2	$600	3	$900	4	$1,200	7	$2,100	7	$2,100
Seeding	LF	$0.05		644	$32	1288	$64	1932	$97	2576	$129	3220	$161
Check Dam	CY	$35.00		0	$0	0	$0	0	$0	0	$0	0	$0
Total Construction Cost					**$3,454**		**$6,623**		**$9,255**		**$12,838**		**$15,525**
Construction Costs Amortized for 20 Years					**$173**		**$331**		**$463**		**$642**		**$776**
Annual Maintenance Expense													
Mowing	AC	$37.00	4	0.3	$44	0.5	$74	0.7	$104	0.9	$133	1.2	$178
Trash and Cleaning	AC	$100.00	4	0.3	$120	0.5	$200	0.7	$280	0.9	$360	1.2	$480
Inspection	MH	$20.00	5	5	$100	5	$100	5	$100	5	$100	5	$100
Silt Removal	CY	$80.00	0.33	140	$3,696	281	$7,418	423	$11,167	564	$14,890	705	$18,612
Total Annual Maintenance Expense					**$3,960**		**$7,792**		**$11,651**		**$15,483**		**$19,370**

Annual Cost Summary Infiltration Trench								
Watershed in Acres	**TSS #/CF**	**TSS #/Year**	**TSS Removed #/Year at 80 Percent Efficiency**	**Construction Cost (20 yr Amortization)**	**Annual Maintenance Cost**	**Total Annual Cost**	**Cost $/# Removed**	**Watershed in Acres**
10	0.0094	1,013	912	$173	$3,960	$4,133	$4.53	**10**
20	0.0094	2,027	1,824	$331	$7,792	$8,124	$4.45	**20**
30	0.0094	3,040	2,736	$463	$11,651	$12,114	$4.43	**30**
40	0.0094	4,054	3,648	$642	$15,483	$16,125	$4.42	**40**
50	0.0094	5,065	4,559	$776	$19,370	$20,146	$4.42	**50**



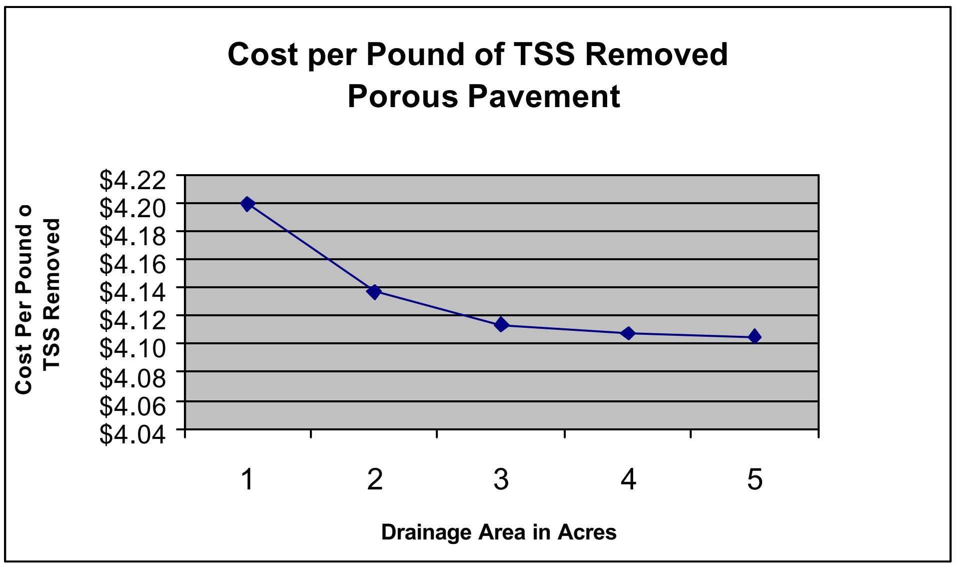
Porous Pavement

Item	Units	Price	Cycles/ Year	Quant. 1 Acre WS	Total	Quant. 2 Acre WS	Total	Quant. 3 Acre WS	Total	Quant. 4 Acre WS	Total	Quant. 5 Acre WS	Total
Grading	SY	$2.00		604	$1,208	1209	$2,418	1812	$3,624	2419	$4,838	3020	$6,040
Paving	SY	$19.00		212	$4,028	424	$8,056	636	$12,084	848	$16,112	1060	$20,140
Excavation	CY	$3.60		201	$724	403	$1,451	604	$2,174	806	$2,902	1008	$3,629
Filter Fabric	SY	$1.15		700	$805	1400	$1,610	2000	$2,300	2800	$3,220	3600	$4,140
Stone Fill	CY	$16.00		201	$3,216	403	$6,448	604	$9,664	806	$12,896	1008	$16,128
Sand	CY	$7.00		100	$700	200	$1,400	300	$2,100	400	$2,800	500	$3,500
Sight Well	EA	$300.00		2	$600	3	$900	4	$1,200	7	$2,100	7	$2,100
Seeding	LF	$0.05		644	$32	1288	$64	1932	$97	2576	$129	3220	$161
Check Dam	CY	$35.00		0	$0	0	$0	0	$0	0	$0	0	$0
Total Construction Costs					**$10,105**		**$19,929**		**$29,619**		**$40,158**		**$49,798**
Construction Costs Amortized for 20 Years					**$505**		**$996**		**$1,481**		**$2,008**		**$2,490**

Annual Maintenance Expense

Item	Units	Price	Cycles/ Year	Quant. 1 Acre WS	Total	Quant. 2 Acre WS	Total	Quant. 3 Acre WS	Total	Quant. 4 Acre WS	Total	Quant. 5 Acre WS	Total
Sweeping	AC	$250.00	6	1	$1,500	2	$3,000	3	$4,500	4	$6,000	5	$7,500
Washing	AC	$250.00	6	1	$1,500	2	$3,000	3	$4,500	4	$6,000	5	$7,500
Inspection	MH	$20.00	5	5	$100	5	$100	5	$100	5	$100	5	$100
Deep Clean	AC	$450.00	0.5	1	$225	2	$450	3	$675	3.9	$878	5	$1,125
Total Annual Maintenance Expense					**$3,960**		**$7,792**		**$11,651**		**$15,483**		**$19,370**

Annual Cost Summary Porous Pavement								
Watershed in Acres	**TSS #/CF**	**TSS #/Year**	**TSS Removed #/Year at 90 Percent Efficiency**	**Construction Cost (20 yr Amortization)**	**Annual Maintenance Cost**	**Total Annual Cost**	**Cost $/# Removed**	**Watershed in Acres**
1	0.0094	1,013	912	$505	$3,325	$3,830	$4.20	**1**
2	0.0094	2,027	1,824	$996	$6,550	$7,546	$4.14	**2**
3	0.0094	3,040	2,736	$1,481	$9,775	$11,256	$4.11	**3**
4	0.0094	4,054	3,648	$2,008	$12,978	$14,985	$4.11	**4**
5	0.0094	5,065	4,559	$2,490	$16,225	$18,715	$4.11	**5**



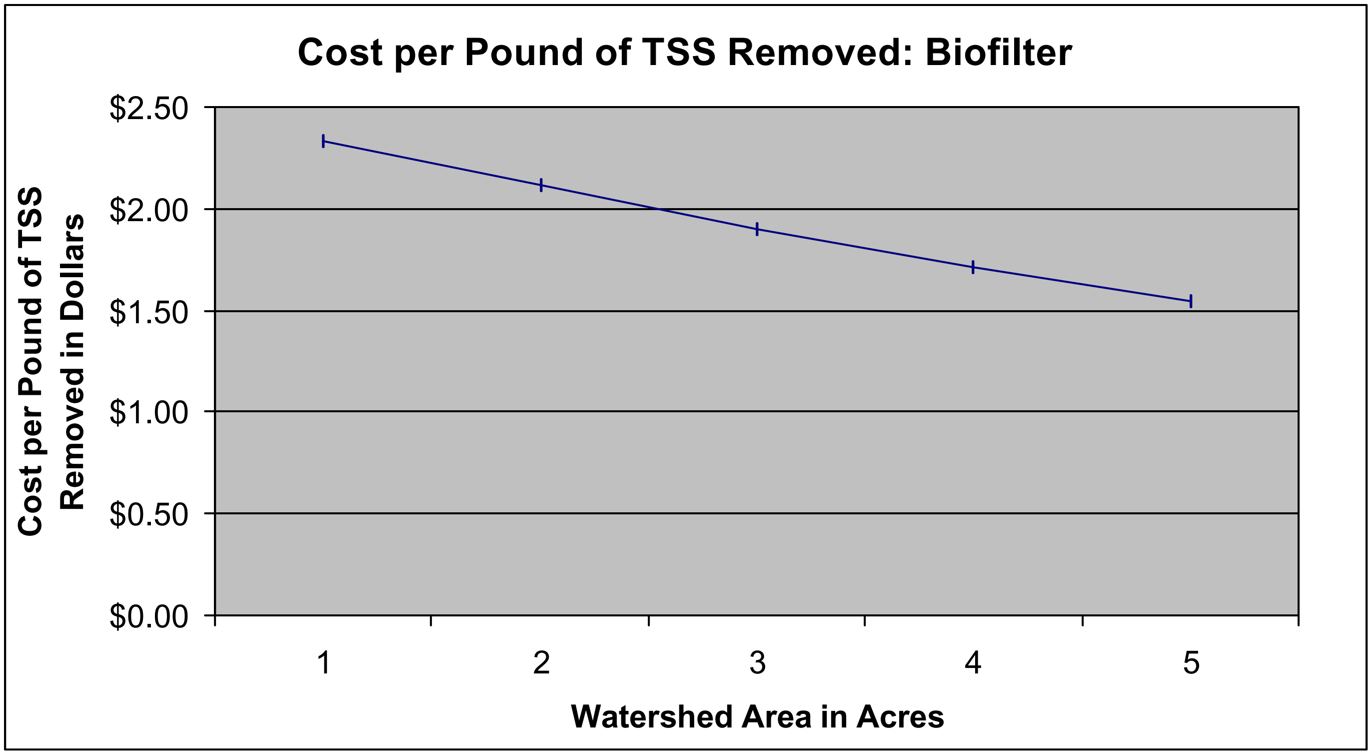
Biofilter

Item	Units	Price	Cycles/ Year	Quant. 1 Acre WS	Total	Quant. 2 Acre WS	Total	Quant. 3 Acre WS	Total	Quant. 4 Acre WS	Total	Quant. 5 Acre WS	Total
Excavation	CY	$3.00		60	$180	120	$360	180	$540	240	$720	300	$900
Top Soil	CY	$8.00		52	$416	104	$832	156	$1,248	210	$1,680	260	$2,080
Mulch	CY	$14.00		20	$280	40	$560	60	$840	80	$1,120	100	$1,400
Gravel	CY	$9.00		17	$153	34	$306	51	$459	78	$702	86	$774
Perforated Pipe	LF	$4.00		60	$240	120	$480	180	$720	240	$960	350	$1,400
Diversion Structure	SF	$35.00		40	$1,400	80	$2,800	120	$4,200	160	$5,600	200	$7,000
Pond Liner	SY	$8.50		33	$281	66	$561	99	$842	132	$1,122	165	$1,403
Grading	SY	$3.00		50	$150	100	$300	150	$450	200	$600	150	$450
Seeding	SY	$1.50		50	$75	100	$150	150	$225	200	$300	150	$225
Plant Material	EA	$200.00		4	$800	8	$1,600	12	$2,400	16	$3,200	20	$4,000
Total Construction Costs					**$11,924**		**$22,257**		**$29,809**		**$35,209**		**$39,263**
Construction Costs Amortized for 20 Years					**$596**		**$1,113**		**$1,490**		**$1,760**		**$1,963**

Annual Maintenance Expense

Item	Units	Price	Cycles/ Year	Quant. 1 Acre WS	Total	Quant. 2 Acre WS	Total	Quant. 3 Acre WS	Total	Quant. 4 Acre WS	Total	Quant. 5 Acre WS	Total
Mowing	AC	$37.00	4	0.3	$44	0.5	$74	0.7	$104	0.9	$133	1	$148
Trash and Cleaning	AC	$100.00	4	0.3	$120	0.5	$200	0.7	$280	0.9	$360	1	$400
Inspection	MH	$20.00	5	5	$100	5	$100	5	$100	5	$100	5	$100
Replace Mulch	CY	$14.00	1	10	$140	20	$280	30	$420	40	$560	50	$700
Rebuild	EA		1	1	$894	1	$1,669	1	$2,236	1	$2,641	1	$2,945
Total Annual Maintenance Expense					**$1,299**		**$2,323**		**$3,139**		**$3,794**		**$4,293**

Annual Cost Summary Biofilter								
Watershed in Acres	**TSS #/CF**	**TSS #/Year**	**TSS Removed #/Year at 70 Percent Efficiency**	**Construction Cost (20 yr Amortization)**	**Annual Maintenance Cost**	**Total Annual Cost**	**Cost $/# Removed**	**Watershed in Acres**
1	0.0094	1,013	811	$596	$1,299	$1,895	$2.34	**1**
2	0.0094	2,027	1,621	$1,113	$2,323	$3,436	$2.12	**2**
3	0.0094	3,040	2,432	$1,490	$3,139	$4,630	$1.90	**3**
4	0.0094	4,054	3,243	$1,760	$3,794	$5,554	$1.71	**4**
5	0.0094	5,065	4,052	$1,963	$4,293	$6,256	$1.54	**5**



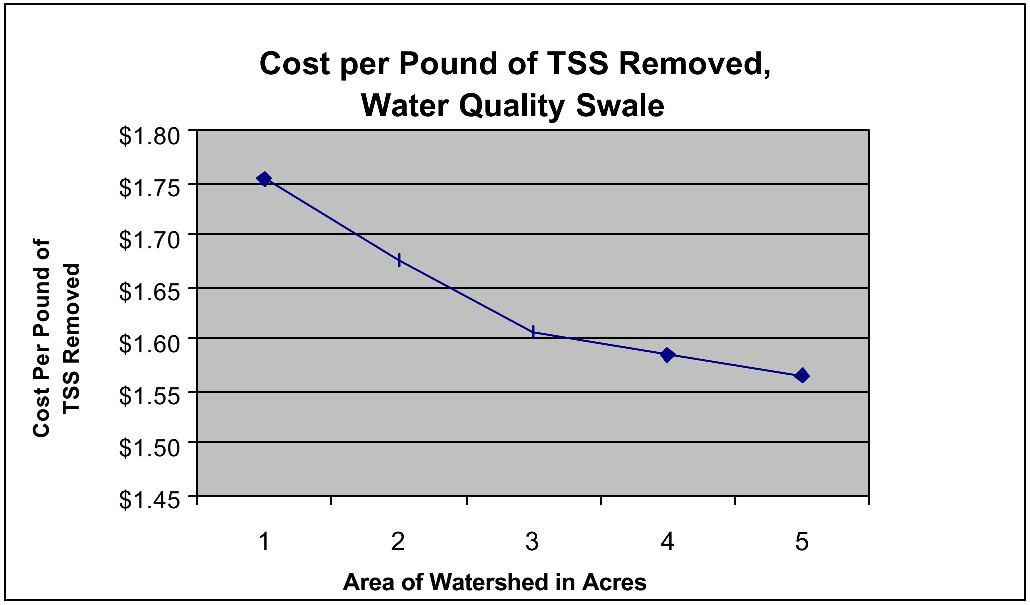
Water Quality Swale

Item	Units	Price	Cycles/ Year	Quant. 1 Acre WS	Total	Quant. 2 Acre WS	Total	Quant. 3 Acre WS	Total	Quant. 4 Acre WS	Total	Quant. 5 Acre WS	Total
Grading	SY	$2.00		644	$1,288	1288	$2,576	1932	$3,864	2576	$5,152	3220	$6,440
Seeding	SY	$0.05		644	$32	1288	$64	1932	$97	2576	$129	3220	$161
Check Dam	CY	$35.00		84	$2,940	168	$5,880	252	$8,820	336	$11,760	420	$14,700
Total Construction Costs					**$4,260**		**$8,520**		**$12,781**		**$17,041**		**$21,301**
Construction Costs Amortized for 20 Years					**$213**		**$426**		**$639**		**$852**		**$1,065**

Annual Maintenance Expense

Item	Units	Price	Cycles/ Year	Quant. 1 Acre WS	Total	Quant. 2 Acre WS	Total	Quant. 3 Acre WS	Total	Quant. 4 Acre WS	Total	Quant. 5 Acre WS	Total
Mowing	AC	$37.00	4	0.3	$44	0.57	$84	0.9	$133	1.1	$163	1.4	$207
Trash and Cleaning	AC	$100.00	4	0.3	$120	0.57	$228	0.9	$360	1.1	$440	1.4	$560
Inspection	MH	$20.00	5	5	$100	5	$100	5	$100	5	$100	5	$100
Silt Removal	AC	$700.00	0.5	0.3	$105	0.57	$200	0.9	$315	1.1	$385	1.4	$490
Check Dam Repair	CY	$40.00		21	$840	42	$1,680	59	$2,360	80	$3,200	98	$3,920
Total Annual Maintenance Expense					**$1,209**		**$2,292**		**$3,268**		**$4,288**		**$5,277**

Annual Cost Summary Water Quality Swale								
Watershed in Acres	**TSS #/CF**	**TSS #/Year**	**TSS Removed #/Year at 70 Percent Efficiency**	**Construction Cost (20 yr Amortization)**	**Annual Maintenance Cost**	**Total Annual Cost**	**Cost $/# Removed**	**Watershed in Acres**
1	0.0094	1,013	811	$213	$1,209	$1,422	$1.75	**1**
2	0.0094	2,027	1,621	$426	$2,292	$2,718	$1.68	**2**
3	0.0094	3,040	2,432	$639	$3,268	$3,907	$1.61	**3**
4	0.0094	4,054	3,243	$852	$4,288	$5,140	$1.58	**4**
5	0.0094	5065	4,052	$1,065	$5,277	$6,342	$1.57	**5**



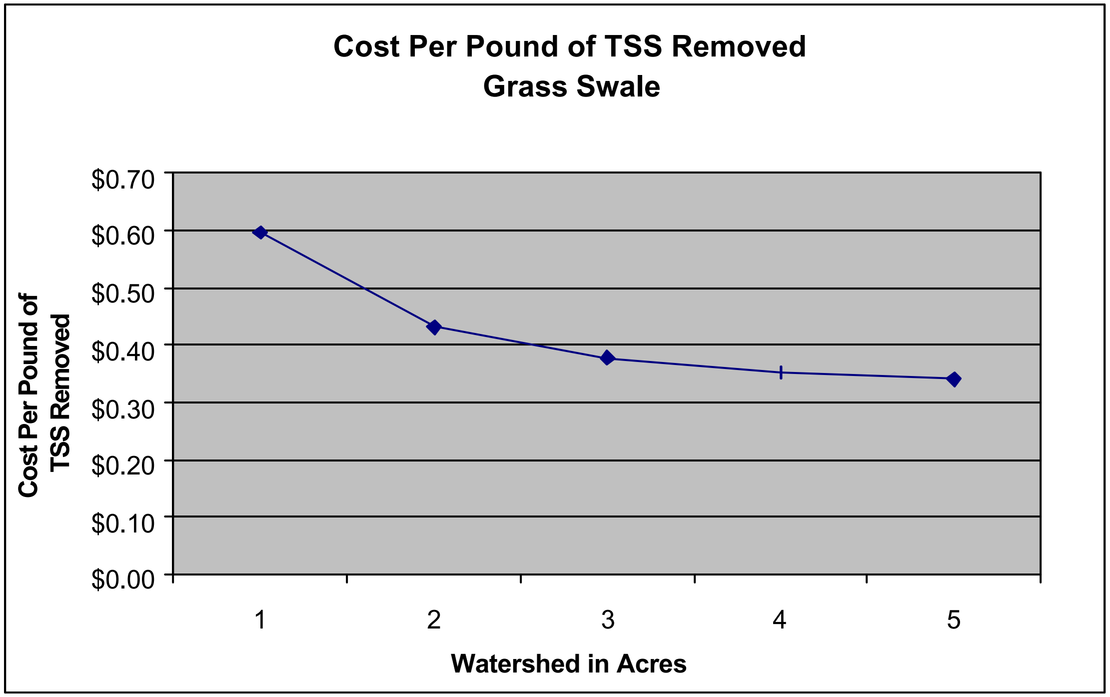
Grass Swale

Item	Units	Price	Cycles/ Year	Quant. 1 Acre WS	Total	Quant. 2 Acre WS	Total	Quant. 3 Acre WS	Total	Quant. 4 Acre WS	Total	Quant. 5 Acre WS	Total
Grading	SY	$2.00		286	$572	378	$756	462	$924	594	$1,188	648	$1,296
Seeding	SY	$0.05		286	$14	380	$19	430	$22	540	$27	680	$34
Check Dam	CY	$35.00		14	$490	14	$490	16	$560	18	$630	24	$840
Total Construction Costs					**$1,076**		**$1,265**		**$1,506**		**$1,845**		**$2,170**
Construction Costs Amortized for 20 Years					**$54**		**$63**		**$75**		**$92**		**$109**

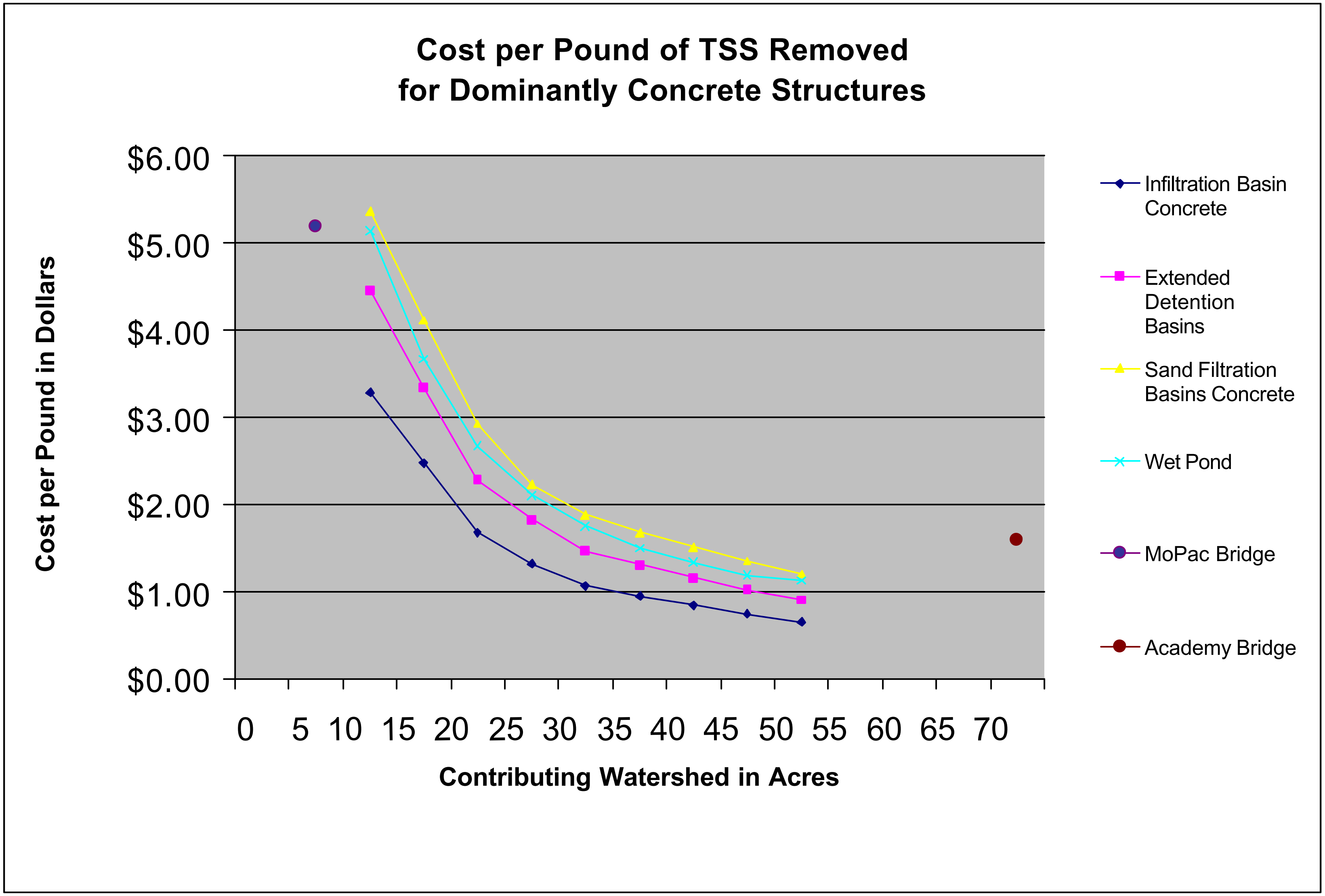
Annual Maintenance Expense

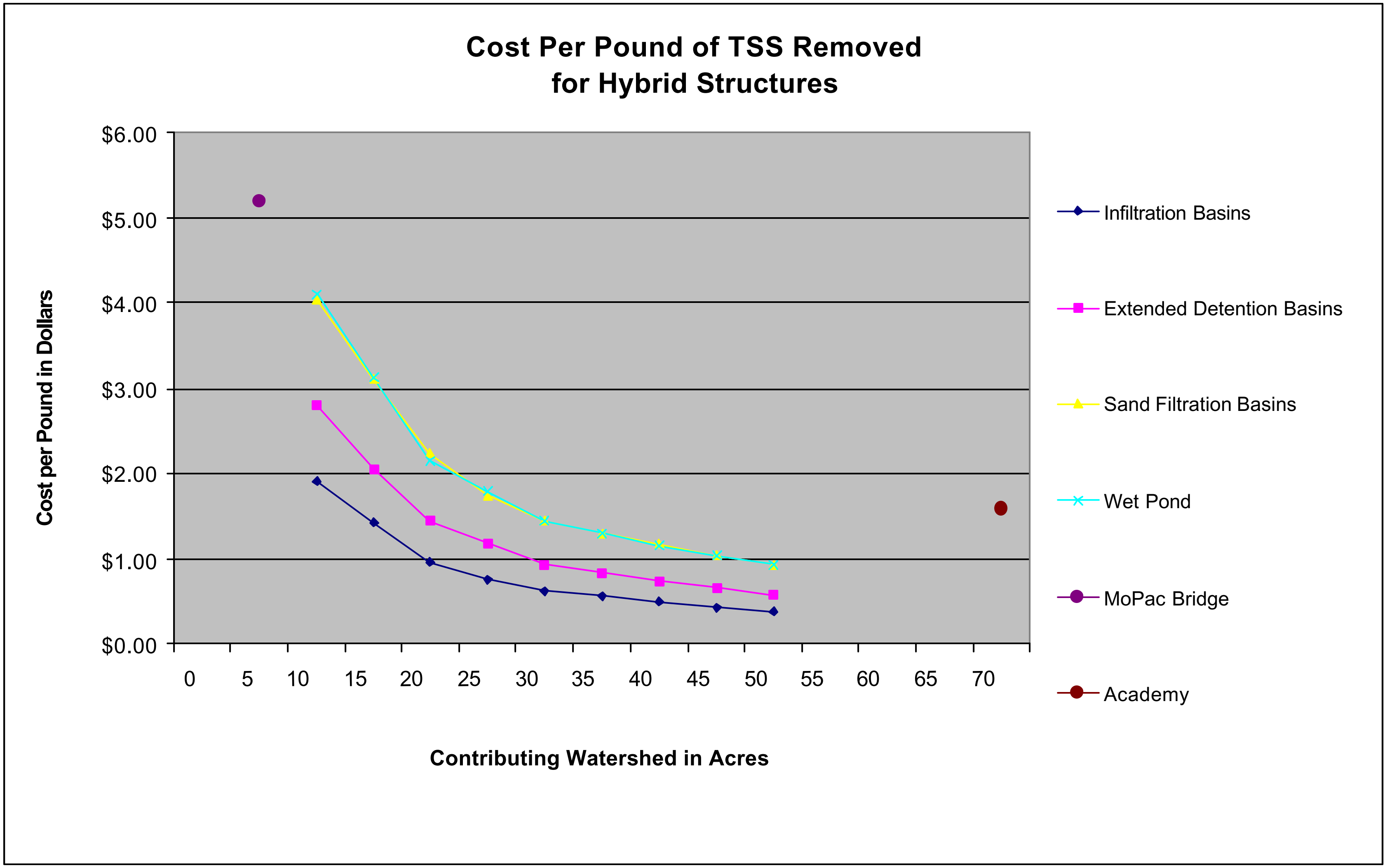
Item	Units	Price	Cycles/ Year	Quant. 1 Acre WS	Total	Quant. 2 Acre WS	Total	Quant. 3 Acre WS	Total	Quant. 4 Acre WS	Total	Quant. 5 Acre WS	Total
Mowing	AC	$37.00	4	0.3	$44	0.5	$74	0.7	$104	0.9	$133	3	$444
Trash and Cleaning	AC	$100.00	4	0.3	$120	0.5	$200	0.7	$280	0.9	$360	4.75	$1,900
Inspection	MH	$20.00	5		$100	5	$100	5	$100	5	$100	20	$400
Silt Removal	AC	$700.00	0.5	0.3	$105	0.5	$175	0.7	$245	0.9	$315	3.2	$1,120
Total Annual Maintenance Expense					**$369**		**$549**		**$729**		**$908**		**$3,864**

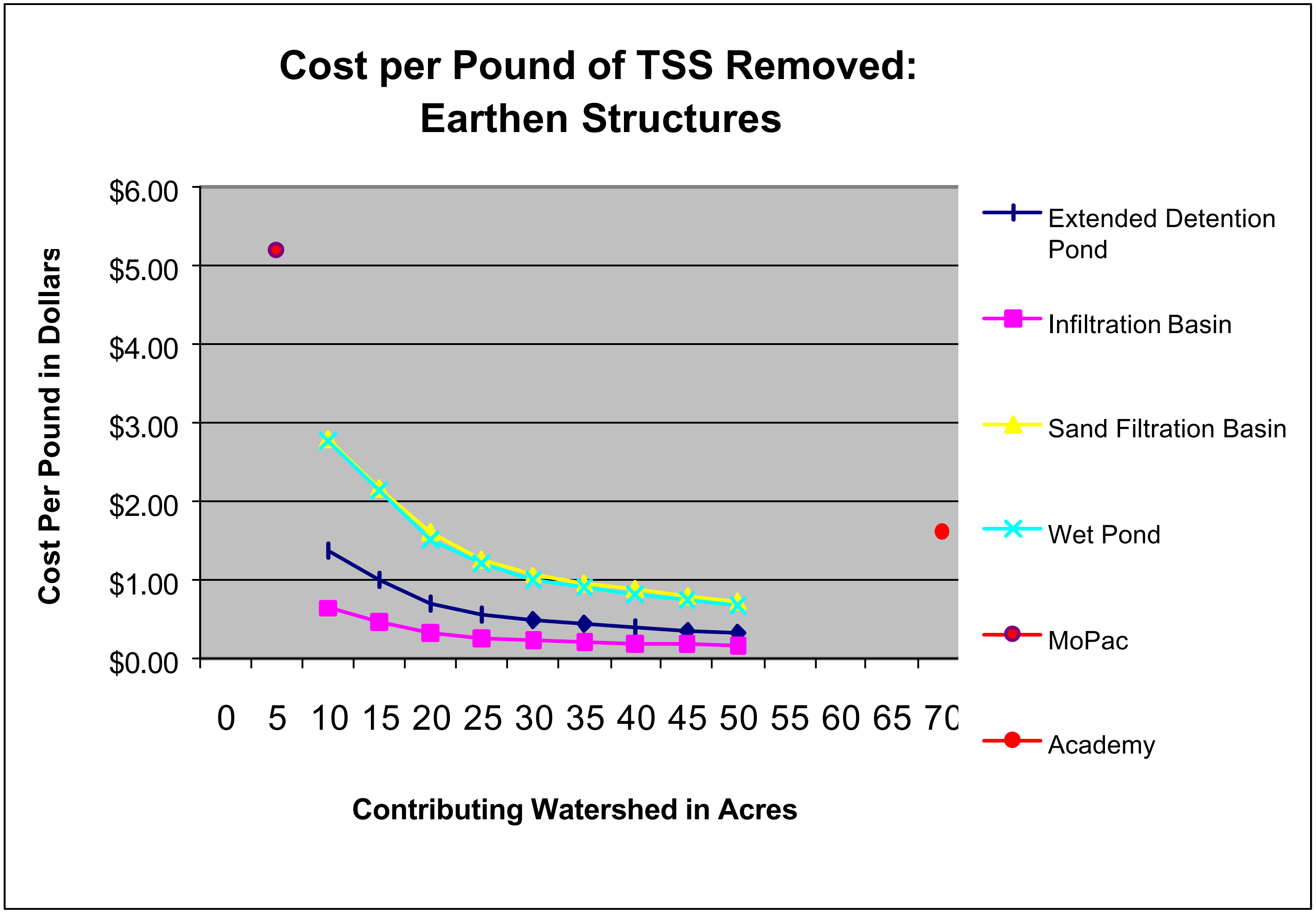
Annual Cost Summary Grass Swale								
Watershed in Acres	**TSS #/CF**	**TSS #/Year**	**TSS Removed #/Year at 70 Percent Efficiency**	**Construction Cost (20 yr Amortization)**	**Annual Maintenance Cost**	**Total Annual Cost**	**Cost $/# Removed**	**Watershed in Acres**
1	0.0094	1,013	709	$54	$369	$423	$0.60	**1**
2	0.0094	2,027	1,419	$63	$549	$612	$0.43	**2**
3	0.0094	3,040	2,128	$75	$729	$804	$0.38	**3**
4	0.0094	4,054	2,838	$92	$908	$1,000	$0.35	**4**
5	0.0094	5065	3,545	$106	$1,102	$1,208	$0.34	**5**

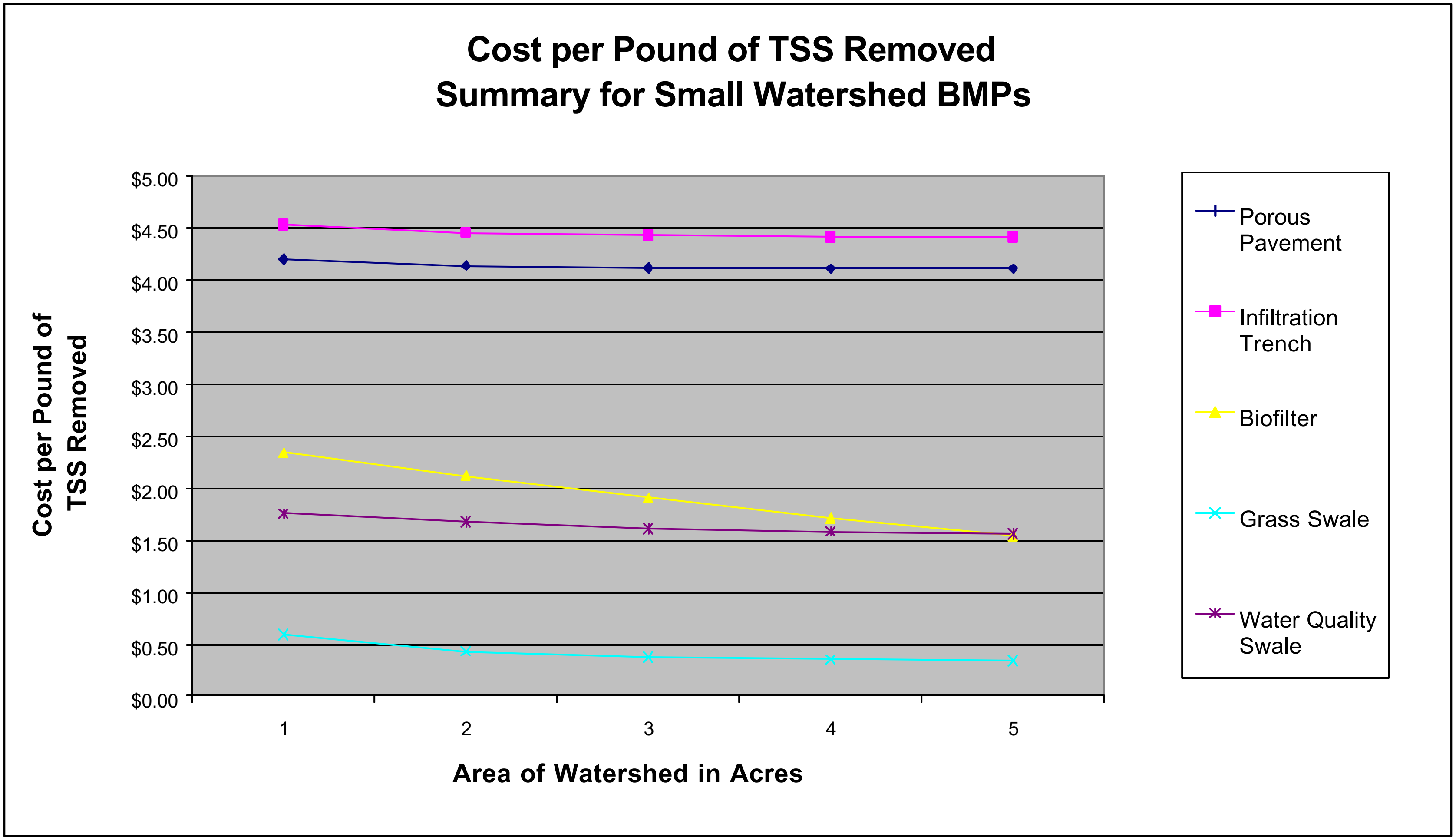


Summary Graphs




Cost Per Pound of TSS Removed
for Hybrid Structures
$6.00
$5.00
$4.00
$3.00
$2.00
$1.00
$0.00
Cost per Pound in Dollars
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
Contributing Watershed in Acres
Infiltration Basins
Extended Detention Basins
Sand Filtration Basins
Wet Pond
MoPac Bridge
Academy


Cost per Pound of TSS Removed:
Earthen Structures
Cost Per Pound in Dollars
$6.00
$5.00
$4.00
$3.00
$2.00
$1.00
$0.00
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
Contributing Watershed in Acres
Extended Detention Pond
Infiltration Basin
Sand Filtration Basin
Wet Pond
MoPac
Academy


Cost per Pound of TSS Removed
Summary for Small Watershed BMPs
Cost per Pound of TSS Removed
$5.00
$4.50
$4.00
$3.50
$3.00
$2.50
$2.00
$1.50
$1.00
$0.50
$0.00
1
2
3
4
5
Area of Watershed in Acres
Porous Pavement
Infiltration Trench
Biofilter
Grass Swale
Water Quality Swale

APPENDIX C

TxDOT Specification Item Numbers Associated with BMP Structures

Item Number	Title	Remarks
110	Excavation	This item will cover most of the general excavation needs. If there are special circumstances see Item 158 Specialized Excavation.
132	Embankment	This item should be sufficient for construction of detention and retention embankments for ponds with no permanent pool and where water depths do not exceed 4 ft. For permanent pools and water depths over 4 ft an appropriate earthen dam specification should be followed.
158	Specialized Excavation	Used in lieu of Item 110.
160	Furnishing and Placing Topsoil	Used for placing topsoil on areas to be revegetated.
162	Sodding for Erosion Control	Used where turf sod is desired for control of erosion.
164	Seeding for Erosion Control	Used for all areas that require seeding.
169	Soil Retention Blanket	Used for selection and application of soil retention blankets. Recommended for all slopes that exceed 6:1.
400	Excavation and Backfilling for Structures	Used for structures such as stand pipes and special walls.
420	Concrete Structures	
421	Portland Cement Concrete	
423	Retaining Wall	Covers most retaining walls. A special specification may be desirable for some segmental (modular) retaining walls.
427	Surface Finishes for Concrete	
432	Riprap	Used for most all types of concrete and stone riprap.
433	Joint Seals and Fillers	
437	Concrete Admixtures	
440	Reinforcing Steel	
445	Galvanizing	May use this for special fabrications related to outlet controls.
450	Railing	
454	Sealed Expansion Joints	
460	Corrugated Metal Pipe	As required for inlet and outfalls.
462	Concrete Box Culverts and Sewers	As required for inlet and outfalls.
464	Reinforced Concrete Pipe	As required for inlet and outfalls.
465	Manholes and Inlets	As required for inlet and outfalls.
466	Headwalls and Wingwalls	As required for inlet and outfalls.
467	Safety End Treatment	As needed for protection of inlet and outfall structures.
471	Frames, Grates, Rings, and Covers	As required for inlet and outfalls.
473	Laying Culvert and Storm Sewer Pipe	As required for inlet and outfalls.
476	Jacking, Boring, or Tunneling Pipe	As required for inlet and outfalls.
532	Concrete Erosion Retards	As required for inlet and outfalls.
550	Chain Link Fence	Recommended for all permanent pool structures.
556	Pipe Underdrains	Use for BMPs that require subdrainage.

Special Specifications with Application to BMP Design

Item Number	Title	Remarks
4087	Thermoplastic Pipe	May be useful if plastic drain pipes are used for inlet and outfall structures.
5005	Rock Filter Dams for Erosion and Sediment Control	Useful for permanent rock filter dams placed in swales to create water quality swales.
5012	Earthwork for Erosion Control	May be preferred to Items 110 and/or 158.
4013	Stone Protection	May be preferred to Item 432.
4008	Corrugated Polyethylene Pipe	Use in cases where polyethylene pipe is used for under drains.
4526	Interlocking Articulating Concrete Blocks	May be used for ground stabilization in work areas of sediment basins in areas with problem soils.
5020	Modular Retaining Walls	Use for situations where Item 423 does not apply.

Items with No Current TxDOT Specification Item Number

Item	Title	Remarks
	Clay Liner	There is no current specification used for impervious clay liners.
	Geosynthetic Pond Liners	If pond liners are used, they should have a thickness of 30 mls and be UV resistant. A clean sand bedding material should be used above and below the membrane to prevent puncture and tearing.
	Filter Sand	The recommended composition of filter sand is shown in the table titled "Suggested Sand Medium Specification," on page of this Appendix. Siliceous sands are preferred, though other materials may be used. Sands should have a minimum conductivity of 1"/hr.

Specification of Impermeable Clay Liner

Property	Test Method	Units	Specification
Permeability	ASTM D-2434	Cm/sec	1 x $10^{-6\ max}$
PI	ASTM D-423 & D-424	%	Not less than 15
Liquid Limit	ASTM D-2216	%	Not less than 30
Particles Passing	ASTM D-422	%	Not less than 30
Compaction	ASTM D-2216	%	95% of standard proctor

Suggested Sand Medium Specification

U.S. Sieve Number	Percent Passing
4	95-100
8	70-100
16	40-90
30	25-75
50	2-25
100	<4
200	<2

APPENDIX D

Texas 2000 Clean Water Act Section 303(d) List
List of Impaired Water Bodies

Texas 2000 Clean Water Act Section 303(d) List

List of Impaired Water Bodies

Explanation of Column Headings

Basin Group:

Letter code (A-E) indicates which group of river basins the segment is associated with in the TNRCC basin planning cycle.

District / County:

District and county in which the water body occurs.

Segment ID (Seg. ID):

This is the classified segment number assigned to a water body or portion of a water body in the Texas Surface Water Quality Standards.

Segment Name:

The name of the water body.

Parameter of Concern:

Those pollutants, or water quality conditions, for which screening procedures indicate an existing impairment or a threat of impairment within the next two years.

Priority for TMDL Development:

The overall priority rank of the water body for TMDL development.
Impaired waters: H = high, M = medium, L = low
Threatened waters: T-H = threatened-high; T-M = threatened-medium.

Source:

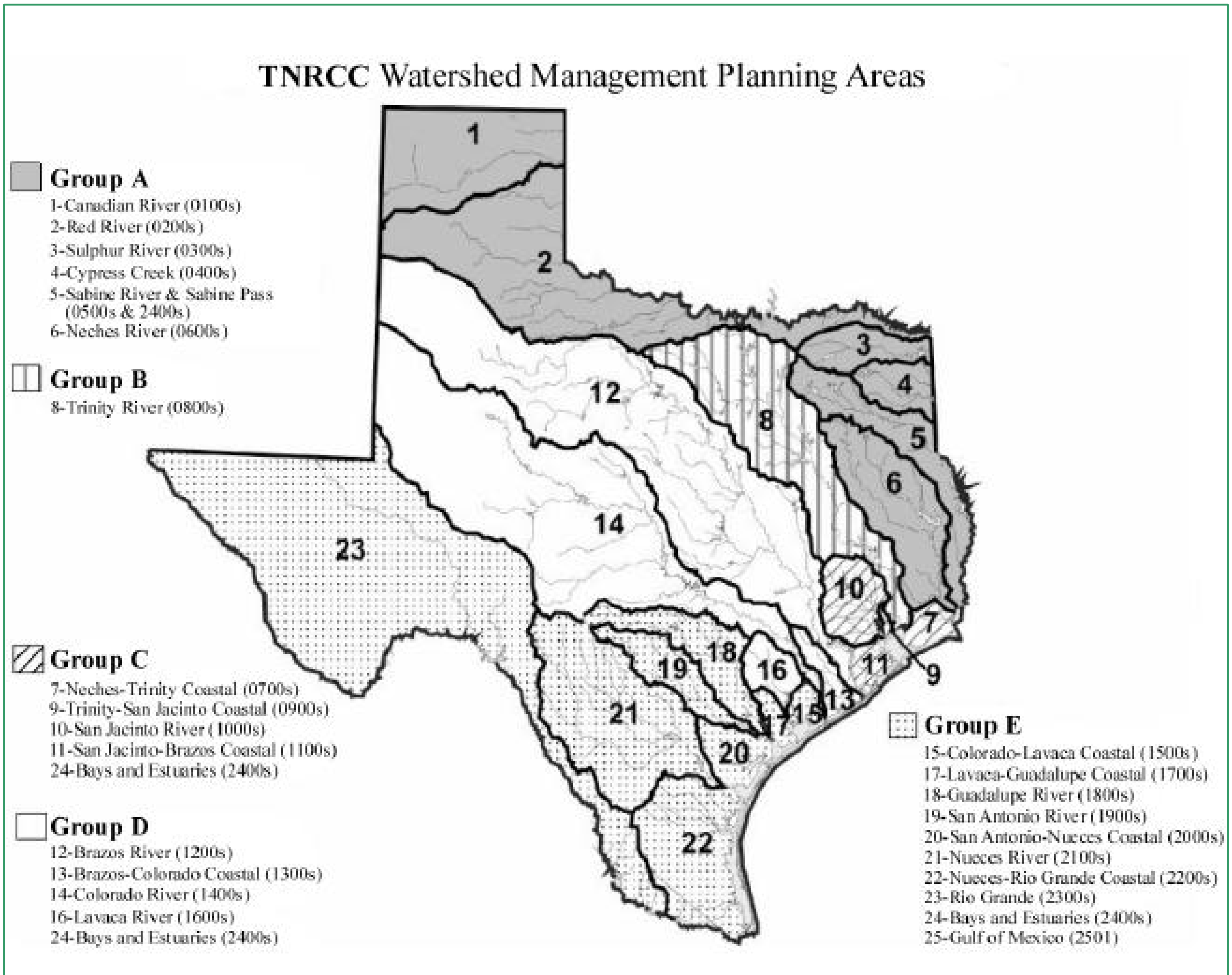
PS indicates that the impairments originate from point sources.
NPS indicates that the impairments originate from non-point sources.

Note: In this paper, The symbol ( ) indicates an impaired stream or a river is located between A and B District. The symbol ( ) indicates an impaired stream or a river is located between A and B County. The symbol ( ) indicates an impaired lake or a reservoir is located between A and B District or County.

Websites: <http://www.tnrcc.state.tx.us/water/quality/tmdl/99map.gif>
< http://www.lib.utexas.edu/maps/states/texas3.gif>

Basin Groups

TNRCC Watershed Management Planning Areas



Texas List of Impaired Waters for 2000

Basin Group	District / County	Seg. ID	Segment Name	Parameter of Concern	Priority for TMDL Development	Source
A	Amarillo / Ochiltree	0101A	Dixon Creek	Pathogens, depressed dissolved oxygen	Low	PS, NPS
A	Amarillo / Hartley	0105	Rita Blanca Lake	pH, total dissolved solids, pathogens	Low	PS, NPS
A	Amarillo / Hansford	0199A	Palo Duro Reservoir	Depressed dissolved oxygen	Low	PS, NPS
A	Amarillo / Hansford	0202D	Pine Creek	Pathogens	Low	PS, NPS
A	Paris / Grayson	0203A	Big Mineral Creek	Pathogens	Low	PS, NPS
A	Wichita Falls / Cooke	0204	Red River above Lake Texoma	Pathogens	Medium	PS, NPS
A	Wichita Falls / Wichita	0205	Red River below Please River	Pathogens	Low	PS, NPS
A	Childress / Childress	0207A	Buck Creek	Pathogens	Low	PS, NPS
A	Wichita Falls / Clay	0211	Little Wichita River	Total dissolved solids, depressed dissolved oxygen	Low	PS, NPS
A	Wichita Falls / Wilbarger	0214A	Beaver Creek	Depressed dissolved oxygen	Low	PS, NPS
A	Childress / Cottee	0218	Wichita/North Fork Wichita River	Selenium	Medium	PS, NPS
A	Childress / Motley Cottee	0221	Middle Fork Please River	Water temperature	Low	NPS
A	Childress / Briscoe	0228	Mackenzie Reservoir	Total dissolved solids	Low	NPS
A	~~Atlanta~~ / Bowie Cass	0302	Wright Patman Lake	pH, depressed dissolved oxygen	Medium	PS, NPS
A	Paris / Delta	0303A	Big Creek Lake	Atrazine in finished drinking water	T-H	NPS

Basin Group	District / County	Seg. ID	Segment Name	Parameter of Concern	Priority for TMDL Development	Source
A	Atlanta / Morris Paris / Hopkins	0303B	White Oak Creek	Depressed dissolved oxygen	Medium	PS, NPS
A	Paris / Hopkins Delta	0306	Upper South Sulphur River	pH, pathogens, depressed dissolved oxygen	Medium	PS, NPS
A	Paris / Delta	0307	Cooper Lake	pH, depressed dissolved oxygen	Medium	PS, NPS
A	~~Atlanta~~ / Marion Harrison	0401	Caddo Lake	pH, mercury in fish tissue, depressed dissolved oxygen	Medium	PS, NPS
A	Atlanta / Harrison	0401A	Harrison Bayou	Depressed dissolved oxygen	Low	PS, NPS
A	Atlanta / Marion	0402	Big Cypress Creek below Lake O' the Pines	pH, mercury in fish tissue, depressed dissolved oxygen	Medium	PS, NPS
A	Atlanta / Cass	0402A	Black Cypress Bayou	Mercury in fish tissue, depressed dissolved oxygen	Medium	PS, NPS
A	Atlanta / Marion	0403	Lake O' the Pines	Depressed dissolved oxygen	High	PS, NPS
A	Atlanta / Titus	0404B	Tankersley Creek	Pathogens	Low	PS, NPS
A	Atlanta / Titus	0404D	Welsh Reservoir	Selenium in fish tissue	Medium	PS, NPS
A	Atlanta / Cass	0407	James' Bayou	Depressed dissolved oxygen	Medium	PS, NPS
A	Atlanta / Harrison	0409	Little Cypress Bayou	Depressed dissolved oxygen	Medium	PS, NPS
A	Beaumont / Newton	0503A	Nichols Creek	Pathogens, depressed dissolved oxygen	Low	PS, NPS
A	Lufkin / Sabine	0504	Toledo Bend Reservoir	Mercury in fish tissue, low and high pH, depressed dissolved oxygen	Medium	PS, NPS

Basin Group	District / County	Seg. ID	Segment Name	Parameter of Concern	Priority for TMDL Development	Source
A	Tyler / Gregg	0505B	Grace Creek	Pathogens, depressed dissolved oxygen	Medium	PS, NPS
A	Tyler / Gregg	0505D	Rabbit Creek	Pathogens	Low	PS, NPS
A	Atlanta / Harrison	0505E	Brandy Branch Reservoir	Selenium in fish tissue	Medium	PS
A	Tyler / Rusk	0505F	Martin Creek Reservoir	Selenium in fish tissue	Medium	PS
A	Atlanta / Harrison	0505G	Wards Creek	Depressed dissolved oxygen	Medium	PS, NPS
A	Tyler / Smith	0506A	Harris Creek	Depressed dissolved oxygen	Low	PS, NPS
A	Paris / Hunt Rains Tyler / Van Zandt	0507	Lake Tawakoni	High pH, depressed dissolved oxygen, atrazine in finished drinking water	Low	PS, NPS
A	Paris / Hunt	0507A	Cowleech Fork Sabine River	Pathogens, depressed dissolved oxygen	Low	PS, NPS
A	Paris / Hunt	0507B	Long Branch	Pathogens	Low	PS, NPS
A	Beaumont / Orange	0508	Adams Bayou Tidal	Pathogens, depressed dissolved oxygen	Low	PS, NPS
A	Beaumont / Orange	0508A	Adams Bayou above Tidal	Pathogens, depressed dissolved oxygen	Medium	PS, NPS
A	Beaumont / Orange	0508B	Gum Gully	Pathogens, depressed dissolved oxygen	Low	PS, NPS
A	Beaumont / Orange	0511	Cow Bayou Tidal	Pathogens, low pH, depressed dissolved oxygen	Medium	PS, NPS
A	Beaumont / Orange	0511A	Cow Bayou above Tidal	Pathogens, depressed dissolved oxygen	Medium	PS, NPS

Basin Group	District / County	Seg. ID	Segment Name	Parameter of Concern	Priority for TMDL Development	Source
A	Beaumont / Orange	0511B	Coon Bayou	Pathogens, depressed dissolved oxygen	Medium	PS, NPS
A	Beaumont / Orange	0511C	Cole Creek	Pathogens, depressed dissolved oxygen	Medium	PS, NPS
A	Tyler / Wood	0512	Lake Fork Reservoir	Total dissolved solids	Low	PS, NPS
A	Beaumont / Newton	0513	Big Cow Creek	Pathogens	Medium	PS, NPS
A	Beaumont / Jefferson	0601A	Star Lake Canal	Depressed dissolved oxygen	Low	PS
A	Beaumont / Hardin	0602A	Booger Branch	Depressed dissolved oxygen	Low	PS, NPS
A	Beaumont / Jasper Tyler	0603	B.A. Steinhagen Lake	Mercury in fish tissue	Medium	NPS
A	Beaumont / Jasper	0603A	Sandy Creek	Pathogens	Low	PS, NPS
A	Tyler / Cherokee Anderson	0604	Neches River below Lake Palestine	Pathogens	Low	PS, NPS
A	Lufkin / Angelina	0604A	Cedar Creek	Pathogens	Low	PS, NPS
A	Lufkin / Angelina	0604B	Hurricane Creek	Pathogens	Low	PS, NPS
A	Lufkin / Angelina	0604C	Jack Creek	Pathogens	Low	PS, NPS
A	Tyler / Henderson	0605A	Kickapoo Creek	Pathogens	Low	PS, NPS
A	Tyler / Van Zandt	0606	Neches River above Lake Palestine	Zinc (chronic), Zinc (acute), total dissolved solids	Medium	PS, NPS
A	Tyler / Smith	0606A	Prairie Creek	Zinc (chronic)	Medium	PS, NPS

Basin Group	District / County	Seg. ID	Segment Name	Parameter of Concern	Priority for TMDL Development	Source
A	Beaumont / Hardin	0607	Pine Island Bayou	Pathogens, low pH, depressed dissolved oxygen	Low	PS, NPS
A	Beaumont / Hardin	0607A	Boggy Creek	Depressed dissolved oxygen	Low	PS, NPS
A	Beaumont / Hardin	0607B	Little Pine Island Bayou	Depressed dissolved oxygen	Low	PS, NPS
A	Beaumont / Liberty	0607C	Willow Creek	Pathogens, depressed dissolved oxygen	Low	PS, NPS
A	Beaumont / Hardin	0608	Village Creek	Low pH	Low	NPS
A	Beaumont / Tyler Hardin	0608A	Beach Creek	Depressed dissolved oxygen	Low	PS, NPS
A	Lufkin / Polk Beaumont / Hardin	0608B	Big Sandy Creek	Pathogens	Medium	PS, NPS
A	Beaumont / Hardin	0608C	Cypress Creek	Pathogens, depressed dissolved oxygen	Medium	PS, NPS
A	Beaumont / Tyler Hardin	0608D	Hickory Creek	Pathogens	Low	PS, NPS
A	Beaumont / Tyler Hardin	0608F	Turkey Creek	Pathogens	Low	PS, NPS
A	Beaumont / Hardin Tyler	0608G	Lake Kimball	Mercury in fish tissue	Medium	PS, NPS
A	Lufkin / San Augustine Nacogdoches Angelina Beaumont / Jasper	0610	Sam Rayburn Reservoir	Mercury in fish tissue, low and high pH, depressed dissolved oxygen	Medium	PS, NPS
A	Lufkin / San Augustine	0610A	Ayish Bayou	Pathogens	Low	PS, NPS
A	Lufkin / Nacogdoches Angelina Tyler / Cherokee	0611	Angelina River above Sam Rayburn Reservoir	Pathogens	Medium	PS, NPS

Basin Group	District / County	Seg. ID	Segment Name	Parameter of Concern	Priority for TMDL Development	Source
A	Tyler / Rusk	0611A	East Fork Angelina River	Lead in water	Medium	PS, NPS
A	Lufkin / Nacogdoches	0611B	Lanana Bayou	Pathogens	Low	PS, NPS
A	Tyler / Cherokee	0611C	Mud Creek	Pathogens	Low	PS, NPS
A	Lufkin / Shelby Nacogdoches San Augustine	0612	Attoyac Bayou	Lead (chronic), cadmium (chronic)	Medium	PS, NPS
A	Lufkin / Nacogdoches	0612B	Waffelow Creek	Pathogens	Low	PS, NPS
A	Tyler / Smith	0613	Lake Tyler/Lake Tyler East	Low pH	Low	PS, NPS
B	~~Lufkin~~ / San Jacinto Polk	0803	Lake Livingston	High pH, depressed dissolved oxygen	Low	PS, NPS
B	~~Bryan / Walker~~ Madison Lufkin / Houston	0804	Trinity River above Lake Livingston	Pathogens	Low	PS, NPS
B	Tyler / Henderson Dallas / Navarro	0805	Upper Trinity River	Pathogens, chlordane in fish tissue	Medium	PS, NPS
B	Fort Worth / Tarrant	0806	West Fork Trinity River below Lake Worth	Pathogens, chlordane in fish tissue	Medium	NPS
B	Fort Worth / Tarrant	0806A	Fosdic Lake	PCBs, dieldrin, DDE, and chlordane in fish tissue	Medium	NPS
B	Fort Worth / Tarrant	0806B	Echo Lake	PCBs in fish tissue	Medium	NPS
B	Fort Worth / Wise	0810	West Fork Trinity River below Bridgeport Reservoir	Pathogens	Low	PS, NPS

Basin Group	District / County	Seg. ID	Segment Name	Parameter of Concern	Priority for TMDL Development	Source
B	Fort Worth / Jack	0812	West Fork Trinity River above Bridgeport Reservoir	Depressed dissolved oxygen, total dissolved solids, chloride	Medium	NPS
B	Dallas / Ellis	0815	Bardwell Reservoir	Atrazine in finished drinking water	T-H	NPS
B	Dallas / Ellis	0816	Lake Waxahachie	Atrazine in finished drinking water	T-H	NPS
B	Dallas / Navarro	0817	Navarro Mills Lake	Atrazine in finished drinking water	T-M	NPS
B	Dallas / Dallas	0819	East Fork Trinity River	Pathogens	Low	PS, NPS
B	Dallas / Collin	0821	Lake Lavon	Atrazine in finished drinking water	T-M	NPS
B	Fort Worth / Tarrant	0829	Clear Fork Trinity River below Benbrook Lake	Chlordane in fish tissue	Medium	NPS
B	Fort Worth / Tarrant	0829A	Lake Como	PCBs, dieldrin, DDE, and chlordane in fish tissue	Medium	PS, NPS
B	Fort Worth / Parker	0831	Clear Fork Trinity River below Lake Weatherford	Depressed dissolved oxygen	Low	PS, NPS
B	Fort Worth / Parker	0833	Clear Fork Trinity River above Lake Weatherford	Depressed dissolved oxygen	Low	NPS
B	Dallas / Navarro	0836	Richland-Chambers Reservoir	Atrazine in finished drinking water	T-M	NPS
B	Dallas / Dallas Fort Worth / Tarrant	0838	Joe Pool Lake	Total dissolved solids, sulfate, atrazine in finished drinking water	Low	NPS
B	Fort Worth / Tarrant	0841	Lower West Fork Trinity River	Pathogens, chlordane in fish tissue	Medium	PS, NPS

Basin Group	District / County	Seg. ID	Segment Name	Parameter of Concern	Priority for TMDL Development	Source
B	Dallas / Dallas	0841A	Mountain Creek Lake	PCBs, heptachlor epoxide, dieldrin, DDT, DDE, DDD, and chlordane in fish tissue	Medium	NPS
C	Beaumont / Jefferson	0701	Taylor Bayou above Tidal	Depressed dissolved oxygen	Low	PS, NPS
C	Beaumont / Jefferson	0702A	Lake Waxahachie	Ambient toxicity in sediment and water	Low	PS, NPS
C	Beaumont / Jefferson	0704	Hillebrandt Bayou	Depressed dissolved oxygen	Low	PS, NPS
C	Houston / Harris Beaumont / Chambers	0901	Cedar Bayou Tidal	Pathogens	Medium	PS, NPS
C	Houston / Harris Beaumont / Liberty	0902	Cedar Bayou above Tidal	Total dissolved solids, pathogens	Low	PS, NPS
C	Houston / Montgomery	1001	San Jacinto River Tidal	Pathogens, dioxins in blue crab and catfish tissue	Medium	PS, NPS
C	Houston / Harris	1005	Houston Ship Channel/San Jacinto River Tidal	Dioxins in blue crab and catfish tissue	Medium	PS
C	Houston / Harris	1006	Houston Ship Channel Tidal	Dioxins in blue crab and catfish tissue, ambient toxicity in sediment and water, thermal modifications	High	PS, NPS
C	Houston / Harris	1007	Houston Ship Channel Buffalo Bayou Tidal	Dioxins in blue crab and catfish tissue, ambient toxicity in sediment	Medium	PS, NPS
C	Houston / Montgomery Harris	1008	Spring Creek	Pathogens, depressed dissolved oxygen	Medium	PS, NPS
C	Houston / Harris	1009	Cypress Creek	Total dissolved solids, pathogens	Medium	PS, NPS

Basin Group	District / County	Seg. ID	Segment Name	Parameter of Concern	Priority for TMDL Development	Source
C	Houston / Harris	1013	Buffalo Bayou Tidal	Pathogens, copper in water	Medium	NPS
C	Houston / Harris	1014	Buffalo Bayou above Tidal	Pathogens	Low	PS, NPS
C	Houston / Harris	1016	Greens Bayou above Tidal	Pathogens	Low	PS, NPS
C	Houston / Harris	1017	Whiteoak Bayou above Tidal	Pathogens	Low	PS, NPS
C	Houston / Galveston Harris	1101	Clear Creek Tidal	Trichloroethane, pathogens dichloroethane, chlordane, and carbon disulfide in fish and crab tissue,	Medium	PS, NPS
C	Houston / Brazoria Harris	1102	Clear Creek above Tidal	Trichloroethane, pathogens dichloroethane, chlordane, and carbon disulfide in fish and crab tissue,	Low	PS, NPS
C	Houston / Galveston	1103	Dickinson Bayou Tidal	Pathogens, depressed dissolved oxygen	Medium	PS, NPS
C	Houston / Galveston	1104	Dickinson Bayou above Tidal	Pathogens	Low	NPS
C	Houston / Brazoria	1108	Chocolate Bayou above Tidal	Total dissolved solids, pathogens	Low	NPS
C	Houston / Brazoria	1109	Oyster Creek Tidal	Pathogens	Medium	NPS
C	Houston / Brazoria	1110	Oyster Creek above Tidal	Pathogens, depressed dissolved oxygen	Medium	PS, NPS

Basin Group	District / County	Seg. ID	Segment Name	Parameter of Concern	Priority for TMDL Development	Source
C	Houston / Harris	1113	Armand Bayou Tidal	Pathogens, depressed dissolved oxygen	High	PS, NPS
C	Houston / Harris	1113A	Armand Bayou above Tidal	Pathogens, depressed dissolved oxygen	High	PS, NPS
C	Houston / Harris	2421	Upper Galveston Bay	Pathogens, dioxins in blue crab and catfish tissue	Medium	PS, NPS
C	Beaumont / Chambers	2422	Trinity Bay	Pathogens	Low	NPS
C	Houston / Galveston	2423	East Bay	Pathogens	Low	NPS
C	Houston / Galveston Brazoria	2424	West Bay	Pathogens, copper in water	Medium	NPS
C	Houston / Harris (North Galveston Bay)	2426	Tabbs Bay	Pathogens, dioxins in fish and crab tissue	Medium	PS, NPS
C	Houston / Harris	2427	San Jacinto Bay	Dioxins in fish and crab tissue	Medium	PS
C	Houston / Harris	2428	Black Duck Bay	Dioxins in fish and crab tissue	Medium	PS
C	Houston / Harris (Buffalo-San Jacinto)	2429	Scott Bay	Pathogens, dioxins in fish and crab tissue	Medium	PS, NPS
C	Houston / Harris (Buffalo-San Jacinto)	2430	Burnett Bay	Dioxins in fish and crab tissue	Medium	PS
C	Houston / Brazoria (West Galveston)	2432	Chocolate Bay	Pathogens	Low	PS, NPS
C	Houston / Harris (Buffalo-San Jacinto)	2436	Barbours Cut	Dioxins in fish and crab	Medium	PS
C	Houston / Galveston	2437	Texas City Ship Channel	Depressed dissolved oxygen	Low	PS
C	Houston / Galveston	2438	Bayport Channel	Dioxins in blue crab and catfish	Medium	PS

Basin Group	District / County	Seg. ID	Segment Name	Parameter of Concern	Priority for TMDL Development	Source
C	Houston / Galveston (Galveston Bay)	2439	Low Galveston Bay	Pathogens, copper in water	Medium	PS, NPS
D	Bryan / Brazos	1209A	Bryan Municipal Lake	Arsenic in water, ambient toxicity in sediment	Medium	PS
D	Bryan / Brazos	1209B	Fin Feather Lake	Arsenic in water, ambient toxicity in sediment	Medium	PS
D	Bryan / Brazos	1209C	Carters Creek	Pathogens	Low	PS, NPS
D	Bryan / Brazos	1209D	Unnamed tributary to Bryan Municipal Lake	Arsenic in water	Medium	PS
D	Waco / Limestone	1210	Lake Mexia	Depressed dissolved oxygen	Low	NPS
D	Bryan / Milam	1214	San Gabriel River	Chloride	Low	PS
D	Austin / Burnet	1217A	Rocky Creek	Pathogens, depressed dissolved oxygen	Low	NPS
D	Waco / Bell	1218	Nolan Creek / South Nolan Creek	Pathogens	Medium	PS, NPS
D	Waco / Hamilton Coryell Brownwood / Comanche	1221	Leon River below Proctor Lake	Total dissolved solids, pathogens	Medium	NPS
D	Brownwood / Comanche	1222	Proctor Lake	Depressed dissolved oxygen	Low	NPS
D	Brownwood / Comanche	1222A	Duncan Creek	Pathogens, depressed dissolved oxygen	Low	NPS

Basin Group	District / County	Seg. ID	Segment Name	Parameter of Concern	Priority for TMDL Development	Source
D	Waco / Bosque	1226	North Bosque River	Pathogens, nutrients	High	PS, NPS
D	Waco / Bosque	1226A	Duffau Creek	Pathogens	Low	NPS
D	Waco / Bosque	1226C	Meridian Creek	Pathogens	Low	NPS
D	Fort Worth / Earth, Hood, Somervell	1229	Paluxy River / North Paluxy River	Total dissolved solids	Low	NPS
D	Brownwood / Stephens	1233	Hubbard Creek Reservoir	Sulfate	Medium	NPS
D	Lubbock / Crosby	1240	White River Lake	Total dissolved solids	Low	NPS
D	Waco / Bosque McLennan	1242	Brazos River below Whitney Lake	Pathogens	Medium	NPS
D	Waco / Bell	1243	Salado Creek	Total dissolved solids, depressed dissolved oxygen	Low	NPS
D	Austin / Williamson Bryan / Milam	1244	Brushy Creek	Total dissolved solids	Medium	PS
D	Houston / Fort Bend	1245	Upper Oyster Creek	Pathogens, depressed dissolved oxygen	Medium	PS, NPS
D	Waco / Hill	1254	Aquilla Reservoir	Depressed dissolved oxygen, atrazine and alachlor in finished drinking water	High	NPS
D	Fort Worth / Earth	1255	Upper North Bosque River	Total dissolved solids, sulfate, pathogens, chloride, nutrients	High	PS, NPS

Basin Group	District / County	Seg. ID	Segment Name	Parameter of Concern	Priority for TMDL Development	Source
D	Yoakum / Austin Colorado	1302	San Bernard River above Tidal	Water temperature	Low	NPS
D	Yoakum / Matagorda	1304	Caney Creek Tidal	Pathogens	Medium	NPS
D	Yoakum / Matagorda	1304A	Linville Bayou	Pathogens	Medium	PS, NPS
D	Yoakum / Matagorda	1305	Caney Creek above Tidal	Depressed dissolved oxygen	Low	PS, NPS
D	Austin / Travis	1403	Lake Austin	Pathogens, depressed dissolved oxygen	Low	NPS
D	Austin / Travis	1403A	Bull Creek	Pathogens	Medium	NPS
D	San Angelo / Coke	1411	E.V. Spence Reservoir	Total dissolved solids, sulfate	High	NPS
D	Austin / Gillespie	1414	Perdenales River	Pathogens	Low	NPS
D	Brownwood / Brown Coleman	1420	Pecan Bayou above Lake Brownwood	Depressed dissolved oxygen	Low	PS, NPS
D	San Angelo / Coke Runnels	1426	Colorado River below E.V. Spence Reservoir	Total dissolved solids	Low	PS, NPS
D	Austin / Travis	1427	Onion Creek	Total dissolved solids, sulfate, pathogens, depressed dissolved oxygen	Medium	PS, NPS
D	Austin / Travis	1427A	Slaughter Creek	Pathogens	Low	NPS
D	Austin / Travis	1427B	Williamson Creek	Pathogens	Low	NPS
D	Austin / Travis	1427C	Bear Creek	Pathogens	Low	NPS
D	Austin / Travis	1428	Colorado River below Town Lake	Pathogens	Medium	NPS
D	Austin / Travis	1428A	Boggy Creek	Pathogens	Low	NPS

Basin Group	District / County	Seg. ID	Segment Name	Parameter of Concern	Priority for TMDL Development	Source
D	Austin / Travis	1428B	Walnut Creek	Pathogens	Low	PS, NPS
D	Austin / Travis	1428C	Gilleland Creek	Pathogens	Low	NPS
D	Austin / Travis	1429A	Shoal Creek	Pathogens	Low	NPS
D	Austin / Travis	1429B	Eanes Creek	Pathogens	Low	NPS
D	Austin / Travis	1430	Barton Creek	Pathogens	Medium	NPS
D	Brownwood / Brown	1432	Upper Pecan Bayou	Total dissolved solids	Low	PS, NPS
D	Yoakum / Lavaca Jackson	1602	Lavaca River above Tidal	Water temperature	Low	NPS
D	Yoakum / Jackson	1604	Lake Texana	Depressed dissolved oxygen	Low	PS, NPS
D	Yoakum / Matagorda	2441	East Matagorda Bay	Pathogens	Low	PS, NPS
D	Yoakum / Matagorda	2442	Cedar Lakes	Pathogens	Low	PS, NPS
E	Yoakum / Matagorda	1501	Tres Palacios Creek Tidal	Depressed dissolved oxygen	Low	NPS
E	Yoakum / Wharton	1502	Tres Palacios Creek above Tidal	Total dissolved solids, pathogens	Low	NPS
E	Yoakum / Victoria	1801	Guadalupe River Tidal	Depressed dissolved oxygen	Low	PS, NPS
E	Yoakum / Gonzales	1803A	Elm Creek	Pathogens, depressed dissolved oxygen	Medium	PS, NPS
E	Yoakum / Gonzales	1803B	Sandies Creek	Depressed dissolved oxygen	Medium	PS, NPS
E	Yoakum / Gonzales	1804B	Peach Creek	Pathogens	Low	PS, NPS

Basin Group	District / County	Seg. ID	Segment Name	Parameter of Concern	Priority for TMDL Development	Source
E	San Antonio / Kerr	1806A	Camp Meeting Creek	Depressed dissolved oxygen	Medium	PS, NPS
E	San Antonio / Comal	1811A	Dry Comal Creek	Pathogens	Low	NPS
E	Austin / Hays	1814	Upper San Marcos River	Sulfate	Low	NPS
E	Austin / Hays	1815	Cypress Creek	Depressed dissolved oxygen	Low	PS, NPS
E	Corpus Christi / Goliad	1901	Low San Antonio River	Pathogens	Low	PS, NPS
E	San Antonio / Medina	1903	Medina River below Medina Diversion Lake	Pathogens	Medium	PS, NPS
E	San Antonio / Bexar	1906	Lower Leon Creek	Pathogens, depressed dissolved oxygen	Medium	PS, NPS
E	San Antonio / Bexar Comal	1908	Upper Cibolo Creek	Depressed dissolved oxygen	Medium	PS, NPS
E	San Antonio / Bexar	1910	Salado Creek	Pathogens, depressed dissolved oxygen	Low	NPS
E	San Antonio / Wilson	1911	Upper San Antonio River	Pathogens	Low	PS, NPS
E	San Antonio / Bexar Guadalupe	1913	Mid Cibolo Creek	Depressed dissolved oxygen	Low	NPS
E	Corpus Christi / Bee, Refugio, San Patricio	2004	Aransas River above Tidal	Total dissolved solids, pathogens	Low	PS, NPS
E	San Antonio / McMullen Corpus Christi / Live Oak	2104	Nueces River above Frio River	pH, depressed dissolved oxygen	Medium	PS, NPS
E	San Antonio / Atascosa	2107	Atascosa River	Pathogens, depressed dissolved oxygen	Low	PS, NPS
E	San Antonio / Uvalde	2110	Low Sabinal River	Pathogens	Low	PS, NPS

Basin Group	District / County	Seg. ID	Segment Name	Parameter of Concern	Priority for TMDL Development	Source
E	San Antonio / Uvalde	2113	Upper Frio River	Depressed dissolved oxygen	Medium	PS, NPS
E	San Antonio / McMullen Corpus Christi / Live Oak	2116	Choke Canyon Reservoir	Pathogens	Medium	NPS
E	San Antonio / Frio, McMullen Laredo / La Salle	2117	Frio River above Choke Canyon Reservoir	Pathogens, depressed dissolved oxygen	Medium	PS, NPS
E	Pharr / Willacy Cameron	2201	Arroyo Colorado Tidal	Depressed dissolved oxygen, ambient toxicity in sediment	High	PS, NPS
E	Pharr / Cameron	2202	Arroyo Colorado above Tidal	Toxaphene in fish tissue, pathogens, DDE in fish tissue, chlordane in fish tissue	High	PS, NPS
E	Pharr / Hidalgo	2202A	Donna Reservoir	PCBs in fish tissue	High	NPS
E	Corpus Christi / Nueces	2204	Petronila Creek above Tidal	Total dissolved solids, sulfate chloride	Medium	NPS
E	Pharr / Starr	2302	Rio Grande below Falcon Reservoir	Pathogens	Low	PS, NPS
E	Pharr / Zapata	2303	International Falcon Reservoir	Total dissolved solids, chloride	Low	NPS
E	Laredo / Val Verde Kinney Maverick Webb	2304	Rio Grande below Amistad Reservoir	Pathogens, ambient toxicity in water	Low	PS
E	Laredo / Val Verde El Paso / Brewster Presidio Odessa / Terrel	2306	Rio Grande above Amistad Reservoir	Pathogens, ambient toxicity in water	Medium	PS
E	El Paso / El Paso Hudspeth	2307	Rio Grande below Riverside Diversion Dam	Total dissolved solids, sulfate, chloride	Low	PS, NPS

Basin Group	District / County	Seg. ID	Segment Name	Parameter of Concern	Priority for TMDL Development	Source
E	Laredo / Val Verde	2310	Lower Pecos River	Total dissolved solids, sulfate, chloride	Low	NPS
E	Yoakum / Matagorda	2451	Matagorda Bay / Powderhorn Lake	Pathogens, depressed dissolved oxygen	Low	NPS
E	Yoakum / Jackson, Matagorda, Calhoun	2452	Tres Palacios Bay / Turtle Bay	Pathogens	Low	PS, NPS
E	Yoakum / Jackson, Calhoun Houston / Brazoria	2453	Lavaca Bay Chocolate Bay	Pathogens, mercury in water, mercury in fish and crab tissue, depressed dissolved oxygen	Medium	PS, NPS
E	Yoakum / Victoria	2453A	Garcitas Creek Tidal	Depressed dissolved oxygen	Low	NPS
E	Yoakum / Matagorda, Calhoun (Central Matagorda Bay)	2454	Cox Bay	Pathogens	Low	PS, NPS
E	Yoakum / Matagorda, Calhoun (Central Matagorda Bay)	2456	Carancahua Bay	Pathogens	Low	PS, NPS
E	Yoakum / Calhoun	2462	San Antonio Bay / Hynes Bay / Guadalupe Bay	Pathogens	Low	PS, NPS
E	Corpus Christi / Aransas	2471	Aransas Bay	Pathogens	Low	NPS
E	Corpus Christi / Aransas	2472	Copano Bay / Port Bay / Mission Bay	Pathogens	Low	NPS
E	Corpus Christi / Aransas	2473	St. Charles Bay	Pathogens	Low	NPS
E	Corpus Christi / Nueces	2481	Corpus Christi Bay	Pathogens	Low	NPS

Basin Group	District / County	Seg. ID	Segment Name	Parameter of Concern	Priority for TMDL Development	Source
E	Corpus Christi / Nueces San Patricio	2482	Nueces Bay	Zinc in oyster tissue	Low	PS, NPS
E	Corpus Christi / Aransas	2483A	Conn Brown Harbor	Depressed dissolved oxygen	Low	PS, NPS
E	Corpus Christi / Nueces (South Corpus Christi Bay)	2485	Oso Bay	Pathogens, depressed dissolved oxygen	Low	PS, NPS
E	Pharr / Willacy Cameron	2491	Laguna Madre	Pathogens, depressed dissolved oxygen	Medium	NPS
E	Gulf of Mexico	2501	Gulf of Mexico	Mercury in king mackerel greater than 37 inches long, depressed dissolved oxygen	Low	NPS