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H. Water Quality

COST TO PERFORMANCE ANALYSIS OF SELECTED STORMWATER QUALITY BEST MANAGEMENT PRACTICES

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Abstract: By reviewing current literature and practice, this project examined alternatives for permanent, water quality improvement structures. The study also recognized that there are significant differences in methods and types of structures appropriate to rural, suburban, and urban conditions. Parallel to this effort, existing water quality improvement structures were identified and monitored in an effort to establish comparative baseline performance data. To develop the performance to cost analysis, a prototype approach was adopted. A total of nine different types of stormwater quality best management practices (BMPs) were evaluated and performance to cost comparisons were made based on contributing watershed size. The findings argue strongly for developing large regional type structures, which implies the need for early planning for the acquisition of sufficient right-of-way to accommodate water quality features.

Introduction

In the Austin, Texas area, the Texas Department of Transportation (TxDOT) has been building and operating stormwater quality structures for over 20 years. These structures protect the Edwards Aquifer, which is the primary source of water for several urban counties that include the cities of Austin and San Antonio. Karst limestone and very shallow soils overlie the Edwards; therefore, pollutants at the surface can transfer directly to the aquifer below.

As development in the region increased, the City of Austin and the Texas Natural Resource Conservation Commission (TNRCC), the state's natural resource regulatory agency, began increasing the performance requirements and complexity of the best management practices (BMPs) required in the Edwards recharge zone. This led to the design and installation of some large and very complex structures that are costly to build and maintain.

In 1998, TxDOT contracted with the Texas Transportation Institute and Texas Tech University to examine these structures and develop a cost to performance measure that would allow a comparison between the more costly structures and less expensive alternatives.

Since the 1970s, the City of Austin focused on sand filtration as the primary stormwater treatment for the area. Over the years, this technology evolved from a simple earthen basin with a clay liner, sand bottom, and underlying drain field, to some rather sophisticated structures that may incorporate hazardous materials traps, floatables collection, and other forms of pretreatment. Because of the preponderance of filtration type BMPs, the field study concentrated on sand filter type structures. Design and performance data for other types of structures used in the comparison were collected from the literature, as well as from contact with agencies and researchers familiar with these alternate types of stormwater treatment.

Prototype Approach to the Study

Based on early field surveys of BMPs that ranged in age from 1 or 2 years to 25 years, it was clear that no meaningful comparison of performance or cost would be possible using site-specific examples. The City of Austin and TxDOT had performance data on a variety of structures, and several studies had been conducted by the City of Austin (1997) and TxDOT (Malina et al 1997). After investigation of these sources, it became apparent that the differences in site conditions, design sampling method, and constituents sampled were so great that no meaningful comparison was possible. In addition, almost no records of cost were available for the older City of Austin structures; therefore, cost comparisons using historic data were not possible.

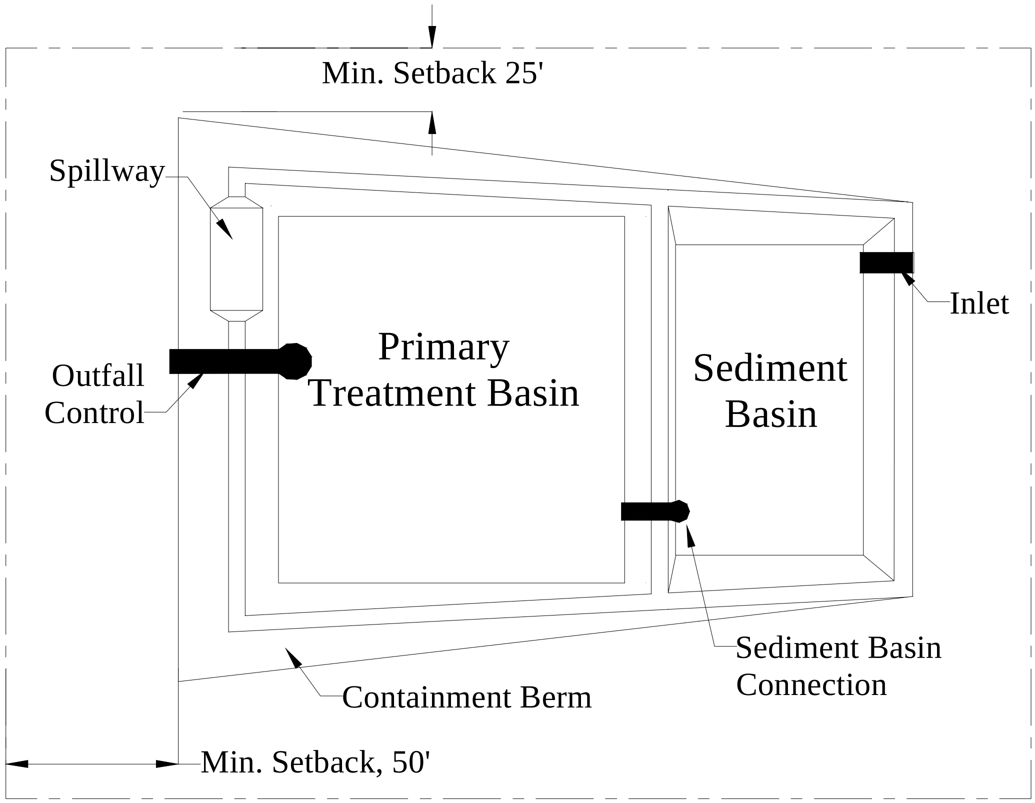

Fig. 1. Prototype Structure for Watersheds over 10 Acres.

The preliminary study design focused on a performance to cost investigation of site-specific structures. Field surveys of Austin area BMPs that ranged in age from 1 or 2 years to 25 years, revealed a deficiency in the data needed to fulfill the initial study objectives. Both the City of Austin (1997) and TxDOT (Malina et al 1997) documented BMP performance. However, because there were significant differences in site conditions, construction materials, structural design, sampling methods, and constituents sampled, no meaningful comparison was possible using actual field data.

For these reasons, the work on the cost to performance analysis portion of the study was accomplished using a prototype approach. For each BMP type included in the study, researchers developed a prototype BMP and several service scenarios, based on differences in the size of the drainage basin served by the structure.
The BMPs studied were further divided into two groups based on watershed size. This categorization recognized that some BMPs are effective for serving small drainage areas, while others are best suited to serving large watersheds. The BMPs included and the groupings are shown in Table 1. The improved grass swale used low berms for velocity reduction.

Table 1
Grouping of BMPs Based on Watershed Size

Watersheds of 1-5 Acres
Grass swale
Improved grass swale
Porous pavement
Infiltration trench
Watersheds of 10 acres and greater
Infiltration basin
Extended detention basin (lined)
Sand filter
Wet pond

Prototype Development

Prototype development for the BMPs serving 10 or more acres began with the simple infiltration basin. The infiltration basin is considered the simplest because it requires the least structural improvements to the site. The primary difference between the infiltration basin and the detention basin was the addition of a clay liner. The liner is necessary to protect groundwater resources that could be polluted by infiltration from the detention structure. The basic prototype basin used is shown in Figure 1.

The prototype for each of the large BMPs was developed for a watershed size of 10, 20, 30, 40, and 50 acres. As the size of the basin was increased, the size and cost of the inlet, outfall, spillway, containment structure, and size of site were taken into account. In addition to the design and construction costs, annual maintenance costs were developed. For the purpose of comparison, a service life of 20 years was used. Maintenance costs included normal maintenance and any major renovation that would be required over the 20-year service life.

The spreadsheet used for calculating the design, construction and maintenance costs for an extended detention basin is shown in Table 2. The size of the wet pond type structures was considerably larger than the other three types because of the permanent pool. Based on Schueler (Schueler 1987) and Young et al (1995) a permanent pool size of 1.5 times the volume of the water quality volume was used.

The maintenance costs for a detention basin are relatively low compared to a sand filter or wet pond because access is relatively simple and no major renovation is necessary over the operational life of the structure. It was estimated that sand filters would require one major renovation over the 20-year service life.

Land costs were considered as a separate item and not lumped in with the costs for analysis. The reason for this is price variability and availability of land. Land costs for the properties investigated ranged from a low of $11,000 per acre in 1987 to a high of about $850,000 per acre in 1997.

The costs for the construction items were taken from TxDOT's cost tracking system using the statewide bid price averages for the year 2000. Maintenance costs were based on interviews and time estimates taken from the Stormwater BMP maintenance crew at TxDOT's Austin South Area Office and from the City of Austin's manager of stormwater maintenance.

<u>Performance Data</u>

Literature

Establishing BMP performance data was difficult. In reviewing the literature it became clear that there was no consistency in the data reported for the Austin area or for the rest of the country. Much of the performance data found in the literature dates back to 1986 and Thomas Schueler's landmark work with the Metropolitan Washington Council of Governments (Schueler 1987). The Federal Highway Administration (FHWA) published an important study in 1996 that focused on BMPs related specifically to highway and transportation applications (Young et al 1995). Young's work made a significant contribution to stormwater quality research by bringing together more technical and performance material, which added to Schueler's work. There were also significant studies performed by City of Austin (1997) and several others by Malina et al (1997), and Barrett et al (1995) in the Austin, Texas, area.

Table 2
Spreadsheet Used to Calculate Construction and Maintenance Costs

Detention Basins 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		7000	$14,000	11340	$22,680	15300	$30,600	19500	$39,000	23100	$46,200
Embankment	CY	$16		478	$7,648	840	$13,440	1560	$24,960	1986	$31,776	2311	$36,976
Stone Riprap, Inlet	CY	$80		2.5	$200	2.8	$224	3	$240	4	$320	7	$560
Stone Riprap, Flume	CY	$80		2.5	$200	2.8	$224	3	$240	4	$320	7	$560
Stone Riprap, Spillway	CY	$80		3	$240	4	$320	4	$320	6	$480	10	$800
Concrete Riprap Spillway	CY	$98		2.4	$235	3	$294	3	$294	8	$784	5	$490
Concrete Riprap, Flume	CY	$98		3	$294	4	$392	4	$392	4	$392	7	$686
Stone Riprap pre treat outfall	CY	$80		2.5	$200	2.8	$224	3	$240	4	$320	7	$560
Stone Riprap Outfall	CY	$80		2.5	$200	2.8	$224	3	$240	4	$320	7	$560
Soil Stabilization	SY	$90		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		3	$3,720		$0		$0		$0		$0
End Wall 4'	EA	$1,430			$0	3	$4,290		$0		$0		$0
End Wall 5'	EA	$1,940			$0		$0	3	$5,820	3	$5,820		$0
End Wall 6'	EA	$2,200			$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		10	$560		$0		$0		$0		$0
Stand Pipe 36" RCP	LF	$80			$0	10	$800	10	$800		$0		$0
Stand Pipe 48" RCP	LF	$175			$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		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			$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		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	4	1.44	$213	2.34	$346	3.16	$468	4.01	$593	4.75	$703
Trash and Cleaning	AC	$36	4	1.44	$207	2.34	$337	3.16	$455	4.01	$577	4.75	$684
Inspection	MH	$20	20		$400	20	$400	20	$400	20	$400	20	$400
Silt Removal	AC	$500	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**

The review of the BMP performance literature indicated marked differences in performance values depending on the data collected, how samples were gathered, structure and watershed size relationships, and a variety of other factors. Due to the variability in the data and the need to have a better understanding of how various BMPs perform, in 1999, the Environmental Protection Agency (EPA) funded the American Society of Civil Engineers' (ASCE) effort to develop a National Pollutant Removal Performance Database for Stormwater Treatment Practices (Winer 2000). This effort places rigorous standards on how data are collected, analyzed, and reported. The second edition of performance data from this study was published in August 2000.

ASCE/EPA applies high standards to research results submitted to the data set, so this database contains a limited number of cases. Currently, these data do little to reduce the wide variability of performance values found in the literature.

Field Data Collected

An effort was also made to collect some performance data as part of the TxDOT project. The objective was to try to make some side-by-side comparisons of the performance of sand filter type structures of significantly different age and design.

Some data collected by the City of Austin early in the research suggested that the performance of some of the more expensive filter type structures did not return to initial performance after renovation. It was thought that this might further the argument for simpler, less expensive structures.

A total of seven older City of Austin structures and three of TxDOT's newer, complex sand filters were monitored. In addition to the 10 structures monitored, four roadside sites were monitored in an effort to look at the buffering effect of the vegetated shoulder of the roadside. All of the structures were located in an area of about 6 square miles, and the rainfall characteristics for the events monitored were generally uniform over the entire watershed area. The pollutants monitored were:

- total suspended solids (TSS),
- total Kjeldahl nitrogen,
- total phosphorous,
- lead,
- zinc, and
- oil and grease.

Sampling began in January and was scheduled to continue through August 2000. Over the course of the monitoring period, there were only nine significant rainfall events, and due to a combination of vandalism, wild animals, and circumstances, some sites produced as few as three usable samples. Samples were collected using a simple gravity sampler that collected runoff from the flow present until the sampler was full. Float valves sealed off the samples. Samples were collected and processed within 36 hours of the rainfall event. At each structure, samples were collected at both the influent and effluent points.

The data generated in the field portion of the study was inconclusive. There was no evidence that the older, simpler design structures were outperforming the TxDOT high cost structures. In fact, it was quite the opposite. The performance of the TxDOT structures appeared to be far more consistent than the City of Austin structures. It is believed this can be attributed to TxDOT's consistent maintenance and oversight of their structures.

Overall, the data trended to the national norms with similar variations between best and worst performance. It was also concluded that a significant part of the variability observed was due to the inconsistent performance and ability to control the collection of samples. However, the variability not withstanding, the fact remains that the more sophisticated structures do seem to outperform the simpler, less expensive version of the sand filter.

Performance Values Used for Cost to Performance Comparison

Given the inconclusive nature of the field data collected, and the fact that the objective was to look at a full range of potentially lower cost BMPs, it was necessary to utilize the best materials that were available in the literature. Since Barrett and Malina (1995) had just completed some monitoring for TxDOT two years prior to this study, we compared their results with values published in the ASCE/EPA database, information from Young et al (1995) and other EPA documents.

While the findings of Barrett et al (1995) were rigorous and well documented, they appeared more optimistic than other values in the literature. Therefore, this study developed more conservative performance values, which reflected a broader view of the literature. These performance values are shown in Table 3. Both Schueler (1986) and Young (1995) used the 1 inch sizing rule for infiltration basins. Young (1995) used a 36 hour detention time for the detention basin.

Table 3
TSS Removal for Selected BMPs by Literature Source

BMP	Schueler (MWCOG) 1986	Young (FHWA) 1995	Malina (TxDOT) 1997	Strassler (EPA) 1999	Winer (ASCE/EPA) 2000	Value Used for Index
Sand Filter (w/ pretreatment)			98	50 - 80	87	**80**
Infiltration Basin	90	90		50 - 80		**80**
Detention Basin	65	82	89	30 - 65	61	**65**
Wet Pond	54	32 - 91			80	**75**
Grass Swale		60	51 - 75	30 - 65	68	**60**
Water Quality Swale		83			74	**70**
Porous Pavement	82 - 95	82 - 95		65 - 100	95	**80**
Infiltration Trench	99	99		50 - 80	100	**90**

Indices

For the purpose of this paper, two indices were used. First, TSS was used as the primary index pollutant. This is because TNRCC and some other agencies target TSS as the means of establishing performance thresholds. Using TSS is based on the fact that many of the metals and some nutrients will adsorb to the solid particles and settle out with the solid materials. This appears to be a valid assumption so long as the particle size is sufficiently large. It is probably a bad assumption in regions with clayey soils.

As a second means of indexing pollutants, a composite index was developed using five index constituents. Removal of all the index pollutants would result in a score of 1, with the worst performance indicated by 0, based on the percent of each pollutant removed. The pollutant removal rates used for each of the BMPs and the scores are shown in Table 4.

Table 4
Removal Rates for Five Index Pollutants by BMP (Percent)

BMP	TN	TP	Pb	Zn	TSS	Score
Large Watershed BMPs						
Extended Detention Pond	45	30	90	50	90	.61
Wet Pond	35	55	65	65	80	.50
Infiltration Pond	80	65	90	90	85	.82
Sand Filter	32	45	71	69	80	.59
Small Watershed BMPs						
Grass Swale	10	15	50	45	60	.36
Water Quality Swale	15	15	55	50	75	.42
Porous Pavement	65	30	65	60	65	.57
Infiltration Trench	75	55	20	50	50	.50

Comparisons

Annual Cost to Performance by Watershed Size Using TSS

Figures 2-5 summarize the results of comparing the cost per pound of TSS removed in relation to the watershed size by structural type. The pollutant loadings were based on Young et al (1995), whose values seem to be consistent with Barrett et al (1995), Strassler et al(1999), and others.

Based on field inventories of numerous structures and the implications in the literature, researchers further divided the structures into three groups according to the type of construction. A wide variety of material combinations were observed, but the primary characteristic that differentiated between structural types was the amount of concrete used in the structure. In the field work, examples were found of all earthen construction; partial earthen construction, where a concrete weir might be used instead of an earthen dam to save space; and other structures that were all concrete, including the bottoms of the chambers. Figure 6 shows the four different examples.

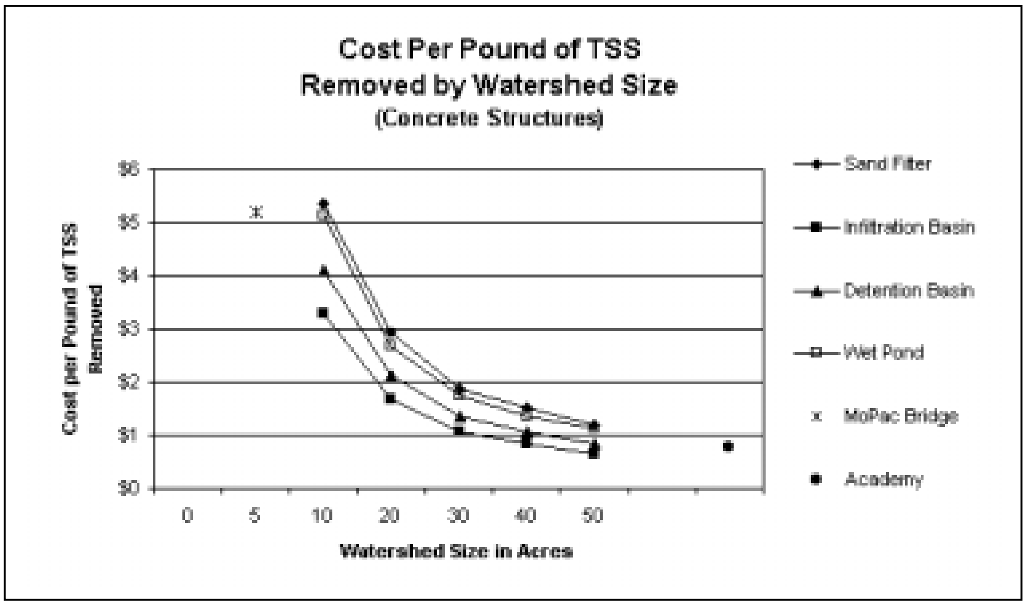

Fig. 2. All Concrete Structures: Cost to Performance by Watershed Size

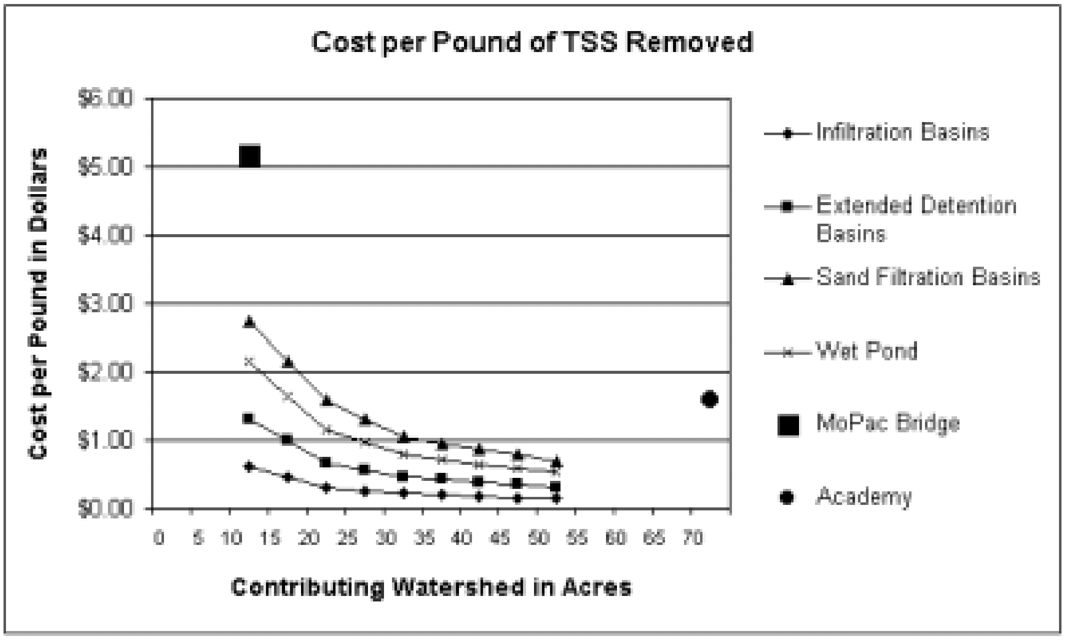

Fig. 3. All Earthen Structures: Cost to Performance by Watershed Size.

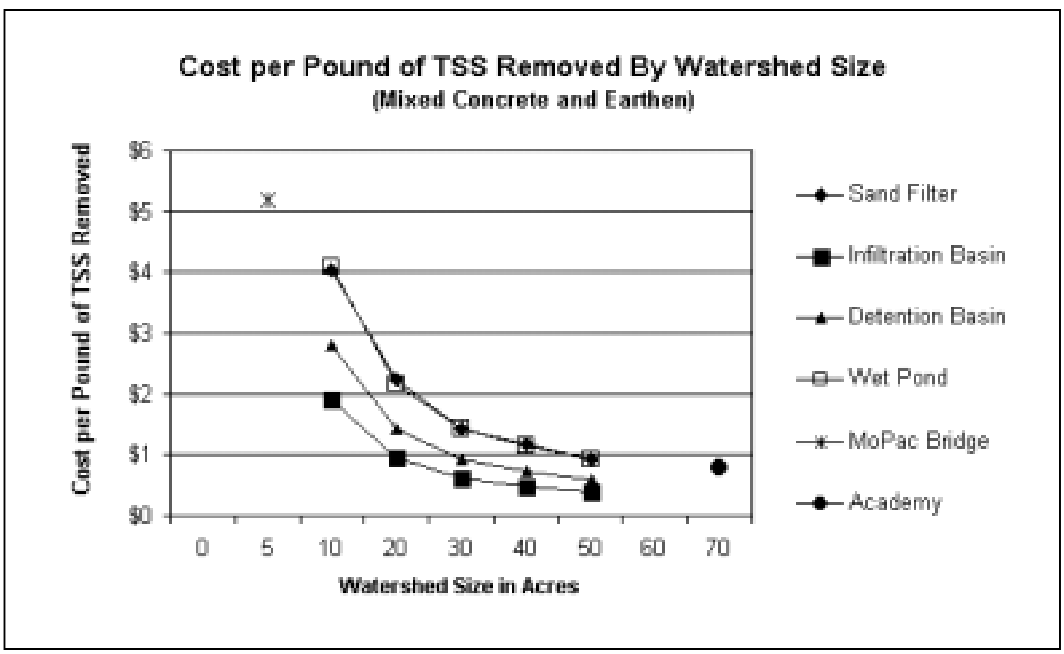

Fig. 4. Mixed Construction BMPs: Cost to Performance by Watershed

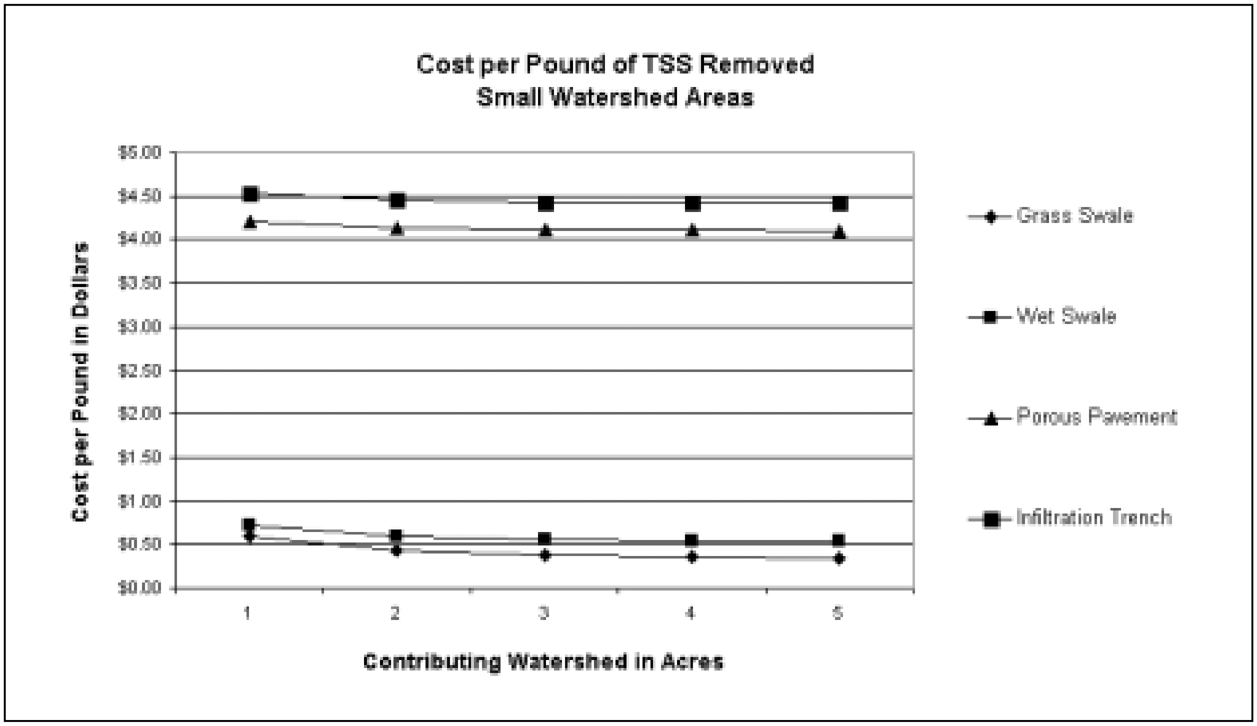

Fig. 5. Small Watershed BMPs Cost to Performance by Watershed Size.

Fig. 6. Examples of BMP Construction Materials Combinations

The cost per pound of TSS removed ranges from $5.28 per pound for a entirely concrete sand filter serving a watershed of 10 acres to a low of $0.28 per pound for an all earthen infiltration structure serving a watershed of 50 acres or more. Clearly there are economies of scale for the all-concrete structures, all-earthen structures and mixed construction structures, which suggests that watersheds in the range of 25 to 30 acres will be the most cost-effective regardless of the construction type.

In addition to the cost per pound of TSS removed, the graphs in Figures 2, 3, and 4 show two other reference points. These data represent actual field data for two sand filter structures located approximately one half mile apart. The MoPac Bridge site is an all concrete structure that serves a watershed area of approximately 7.5 acres and the Academy structure, the lower right hand corner of Figure 6, is all concrete and serves a watershed area of around 72 acres. This suggests that the size relationships are reasonably consistent for at least the concrete structures.

For small watersheds (figure 5) there is much less impact on cost and performance related to the size of the drainage area. This is primarily attributed to the direct correlation between space and materials and the volume of runoff processed by these types of BMP. The least expensive option is the simple grass swale, followed by the improved water quality swale and biofiltration/bioretention type BMPs. Porous pavements and infiltration trenches have costs per pound of TSS removed similar to sand filters and wet ponds.

Annual Cost to Performance by Watershed Size Using Index of Five Pollutants

Using the index pollutant performance values developed from the literature sources shown in Table 3, the performance to cost index was developed and plotted for each group of BMPs in relation to the watershed size served. Figure 7 shows the results for the large watershed BMPs and Figure 8 shows the results for the small watershed BMPs.

The results shown for the large watershed BMPs are for earthen structures. The shape of the curves is constant, where only the index numbers change. The performance cost index values for concrete sand filters was 0.003 for 10 acres to 0.0009 for watersheds of 50 acres and greater.

The Impact of Land Costs on BMP Cost Effectiveness

Land costs have a significant impact on surface BMP structures in direct proportion to the land area required. Because of this, land costs become a primary consideration in BMP selection, even though they have little to do with the utility of a particular BMP. In addition, the land that may be available often has topographic constraints that further complicate the land cost issues. For example, land with steep slopes leads to wide variation in basin depths or requires extensive grading to develop the structure. Steep slopes also complicate the use of earthen containments. Finally, in ultra-urban areas land is simply not available. In these situations the higher cost, small footprint type BMPs offer the only reasonable alternative. This is a particularly difficult situation on projects that may require retrofitting to meet water quality goals.

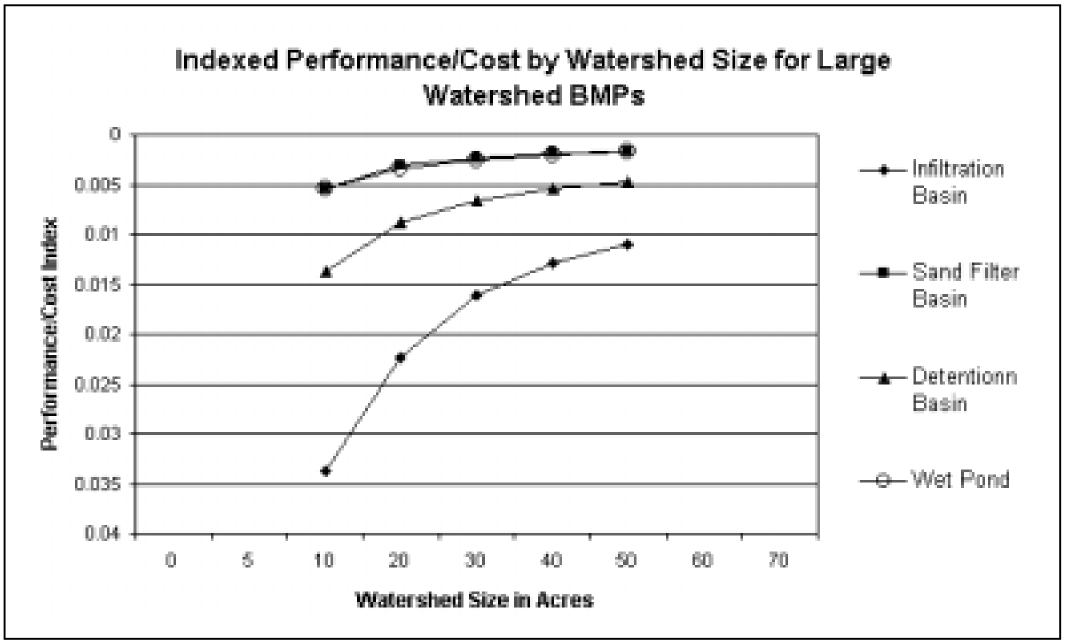

Fig. 7. Performance to Cost Index for Large Watershed BMPs.

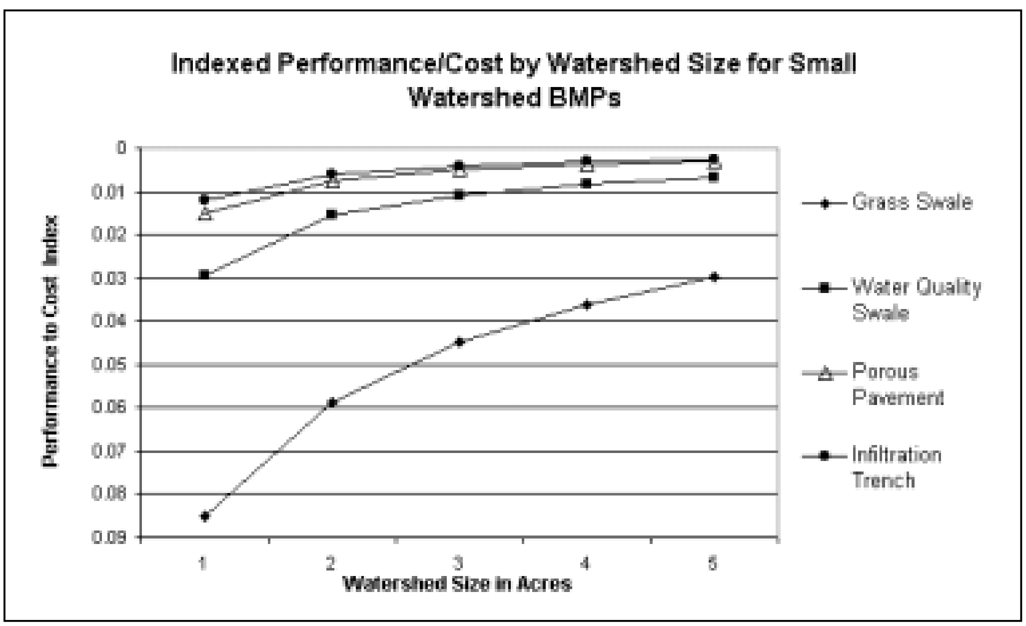

Fig. 8. Performance to Cost Index for Small Watershed BMPs.

Figure 9 plots the cost per pound of TSS removed for two land-cost conditions. The rural situation assumes a right-of-way (ROW) cost of $10,000 per acre for land and the urban land cost is set at $250,000. The cost performance increases significantly. In the case of land costs at the high end of the scale, exploration of underground, small footprint devices becomes a more cost-effective option for stormwater treatment. For small watersheds, the use of onsite controls and some of the available proprietary technologies with small footprints need to be explored.

Other Key Factors that Modify Performance/Cost as a Measure of Cost-effectiveness

Runoff Constituents

Ultimately, cost-effectiveness involves several other considerations. First, the index pollutants used in this analysis, while common to highway runoff, may not be the only considerations. Hydrocarbons, floatables and differing concentrations of constituents may require additional components or make other options more attractive to meet the water quality goal.

Maintaining Suitable Detention Times

Infiltration and detention structures must retain water for extended periods in order to be effective. In regions with a high probability of recurring rainfall events within a 48 hour period, the effectiveness of these structures would be reduced significantly due to bypass events. Standing water may also be a nuisance factor or even a hazard that further reduces the attractiveness and ultimately the cost-effectiveness of the infiltration and extended detention options.

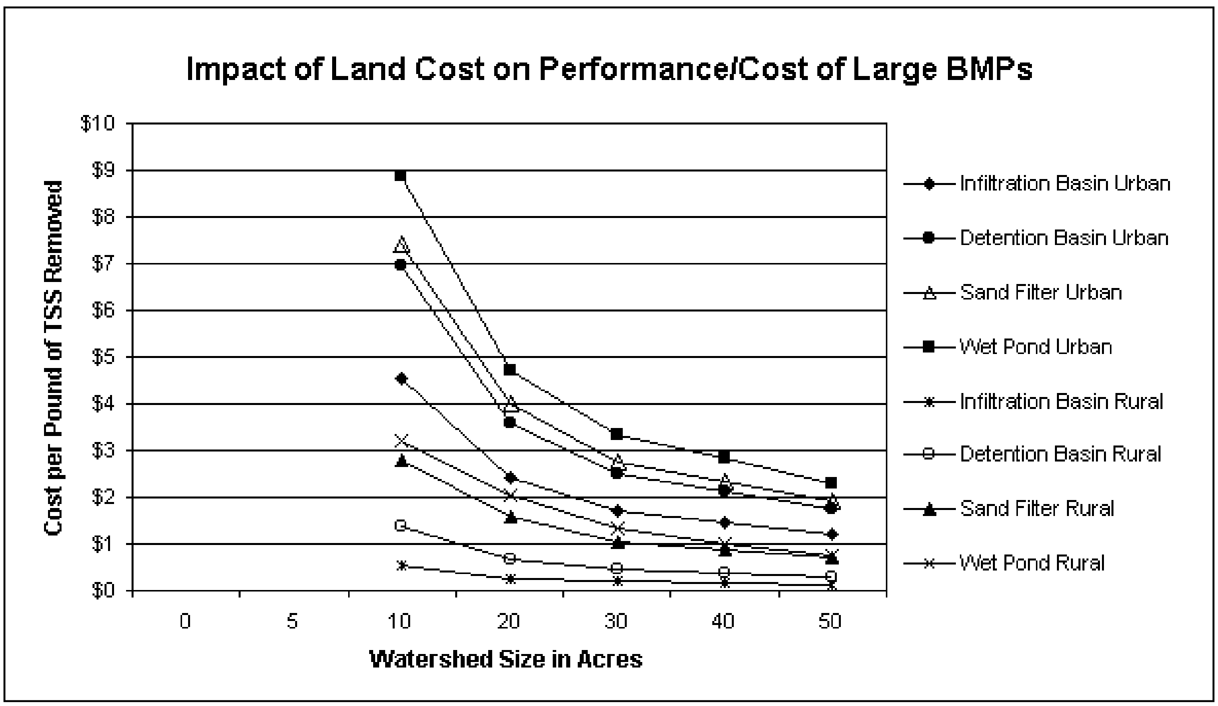

Fig. 9. Impact of Land Cost on Cost per Pound of TSS Removed, Large Watershed BMPs.

Space Requirement and Aesthetic Considerations

All surface type BMPs, infiltration, detention, wet ponds, wetlands, grass swales, filter belts, and the like are space intensive. They require significant land resources. Depending on the surrounding land use, significant site and aesthetic improvements may be needed just to integrate the facility into the neighborhood. Long-term maintenance of these site improvements can significantly increase operating costs over the life of the structure.

Topographic Constraints

Costs for construction and maintenance can escalate rapidly in flat or difficult terrain. Steep topography complicates the construction of basin-type BMPs while flat terrain often does not have sufficient slope to allow efficient gravity operation of a structure.

Land Cost and Availability

As illustrated in the earlier discussion, land cost and availability is probably the single most confounding variable in determining the most cost-effective BMP for a project. In ultra-urban settings land simply may not be available. In other situations, the cost of the land may be so high that the use of a small footprint underground structure proves the most effective solution.

Conclusions

Performance/Cost as a Measure of Cost-effectiveness

There is no easy answer as to which BMP will be most cost-effective. If one looks only at the pollutant removal effectiveness of the available stormwater BMPs, the literature makes a stronger and stronger case for the use of extended detention facilities where groundwater pollution may be a hazard. A detention structure can be sealed, preventing pollutants trapped from leaching into the groundwater, and where residence times of 48 hours or greater are possible, pollutant removal efficiencies are good for solids, nutrients and metals.

If infiltration poses no threat to groundwater resources, infiltration appears to be the most cost-effective option. Strassler et al (1999) and Young et al (1995) both reported very high values for removal of all types of pollutants especially phosphorous and nitrogen. Winer (2000) on the other hand, does not report any performance data for infiltration practices other than trenches and porous pavements. The numbers for these practices appear to be in-line with those reported in Young (1995) and Strassler (1999) for larger infiltration structures. No single index can be used because of the radical impact of land availability, topography and cost.

It is tempting to apply a measure such as the cost per pound of pollutant removed to judge whether the cost of a BMP provides a reasonable benefit. However, the impact of factors external to the ultimate cost of a single structure are so varied that no simple answer is possible. On the other hand, some basic conclusions are possible.

1. When land is available for surface-type BMPs, maximizing the size of the watershed served will increase performance/cost relationships.
2. Construction costs will be lowest when berms, weirs, and outfalls are of earthen construction.
3. In the case of highways and transportation facilities, grass swales, vegetated borrow ditches, and shoulders should be maintained and improved to the extent possible. These sometimes ignored parts of the right-of-way represent a significant, existing water quality benefit.

Biographical Sketch: Dr. Harlow Landphair is a Research Scientist with the Texas Transportation Institute (TTI), and Professor in the Department of Landscape Architecture and Urban Planning, College of Architecture, Texas A&M University. He earned a Doctor of Environmental Design degree from Texas A&M University in 1977 with an emphasis on landscape construction and rehabilitation of drastically disturbed lands. He earned a Master of Extension Education degree from Mississippi State University, with a major in turf science in 1974, and a Bachelor of Landscape Architecture degree from the University of Florida, 1963. His primary research interests include: Bio-Technical Slope Stabilization, Stormwater Quality, Sediment and Erosion Control, Context Sensitive Design in Transportation and Public Works.

Dr. Landphair has extensive research experience in the area of landscape construction technology, computer applications, and visualization, in transportation design. He currently is manager of TTI's Environmental Management Program, which includes the following activities. The TTI/TxDOT Hydraulics Erosion and Sedimentation Control Laboratory that conducts research and evaluations of erosion control blankets, temporary flexible channel lining materials and hydraulic mulches and The Pedestrian Simulation Laboratory which conducts research in pedestrian behavior and response related to transportation facility planning design and operation.

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EFFECTIVENESS OF STORMWATER BEST MANAGEMENT PRACTICES ALONG THE SOUTHEAST EXPRESSWAY, BOSTON, MASSACHUSETTS

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Abstract: Suspended particulate matter transported from roadway surfaces represents one of the most substantial sources of non-point source pollution in highway runoff. In addition to increasing turbidity and depositional loading, suspended sediment can retain and transport other pollutants to receiving water bodies. Roadway suspended solid loads may be reduced by using Best Management Practices (BMPs) for stormwater. Non-structural BMPs involve the removal of particulate matter from roadway surfaces prior to runoff transport (e.g., street sweeping), whereas various structural BMPs involve end-of-pipe devices that remove suspended solids prior to discharge to receiving waters. Two types of structural BMPs, a deep-sumped hooded catch basin and three 1500-gallon offline water quality inlets (WQIs), were investigated to assess their effectiveness in reducing highway contaminant concentrations along the Southeast Expressway in Boston, Massachusetts. Automatic monitoring techniques were used to characterize the temporal and spatial variability in suspended sediment transport through each structural BMP. The effectiveness of each BMP in reducing suspended sediment loads was assessed using a mass balance approach. The suspended sediment removal efficiency for the catch basin and two 1500-gallon WQIs was 39, 35, and 28 percent, respectively. The particle size distribution of the suspended sediment entering the structural BMPs indicated more than half of the suspended sediment in highway runoff was material less than .062 millimeters (mm) in diameter (sand/silt break). However, particle-size analysis of retained bottom sediment from three WQIs at the conclusion of the study indicated that an average of 74 percent of retained sediment particles were greater than .062 mm in diameter. About 92 percent of the material found in the deep-sumped hooded catch basins was comprised of these larger particles. The primary factor controlling the suspended sediment removal efficiency of each structural BMP was residence time. For example, the average removal efficiency of the WQIs during storms with rainfall depths less than 0.2 inches was 43 percent. This increased efficiency was a function of residence time rather than from "active" stormwater treatment. Flows from small storms simply displaced previously collected stormwater in which the suspended sediments had time to settle during the static antecedent period. The capture efficiency of suspended sediment was further reduced by re-suspension of fine-grained sediments within the WQIs, as well as from high flows bypassing the WQIs. Re-suspension also occurred within the catch basin. Moreover, collection of floatable debris at the outlet of a WQI suggests that floatable debris also was not indefinitely retained by either structural BMP. Due to the exorbitant costs of more frequent clean-up efforts (e.g., street sweeping, and clean-out of catch basins and WQIs) or more WQIs along the Southeast Expressway, source control measures are the most practicable means of reducing Suspended Sediment Concentration (SSC) loading from the highway. Future research includes developing a model that estimates contaminant loading from highway runoff, and evaluating conventional as well as innovative WQIs with real-time, flow-weighted sampling to assess whether their performance justifies their widespread use, especially along roadways.

Introduction

Suspended particulate matter transported from roadway surfaces represents one of the most substantial sources of non-point source pollution in highway runoff (Young and others 1996). In addition to increasing turbidity and depositional loading, suspended sediment can retain and transport other pollutants to receiving water bodies.

A common Best Management Practice (BMP) used by state highway agencies to reduce the impacts of stormwater runoff is to divert runoff collected from highway surfaces to detention basins or water quality swales where suspended sediments are captured and allowed to settle out. However, where highways cross through urbanized areas, the necessary space for such structural BMPs is seldom available. As a consequence, industry has created various types of structural BMPs, commonly called water quality inlets that can be installed underground and integrated within the existing drainage system. These devices are generally set off-line, contain two or three serial chambers designed to settle grit, and in theory capture oil and grease. The effectiveness of these BMPs is limited by the site-specific particle size distribution and quantity of the source material.

The U.S. Geological Survey, in cooperation with the Massachusetts Highway Department (MassHighway), began a study in November 1998 to determine the effectiveness of current BMPs in reducing suspended solid loads along the Southeast Expressway (Interstate Route 93) in Boston, Massachusetts. The Southeast Expressway, typical of heavily used highways within urban and industrialized areas, runs through the coastal zone watershed of Dorchester Bay in South Boston. During 1994, in an effort to remove contaminants from the highway runoff, five offline WQIs were integrated into the drainage system of the Expressway which runs adjacent to Dorchester Bay, as well as to two public beaches: Malibu and Tenean.

The BMPs examined in this study include a single, deep-sumped, hooded catch basin and three 1500-gallon offline WQIs. The effectiveness of each structural BMP was estimated by monitoring the water quality and quantity of stormwater at the inlet and the outlet of each device. At the end of the monitoring period, each device was drained and the captured material was measured and quantified. The monitoring results provide State and municipal highway planners with specific information regarding the current quality and quantity of highway runoff from major urban highways and the scientific basis for future consideration and application of these BMPs. Monitoring methods developed during this study also may be useful for evaluating the effectiveness of new BMPs.

Objectives

The purpose of this report is to describe the following: effectiveness of each structural BMP along the Southeast Expressway in reducing SSC loads and debris loads; document the monitoring methods used to evaluate each BMP; and estimate SSC loads from the highway within the Study area.

Study Area

The study area includes about 2 miles of the Southeast Expressway from the Neponset River to Savin Hill in South Boston (see figure 1). The highway section (including ramps) within the study area represents about .06 percent (34.6 acres) of the total watershed (approximately 58,000 acres) of Dorchester Bay.

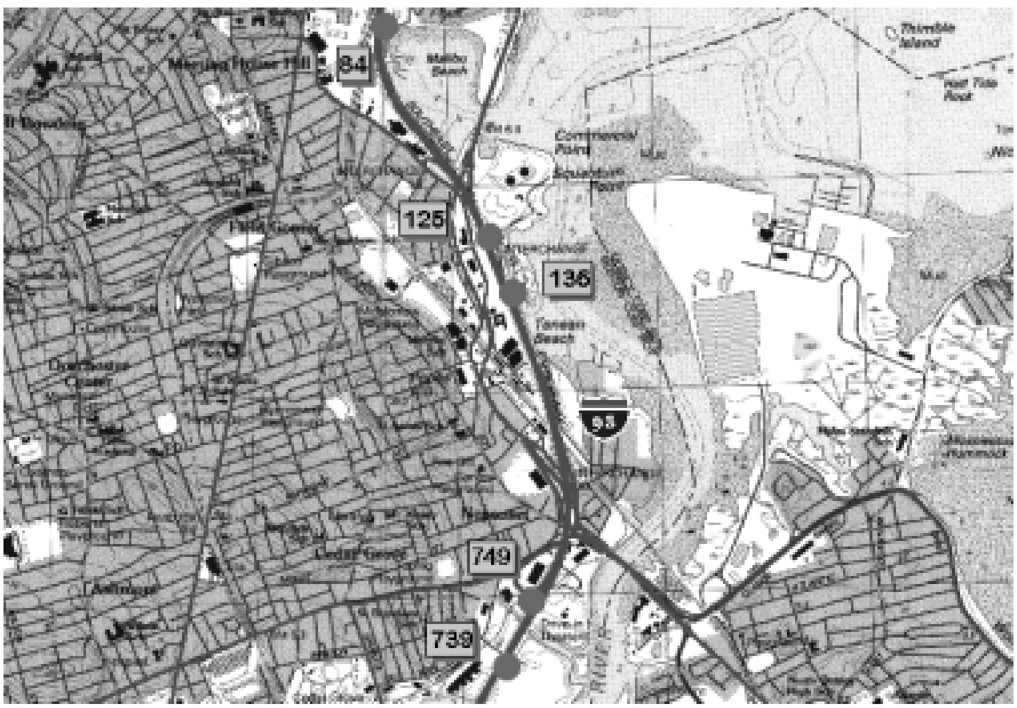

Fig. 1. Map of study area

Primary treatment for highway stormwater runoff was provided by 209 catch basins containing hinged cast-iron hoods over the outlet, 184 had 4-ft deep sumps (i.e., "grit" storage below the outlet pipe), and the remaining 25 had 3-ft sumps. The purpose of the catch basin hoods is to retain floatable debris at the water's surface. The hoods encapsulate the entire outlet opening and extend down to about 0.5 ft below the bottom of the outlet pipe.

One three-chambered 4500-gallon offline WQI and four two-chambered 1500-gallon offline WQIs provided additional stormwater treatment. WQIs are large cast-concrete containers, sub-divided by one or more baffles, and buried beneath the land surface next to the highway. Each WQI included a bypass pipe that limited the amount of flow through the device using a diversion weir positioned near the inlet of the WQI. Although this design feature allows untreated stormwater to bypass the WQI, it theoretically prevents extreme flows from flushing (re-suspending) captured materials from the WQI. The stormwater “treatment train” of the catch basins to the WQI to the outfall pipe is depicted in figure 2.

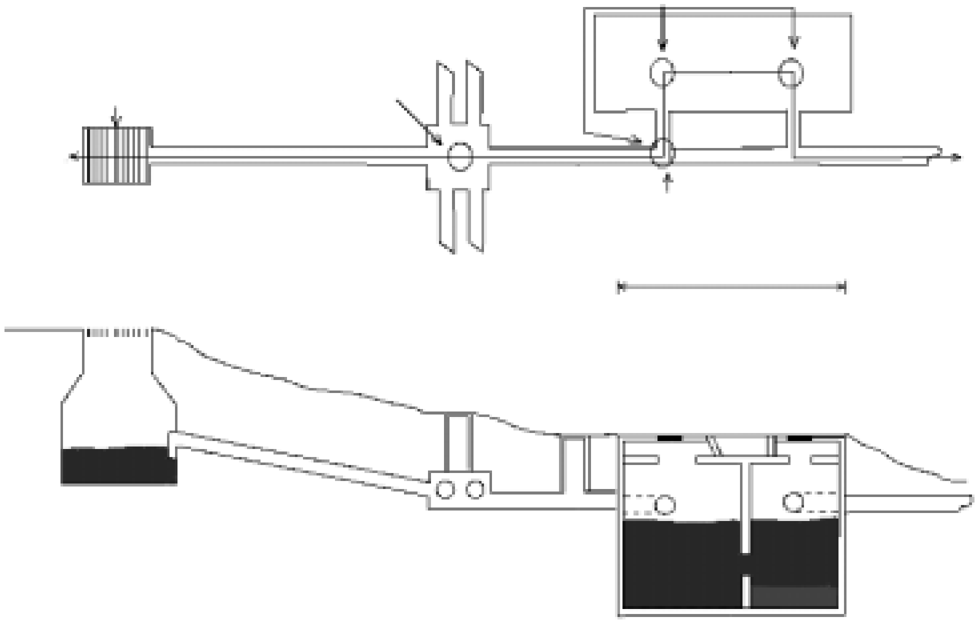

Fig. 2. Diagram of the stormwater “treatment train” of the catch basin.

Methods

Automatic monitoring techniques were used to characterize the temporal and spatial variability in suspended sediment transport through each structural BMP. Water-quality samples of Suspended Sediment Concentration (SSC) and continuous measurements of BMP water level and velocity (as well as site precipitation, site air temperature, specific conductance, and water temperature) were collected from April 1999 through June 2000 for the deep-sumped hooded catch basin and the 1500-gallon WQI at Station 136, and from August 1999 through June 2000 for the 1500-gallon WQI at Station 739 (see Figure 1 for WQI locations). These two WQIs received flow from 8 and 12 catch basins, respectively. During rainfall events highway runoff was collected flow-proportionally at the inlet and outlet of each structural BMP by automatic samplers under data logger control.

Solid phase concentration values in water may be determined by the Suspended Sediment Concentration (SSC) or the Total Suspended Solids (TSS) method. Although SSC and TSS are often used interchangeably in the literature to describe the total concentration of suspended solid-phase material, the analytical methods differ and can produce substantially different results (Bent and others 2000). The SSC method (American Society for Testing and Materials 2000) uses standardized procedures and equipment to measure all of the sediment and the net weight of the water-sediment mixture to calculate concentration, whereas the TSS method (American Public Health Association, American Water Works Association, and Water Pollution Control Federation 1995) requires analysis of a sub-sample extracted from the original sample. Contrary to the literal description, SSC include clays, silts, sands, gravels, asphalt particles and other road surface debris, and organic and synthetic materials. Although analytical uncertainties for each method are similar, errors that occur during processing of TSS samples can be large because agitation of a sample containing sand-size materials generally does not produce representative aliquots and can under-represent the true sediment concentration (Gray and others 2000). Therefore, the SSC method was chosen to measure the solid-phase concentrations to provide the most accurate assessment of BMP efficiencies. Samples were analyzed for SSC and particle size at the USGS Kentucky District Sediment Lab (Guy 1970; Sholar and Shreve 1998).

A total of 74 and 59 events produced measurable runoff during the monitoring period at Stations 136 and 739, respectively. SSC samples were collected at the inlets and outlets of the two WQIs and the catch basin during 53, 49, and 32 storms, respectively. Any lack of sampling was due to equipment malfunctions or shallow water depths from very small flows (i.e., light rainstorms). Nonetheless, the relatively high number of sampled storms has generated stormwater data with good statistical confidence.

Sampler intakes were fixed to static mixers at each sampling point with the exception of the catch basin inflow sampler, which was connected to a stormwater collection structure mounted below the trash bars of the catch basin. Sampler intakes were orientated in a horizontal and downstream direction (as depicted in figure 3). This configuration minimized debris accumulation by forming a small eddy at the intake, which envelops the sand particles and thus allows the sampler to collect a more representative sample of the coarse particle load (Edwards and Glysson 1999). The static mixer provided a secure and consistent mount for the sampler intake, reduced transport velocity, and provided agitation to produce a sample that represented the average SSC.

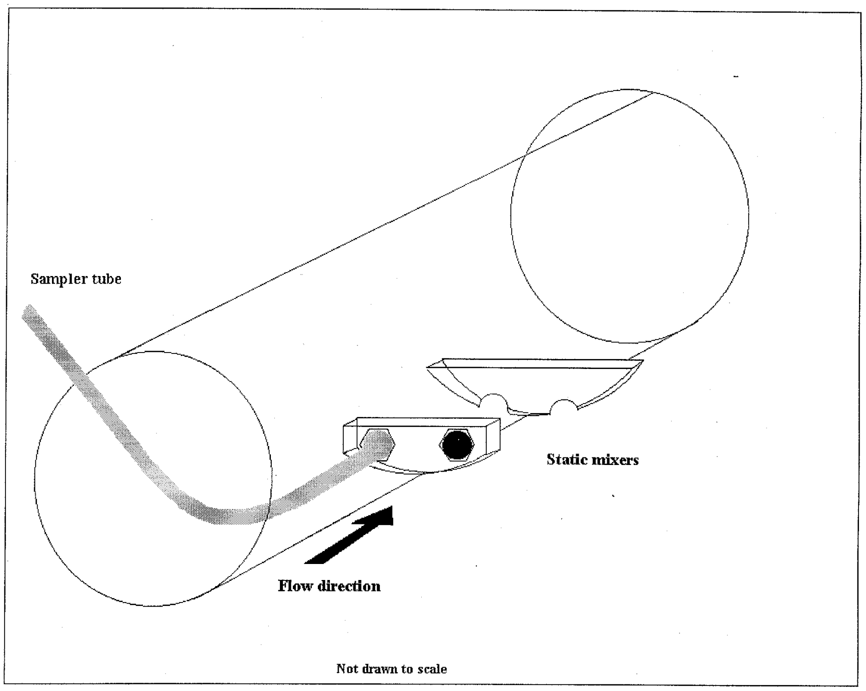

Fig. 3. Schematic diagram of a static mixer

Bottom sediment samples were collected from three WQIs (at Stations 136, 739, and 749) in November 1998, and December 1999 through January 2000. Bottom material depths were measured in each structural BMP prior to the first scheduled cleaning, during bottom material sample collection, and at the conclusion of the monitoring period. These samples were collected in the deep-sumped hooded catch basin and each chamber of the WQIs. Bottom sediment samples were wet-sieved into size classes less than .062 mm in diameter, between .062 mm and 2.00 mm in diameter, and greater than 2.00 mm in diameter.

Quality control procedures for the USGS Kentucky District Sediment Laboratory are described in Sholar and Shreve (1998). Quality control data indicated that most data were within the accumulative uncertainties of the various measurement, sampling, and analytical processes. However, the data indicated that particles greater than .062 mm in diameter were not evenly distributed throughout the water column at the inlet of the WQIs. Therefore, in order to avoid overestimating inlet loads, an adjustment equation was developed that normalized the mean SSC within the water column at the sample intake location of the WQIs.

Findings

BMP Treatment Efficiency

The overall monitoring period efficiency for the deep-sump hooded catch basin was about 39 percent. An estimated 234 Kg of solids was retained by the catch basin. There was no substantial difference between the catch basin outlet suspended sediment load, several weeks before and after annual catch basin cleaning. This finding indicated that the volumes of retained bottom material in the catch basins located within the drainage areas of Station 136 and 739 were not sufficient to substantially impact catch basin performance.

The overall monitoring period efficiency for the WQIs at Station 136 and 739 was 35 and 28 percent, respectively. The WQIs retained 477 Kg and 190 Kg of solids, respectively. In the combined treatment system in this study, where catch basins provide primary suspended sediment treatment, the WQIs reduced the initial pavement SSC by about an additional 19 percent (assuming an average catch basin efficiency of 39 percent). The efficiency computed using the measured quantity of material retained at the conclusion of the monitoring period and the total outflow load was 32 and 24 percent, respectively. The small difference between the two methods used to estimate the efficiency of the WQIs suggests that the adjustment equation used to normalize the inflow loads was reasonable. The estimated mass balance difference was within the accumulative uncertainties of the various measurement processes.

Discrete inlet suspended sediment sample concentrations for the WQIs and the deep-sumped hooded catch basin ranged from 8.5 to 7,110 mg/L and 32 and to 13,600 mg/L, respectively. Discrete outlet SSCs ranged from 5 to 2,170 mg/L and 26 to 7,030 mg/L, respectively. The median suspended sediment inlet and outlet Event Mean Concentrations (EMCs) for the WQIs at Stations 136 and 739 were estimated to be 333 and 150, and 145 and 96 mg/L, respectively. The lower suspended sediment EMCs at Station 739 was likely a function of a greater portion of the drainage perimeter being isolated from the earth shoulder resulting in less erosion onto the pavement. The median suspended sediment inlet and outlet EMCs for the deep-sumped hooded catch basin was estimated to be 280 and 195 mg/L, respectively.

Particle Size Distribution

During this study, the structural BMPs only were able to capture relatively coarse-grained particles. For example, more than 90 percent of the particles in typical WQI outlet samples were less than .062 mm in diameter. However, the particle size distribution of bottom sediments varied substantially between the deep-sumped hooded catch basin and three offline WQIs (see figure 4). Bottom sediments in the catch basin were coarse-grained (using weighted averages, about 83 and 92 percent was greater than 0.25 and .062 mm in diameter, respectively), whereas the sediment in WQIs was generally finer-grained (about 50 and 85 percent was greater than 0.25 and .062 mm, respectively). The primary chamber of the WQIs contained higher concentrations of coarse material (about 89 percent was greater than .062 mm), while finer and less dense particles were found in the second chamber (about 60 percent was greater than .062 mm), which suggests that particles in the smaller size range located in chamber one were re-suspended during flow events. However, it is unlikely that particles less than .062 mm in diameter were deposited during flowing conditions because it can take an hour to several days for particles in this size class to settle under static conditions. Thus, the occurrence of bottom material in this particle range was likely a result of static particle settling that occurred subsequent to each storm.

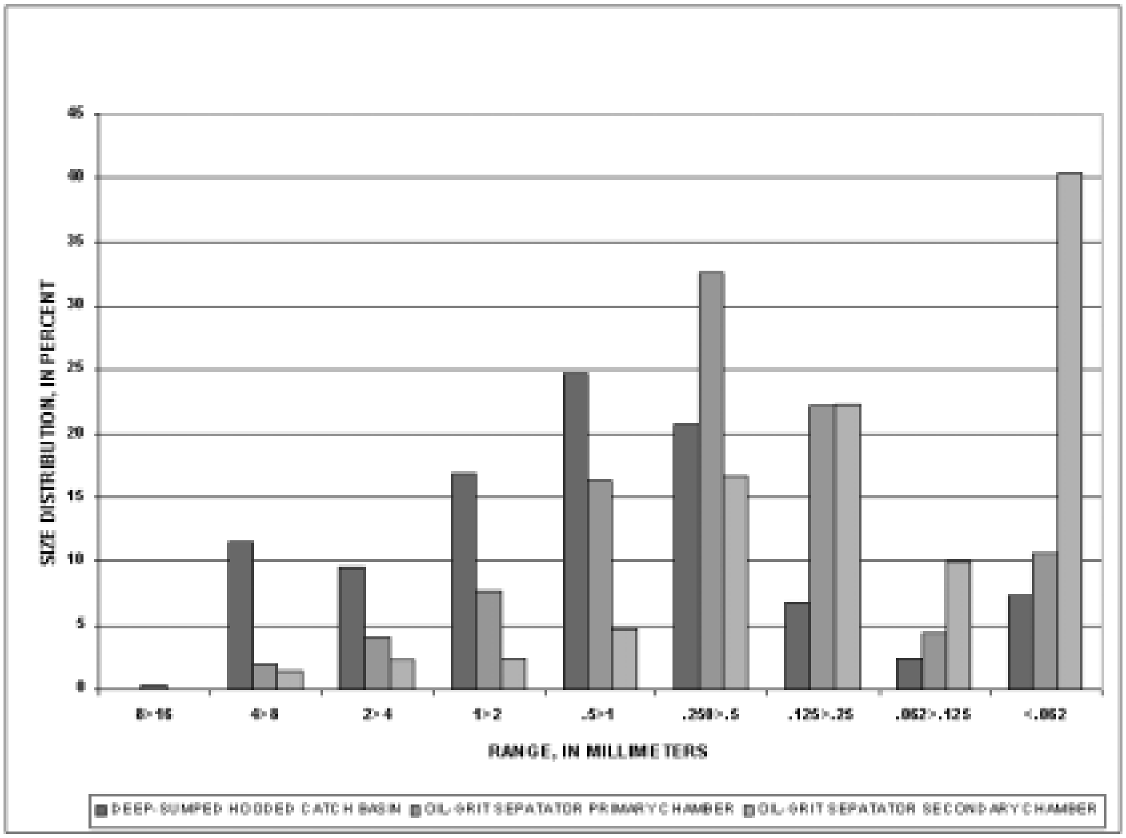

Fig. 4. Weighted average particle size distribution of bottom sediment

Figure 5 depicts the median (and variability) ranges of the suspended sediment fraction greater than .062 mm in diameter, from the inlet and outlet samples of each structural BMP. Based on 17 samples taken during six storms, generally 80 percent of the suspended sediment in highway runoff (i.e., catch basin inlet flow) consisted of material less than .062 mm. This is consistent with the findings of other studies. Yousef and others (1991) reported 70 to 80 percent of the particles in highway runoff were less than .088 mm in diameter. Prych and Ebbert (1986) noted most of the suspended material was less than .062 mm in diameter for many urban runoff conditions.

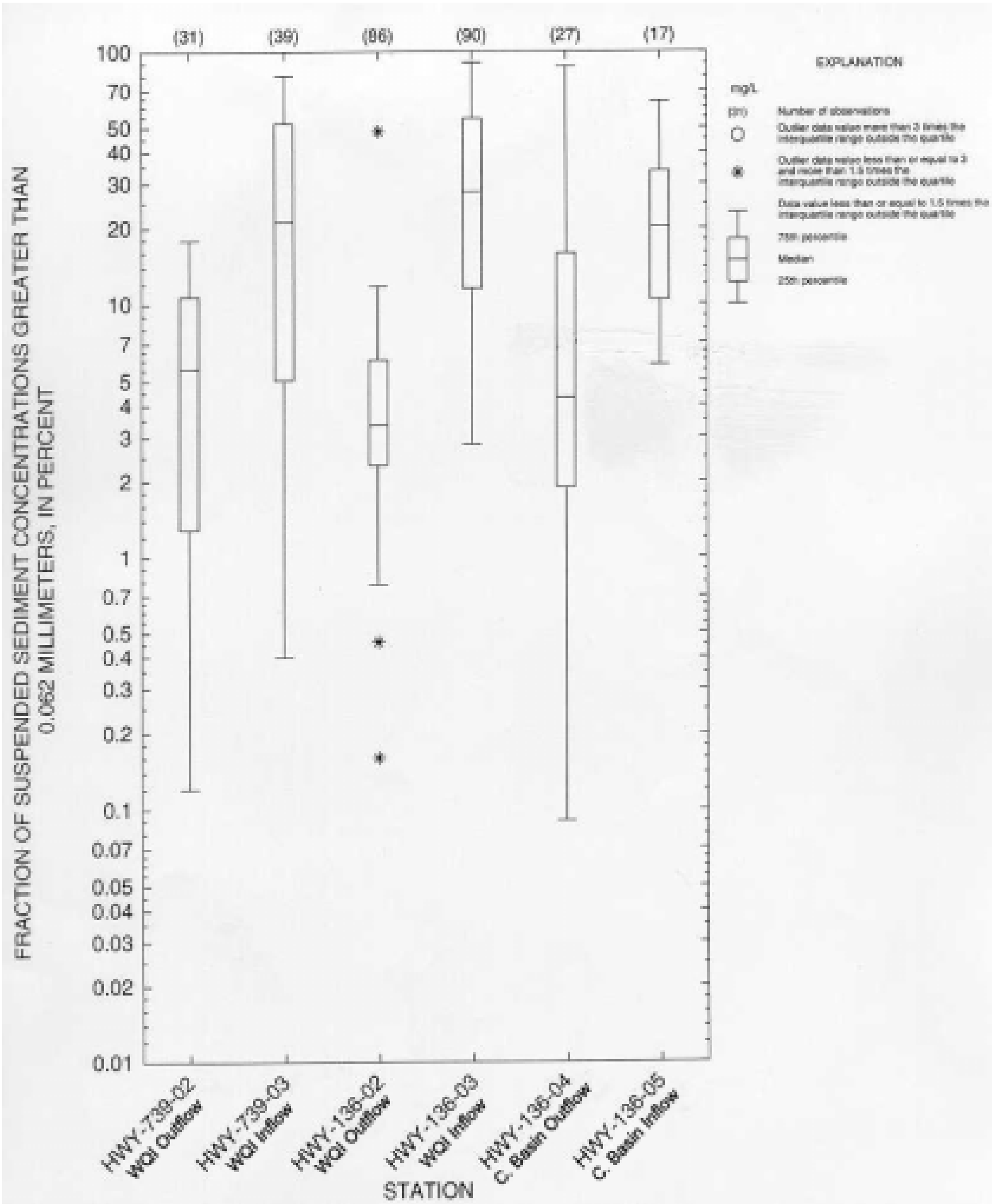

Fig. 5. Particle size distribution of suspended sediment samples

In this combined system, the deep-sumped hooded catch basin and offline WQI efficiencies were inversely related. Catch basin SSC removal efficiency decreased with an increase in discharge (i.e., flow) resulting from a decreased settling time. Conversely, the WQI performance improved with an increase in discharge despite a decrease in residence time. This was due, in part, to a change in the particle size distribution during periods of greater flows. During low flow, larger particulate matter settled in the catch basins while the finer material exited to the WQI. While the 1500-gallon WQI volume was greater than that of a single catch basin, the combined flow from multiple catch basins discharged to each WQI thereby reducing the settling time and inhibiting the capture of fine material. However, as flow increased, roadway suspended sediment and particle size tended to increase as coarse material was discharged from the catch basin, subsequently increasing the WQI performance.

Residence Time

The primary factor controlling the suspended sediment removal efficiency of each structural BMP was residence time. Intense flows also affected the efficiency, but to a lesser extent. The ability of the WQIs to reduce suspended sediment, characteristic of what is found along the Southeast Expressway was limited because the average particle size was less than .062 mm in diameter and the average structural BMP residence time ranged from about one hour to less than a minute. Although the 1500-gallon WQI volume was greater than that of a single catch basin sump (approximately 67 gallons), combined flows from multiple catch basins fed each WQI increasing flow and reducing settling time thereby inhibiting capture of fine material. This point is illustrated in Figure 6. Since settling velocities for urban and highway sediments can range from .03 to 65 feet per hour (Dorman and others 1996), then fine sediment particles require several days under static conditions to completely settle out.

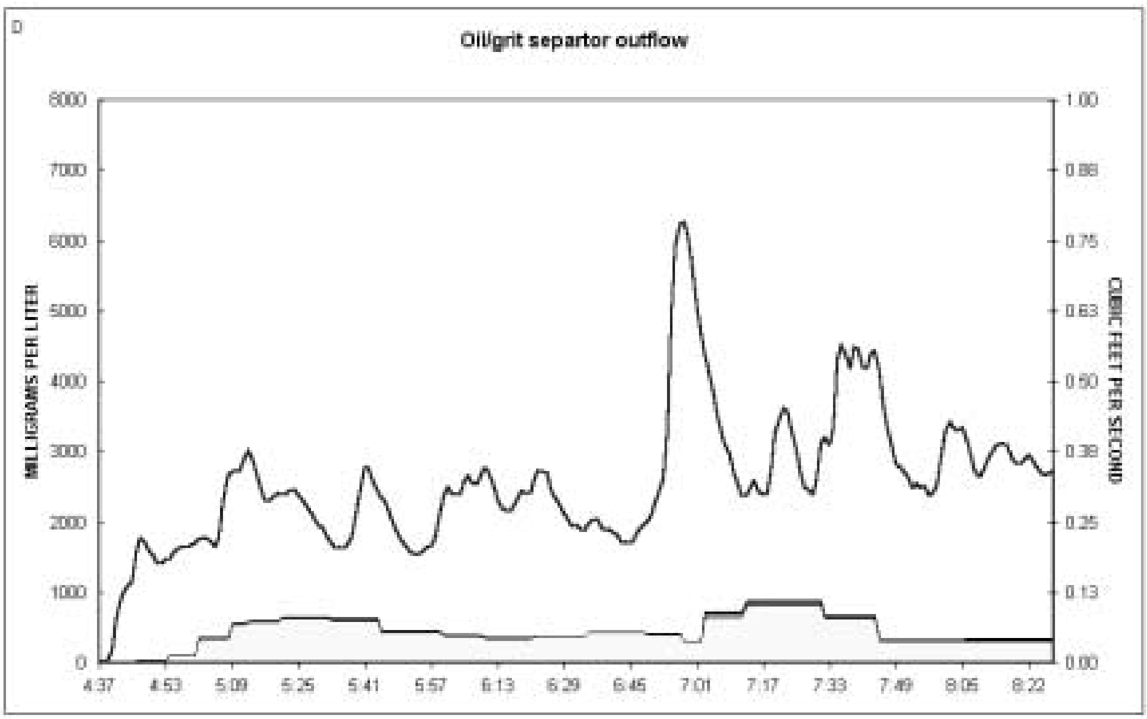

Fig. 6. Suspended sediment concentration and associated particle size

This effect of settling time becomes clear when examining the data. For example, the average removal efficiency of the WQIs during storms with less than 0.2 inches was 43 percent. This increase in efficiency is a function of residence time and not a function of active treatment of the stormwater. Flows from small storms displaced previously collected stormwater where the suspended sediments were reduced from settling during the static antecedent period. Consequently, the average event efficiency ranged from about 32 to 81 percent when the same storms were sorted according to the antecedent period ranging from less than a day to nearly six days (see Figure 7). During this study, the median antecedent dry period was about 4.5 days.

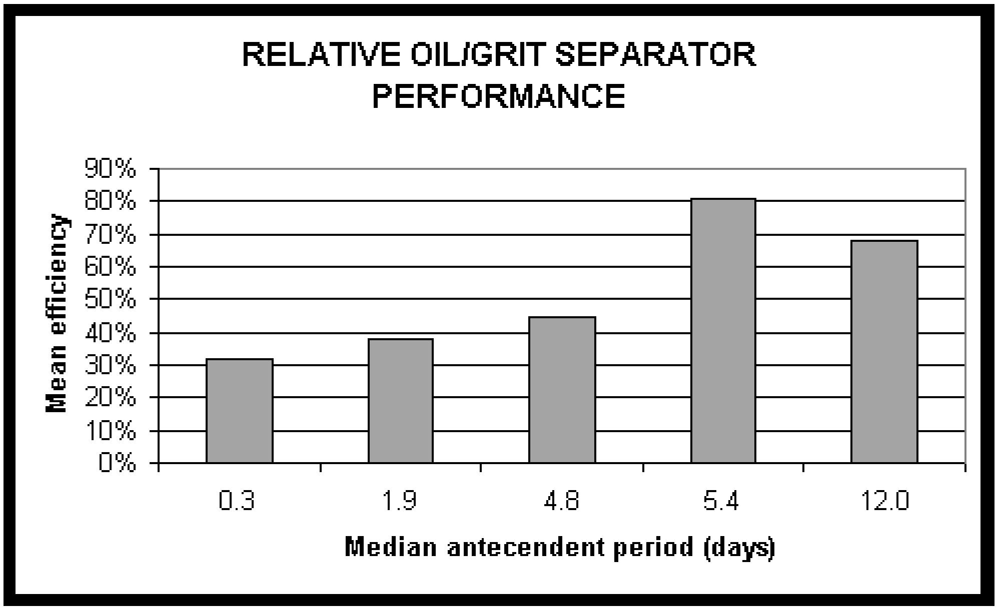

Fig. 7. The relation of antecedent dry period to precipitation events

Storm characteristics also influenced treatment efficiency by affecting the hydraulic detention time, catch basin turbulence, and the mobilization of roadway suspended sediment. The average catch basin residence time was about one hour, however, residence times as low as 37 seconds occurred during brief periods of peak flow. The catch basin lacked sufficient residence time, even during flows as low as .03 cfs, to retain suspended sediment less than .062 mm in diameter. Particles less than .062 mm in diameter retained in the deep-sumped hooded catch basin were the result of static settling. In general, the catch basin retained high-density medium and coarse-grain particles. Thus, the performance of the catch basin increased when these respective particle sizes were mobilized in storm flows. Catch basin performance declined as flows increased, catch basin turbulence increased, and residence time decreased. Lager and others (1977) found a 93 percent reduction in catch basin performance with respect to small particles (.25 to .10 mm in diameter) over a flow range of .25 to 6.3 cfs in a clean catch basin, but only a 60 percent reduction in catch basin performance with respect to heavy solids (greater than .25 mm in diameter).

Sediment Re-suspension

Previous studies found re-suspension to be a common problem of WQIs that were not located off-line (Schueler and Shepp 1993). By locating the WQI off-line, untreated stormwater can bypass the WQI during high flows and reduce the potential for flushing captured materials. In this study, bypass loads accounted for approximately three percent of the total suspended sediment load for each WQI. Bypass flow began to occur near 0.4 and 1.9 cfs at Station 136 and 739, respectively. The difference between the points where bypass flow began to occur for each station was attributed to the dissimilarity in the diversion weir height.

Re-suspension of bottom sediments was caused by excessive turbulence within the catch basin during peak flows. The literature suggests that re-suspension occurs when the level of retained material approaches or exceeds 50 percent of the catch basin sump depth. In simulated tests, the accumulation of bottom material in catch basins did not affect suspended sediment removal efficiencies until 40 to 50 percent of the storage depth was filled (Lager and others 1977). In this study, re-suspension was detected during several events although the volume of bottom sediment retained in the catch basin was less than 25 percent at the conclusion of the monitoring period. Figure 6 illustrates the re-suspension of SSC within the catch basin at Station 136 as it flows through the BMPs during a storm event. The frequency of cases where re-suspension was detected did not increase with an increase in captured sediment. The estimated amount of re-suspended sediment represented 18 percent of the catch basin's final retained suspended sediment load.

The WQIs' capture efficiency of suspended sediment also was reduced by the re-suspension of fine grain sediments, as well as by the bypassing of SSC within especially high flows. Despite the presence of a bypass pipe, previously captured fine bottom sediments were re-suspended and discharged from the WQIs nine and seven times at Stations 136 and 739, respectively. Re-suspension was detected at five-minute rainfall intensities and storm flows greater than .04 inches and about 0.46 cfs at each station, respectively. Storm flows from the WQI at 136 and 739 exceeded 0.46 cfs 33 and 22 times, respectively, during the monitoring period (the Station 136 WQI exceeded this threshold 24 times during the same operating period as Station 739). The amount of re-suspended sediment estimated for both WQIs represented about eight percent of the final retained suspended sediment loads. The frequency of cases where re-suspension was detected did not increase with an increase in captured sediment in either WQI. However, the level of captured sediment in chamber two of each WQI was several inches below the baffle.

The estimated quantity of suspended sediment in flows that bypassed the WQIs at Station 136 was about 20 percent higher than the amount of fine-grained sediment that was re-suspended and flowed out of the WQI. The inverse was true for Station 739 where the amount of bypassed suspended sediment was about 16 percent less than the amount of re-suspended sediment. This is logical considering that bypass flow occurred more frequently at the Station 136 WQI. Without the ability to limit flow to less than 0.46 cfs through the device, changes in the diversion weir height would not substantially affect the device performance. If the weir were raised, fine sediments – representing a relatively small fraction of the retained bottom material composition – would be re-suspended; and if the weir were lowered, a portion of coarse sediments -- readily mobilized during peak flows and retained by the WQI -- would bypass the device.

Debris Capture

Analysis of bottom material samples indicated that “floatable” debris was able to circumvent the catch basin hood and the WQI baffles. The relative ability of a WQI to retain large buoyant particles was further documented by attaching a debris collection device to the outlet headwall at Station 739. The quantity of material collected, for a total of 12 events, increased with an increase in peak discharge. About 71 percent (by mass) of the total debris collected was associated with runoff events where bypass flow occurred, which were exceptionally high runoff events. The quantity of material contained in the bypass flow, as opposed to the quantity of material passing through the WQI, was not determined. The quantity of floatable debris retrieved from the collection structure during the two-month period represented about 23 percent of the total estimate of floatable debris retained in the WQI after 10 months of operation. If the two storms where bypass flow occurred—and their associated debris load—are excluded, then the relative debris estimate is reduced to about eight percent of the total WQI capture estimate.

Although visual observations suggested the WQIs were at least temporarily effective at removing floatable debris, the distribution of potentially floatable debris in bottom materials relative to each chamber and the quantity of debris collected at the WQI outlet indicated the devices can only be effective if regular cleaning is performed. Moreover, the absence of debris in the deep-sumped hooded catch basin at the conclusion of the monitoring period and the large quantity of floatable debris found in each WQI suggested the catch basin hoods were not effective in reducing floatable debris.

Total SSC Loading

Suspended sediment loads for the entire study area were estimated based on the long-term average annual precipitation and the estimated inlet and outlet loads of the two 1500-gallon WQIs. The estimated annual suspended sediment load for the entire study area was about 29,000 Kg. Approximately 24,000 Kg discharged near Malibu Beach and Tenean Beach embayments and the remaining 5,000 Kg discharged to land surface where it infiltrated into the ground. These loads do not include an estimated 2,000 Kg of sediment retained by the five WQIs.

The findings of this study on the effectiveness of deep-sumped hooded catch basins and 1500-gallon WQIs in removing SSC from stormwater were based on the physical and environmental conditions occurring during the monitoring period. Many of the conditions at this site (e.g., daily traffic volume) were unique within the State of Massachusetts. Findings on other highway locations that have stable shoulders, lower traffic volumes, and different particle size distributions may be different.

Recommendations

Since it is not practicable to clean structural BMPs, or conduct street sweeping much more frequently, or install many more of these devices, then SSC source control is the most practicable approach. These methods are summarized below.

1. Catch basin cleaning, and street sweeping, should occur during Spring in order to avoid high-intensity rainfalls, characteristic of summer thunder storms, that re-suspend particles and/or mobilize sediments in the gutters to receiving waters.
2. In an effort to prevent erosion of the roadway shoulder (i.e., where the pavement edge meets the adjacent soil) onto the highway, and to enhance the effectiveness of street sweeping, a low-lying berm should be installed along this area of the Southeast Expressway. An alternative might be to grade the shoulder to an elevation below the edge of the pavement in order to prevent erosion onto the highway.
3. Consider significant reductions in sand application for snow and ice control. Sand probably provides minimal improvement for traction control along this highway anyway due to pulverizing (Comfort and Dinovitzer 1997) and blow-off (Nixon 2001). Road salting alone should be the primary emphasis along this highway, especially since the Expressway is immediately adjacent to a saltwater embayment.
4. Use more efficient maintenance equipment, such as vacuum pump trucks for cleaning out catch basins, in order to minimize the opportunity for re-suspension of captured sediments.
5. Apply more emphasis to litter pick-up efforts. This includes more signage and enforcement for littering, as well as other public outreach and educational efforts (e.g., public service announcements).

Future Research

1. Further work is needed to characterize the concentrations of the whole range of contaminants (e.g., nutrients, metals, hydrocarbons, and bacteria) in highway runoff that adequately accounts for rainfall intensity, antecedent conditions, particle sizes, traffic volume, pavement area, and flow. These factors have been shown to influence the estimates for contaminant loading from highway runoff. With this information, based on real-time flow-weighted data, a model could be developed that would more accurately estimate contaminant loading from highway runoff.
2. There should be an investigation into the degree to which bacteria survive and propagate in catch basins and WQIs. The static pool within these BMPs is generally dark (no light penetration), thermally stable, nutrient enriched, and free from predation. These factors may enhance the growth of fecal bacteria (Schueler 1999). The effectiveness of WQIs and catch basins in reducing fecal indicator bacteria concentrations is likely poor because bacteria share the same settling characteristics as particles less than .062 mm in diameter. Absolute bacteria removal in each BMP is dependent on the fecal indicator bacteria survivability prior to the subsequent event and the potential for exportation during the subsequent event.
3. Evaluate the effectiveness of hoods in capturing floatables; investigate the use of different types; what are their benefits/costs and to what degree do they interfere with maintenance and/or the drainage function of the catch basin.
4. Due to their limited water quality benefits, innovative water quality inlets should be more comprehensively evaluated before their widespread use. Such evaluations, employing the sampling methodologies described herein, will demonstrate the cost-effectiveness of these BMPs (i.e., determine if the environmental benefits exceed the costs of installation and maintenance). This information will provide a basis for their use by community planners, water managers, and others interested in storm water management.

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Before his experience with MassHighway, Henry worked for 3 years with the Wetlands Conservancy Program of DEP. He also has more than 5 years experience as a regional planner in Vermont and New Hampshire. In addition, Henry holds an M.S. in Natural Resource Planning from the University of Vermont, and a B.S. in Environmental Science from the University of Massachusetts in Amherst.

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FEASIBILITY, PROS, AND CONS OF USING DOT RIGHTS-OF-WAY FOR STORMWATER QUALITY TREATMENT

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Abstract

In the past, DOT stormwater drainage facilities have been designed solely on the conveyance of runoff from DOT facilities in terms of immediate discharge and runoff volume. Since the emergence of the National Pollutant Discharge Elimination System (NPDES) Phase I requirements, DOTs have relied on Best Management Practices (BMPs) for controlling stormwater. The idea has been that as long as one of the BMPs was being utilized, then the quality of the treatment and discharge was sufficient. Now, with the onset of the Phase II mandates, municipalities are scrambling to meet numeric concentration and mass limit restrictions on stormwater discharge. The implications in terms of implementation cost, monitoring, land-use planning, and acquisition could be staggering. These issues are weighing heavily on the minds of DOT personnel who are searching for solutions that are achievable within the logistic realm of current practices.

This paper discusses the feasibility, pros, and cons of using the expansive areas of land available at large highway interchanges, as a resource for treating stormwater runoff. Current practices for these areas do not typically utilize the available space for water quality. These large grassed areas require frequent mowing and weed control. In some instances, reforestation and landscape projects are being implemented, but with a little more attention to detail and very little added cost, they could perform a functional need. These large areas at interchanges could be valuable resources in terms of meeting Phase II requirements, and doing their part to service the entire watershed.

Biographical Sketch: Michael Teal has been with the Texas Transportation Institute's Environmental Management Program since February 1994. He has a Bachelor of Science in Horticulture from Stephen F. Austin State University, and a Master of Landscape Architecture from Texas A&M University. His professional interests are transportation aesthetics, maintainability of landscape development, corridor management for visual and environmental quality, and user perception of transportation systems. He has great interest in better understanding and managing the effects of design and implementation upon the natural systems within the transportation corridor. Current projects include landscape development for TxDOT's Construction Landscape Program. He has also written and lectured the Roadside Development section of the Texas Garden Club Master Gardener Certification Course.

USE OF BIODETENTION FACILITIES FOR BIOLOGICAL IMPROVEMENT OF WATER QUALITY

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Abstract

Constructed wetlands have similar beneficial characteristics as a natural wetland and can be designed to remove pollutants from storm water run-off. By the use of biodetention facilities, the combination of proper plant selection and design and construction techniques, water quality enhancements can occur. The water quality is enhanced by emergent plants filtering sediments, uptaking and incorporating nutrients (*e.g.* nitrogen and phosphorus) into plant tissues, creating litter when they die and decay, and transferring gases between the atmosphere and sediments. Furthermore, these constructed communities provide essential habitat important for microbial components involved in nutrient cycling. Native species should be used because they are adapted to the local climate, soils, and surrounding plant and animal communities. Some emergent plants in the class Liliopsida are used in the uptake of nutrients because of their ability to grow fast and form dense colonies.