Storm Water Program

California State University, Sacramento (CSUS)

University of California, Davis (UCD)

California Department of Transportation (Caltrans)

California Department of Transportation BMP Retrofit Pilot Program

Presented at:

Transportation Research Board 8th Annual Meeting, Washington, D.C. January 7-11, 2001 (included in conference proceedings).

Authors:

Brian Currier, Caltrans/UCD Environmental Program
Scott M. Taylor, RBF Consulting
Yulya Borroum, Carter & Burgess, Inc.
Gary Friedman, Montgomery Watson
Doug Robison, Brown and Caldwell
Mike Barrett, The University of Texas at Austin
Steve Borroum, Caltrans Environmental Program
Catherine Beitia, Caltrans/CSUS Storm Water Program

Disclaimer:

Stormwater Program
CSUS Office Of Water Programs
7801 Folsom Boulevard, Suite 102, Sacramento, CA 95826

California Department of Transportation BMP Retrofit Pilot Program

Brian Currier (1), Scott M. Taylor (2), Yulya Borroum (3), Gary Friedman (4), Doug Robison (5), Mike Barrett (6), Steve Borroum (7), and Catherine Beitia (8)

(1) Caltrans/UCD Environmental Program, P.O. Box 942874, Sacramento CA 94274-0001; PH: (916) 653 8809, email: bkcurrier@ucdavis.edu

(2) RBF Consulting, P.O. Box 57057, Irvine, CA 92619-7057; PH: (949) 855 3629, email: staylor@rbf.com

(3) Carter & Burgess, Inc., 2033 Howe Avenue, Suite 220, Sacramento, CA 95825, PH: (916) 929-3323, email: borroumyb@c-b.com. Formerly Caltrans/UCD Environmental Program.

(4) Montgomery Watson, 1230 Columbia Street, Suite 750, San Diego, CA 92101-8131; PH:(619) 699-4152, email: gary.friedman@mw.com

(5) Brown and Caldwell, 16735 Von Karman Ave Suite 200, Irvine, CA 92606-4953; PH: (949) 660-1070, email: drobison@brwncald.com

(6) CRWR, PRC #119 (R8000), The University of Texas at Austin, Austin, Texas 78712-4497; PH: (512) 471-0935, mbarrett@mail.utexas.edu

(7) California Department of Transportation, Environmental Program, P.O. Box 942874, Sacramento CA 94274-0001; PH: (916) 653-7396, email: Steve_Borroum@dot.ca.gov

(8) Caltrans/CSUS Storm Water Program, 7801 Folsom Blvd Suite 102, Sacramento, CA 95826; PH (916) 278-8108, email: cathy.beitia@owp.csus.edu

ABSTRACT

The California Department of Transportation (Caltrans) is conducting a multi-year study in Los Angeles and San Diego to examine the technical feasibility, costs, and operation and maintenance requirements of retrofitting structural Best Management Practices (BMPs) into existing highway and related infrastructure. Thirty-three locations are being retrofitted with thirty-nine BMPs using twelve different types of BMP technology. Automated monitoring stations have been installed upstream and downstream of each BMP to determine removal efficiencies from flow weighted composite samples. Constituents monitored in the runoff include: suspended solids (e.g., sediment), metals, nutrients, and organics (e.g., gasoline).

To date, most projects have been sited, designed, constructed and monitored for at least one year. The purpose of the program is to identify the problems and solutions that occur with structural BMP retrofit, and to collect operation, maintenance, and performance data for the BMPs. Results to date indicate that there are substantial construction, maintenance, and cost challenges in retrofitting existing infrastructure with conventional structural BMP technology. Water quality monitoring results to date indicate that average pollutant removal efficiencies are

consistent with published values. Upon completion of the study, the information collected will enable more accurate prediction of cost and performance of BMPs for treating highway runoff.

INTRODUCTION

The BMP Retrofit Pilot Program was developed to determine the costs and benefits of retrofitting highway infrastructure, maintenance stations (corporation yards) and park and ride lots with conventional structural Best Management Practices (BMPs). The program was developed to track costs (construction, operation and maintenance) and constituent removal by constructing field-scale devices at selected locations in the California Department of Transportation (Caltrans) system. The devices shown in Table 1 are under study as a part of this program:

Table 1. Device Types and Number of Installations

Device	Number of Sites	**Device**	Number of Sites
Extended Detention Basin	5	Biofilter Strip	3
Infiltration Basin	2	Infiltration Trench	2
Wet Basin	1	Drain Inlet Insert	6
Sand Media Filter[3]	8	CDS™ [2]	2
MCTT [1, 3]	3	Oil/Water Separator	1
Biofilter Swale	6	Perlite/Zeolite Filter	1

1 Multi-Chambered Treatment Train
2 Continuous Deflection Separator
3 One MCTT and one sand filter is in the design/construction phase.

The structural BMPs tested for this program are considered ‘conventional’ though some of the technologies (MCTT and perlite/zeolite filter) are of relatively recent origin. The research objectives of the study are as follows:

- Evaluate constituent removal efficiency of the devices
- Evaluate technical feasibility of implementation in a retrofit environment
- Determine costs of construction, operation and maintenance

Detailed records of siting, design, construction and operation and maintenance are being compiled as each phase of the study proceeds. A primary emphasis of the study is to identify the problems of retrofit of structural BMPs and look for solutions to the problems encountered. The study plan calls for the BMPs to be sited, designed, constructed, operated and maintained at ‘state-of-the-art’ levels.

The schedule for the project is shown in Table 2. Some BMP installations were delayed and do not follow this schedule exactly.

Table 2. General Schedule for BMP Retrofit Pilot Studies

Activity	Schedule
Scope Development	October 1997 through November 1997
Siting	October 1997 through December 1997
Design/Approval	January 1998 through May 1998
Bid and Construction	June 1998 through January 1999
Monitoring	January 1999 through April 2001
Final Report	July 2001

This paper will present issues relative to the siting, design, construction, operation, and maintenance of the BMP Pilot Studies identified to date. The entire data set will be analyzed and the performance of these devices will be determined after the program is complete. Similarly, operation costs will be determined after the monitoring period is complete.

BMP SITING

The devices listed in Table 1 were placed at 33 sites in Los Angeles and San Diego Counties in California. Some sites contain more than one device (e.g., multiple drain inlet inserts at one maintenance station, or treatment trains of an infiltration trench preceded by a biofiltration strip). General siting criteria for the devices were developed to reflect conditions of wide-scale deployment. They included:

- Appropriateness for the capabilities of the BMP (i.e. an Oil/Water Separator requires free oil and grease concentration above a certain threshold to perform effectively)
- Presence of a realistic opportunity to install, operate and observe the BMP
- Ability to address an identified water quality problem

The specific sites were selected using a weighted decision matrix process. Criteria significant in the selection of the sites for each type of device were compiled and then assigned a weighting factor to emphasize the most important criteria. The order of site selection was also established to ensure that the devices with the most restrictive criteria were located first, followed by devices with less restrictive criteria in descending order. Infiltration sites generally had the most restrictive siting criteria with CDS units the least restrictive. The 'best' sites were selected as those accumulating the highest composite score for all of the criteria established for the particular device. Some of the more site specific siting criteria included:

- Availability of space
- Maintenance access and crew safety
- Presence of vehicles and heavy equipment (maintenance stations and park and ride facilities)
- Proximity to existing structures
- Site drainage pattern.

Several constraints were encountered during the siting process. First, there is a limited amount of suitable and available surplus area within the right-of-way owned by Caltrans. No right-of-way was to be purchased as a part of this program. Second, safety concerns dictated the reservation of a 30-foot clear recovery zone around the perimeter of devices that stored water (such as basins) or around fixed objects that present a vehicle collision hazard. Alternatively, a fixed barrier to traffic (guardrail) was used at some locations adjacent to freeways. A setback criteria from existing structures (bridge columns and abutments) was also established for infiltration devices to avoid saturation of the area around the structure foundation.

Drainage patterns of existing sites also proved to be a significant siting constraint. Most maintenance stations and park-and-ride lots were designed to sheet flow through the facility entry gate to the street, limiting opportunities to retrofit without a significant reconstruction of the facility. In addition, area available to construct a device was often not located at the topographic low point of the site.

Suitable sites were found for most devices with the exception of infiltration BMPs. The study originally envisioned the retrofit of nine infiltration devices (three basins and six trenches), but this wasn't possible. After sites were first identified as suitable for infiltration (basin or trench), they were tested to estimate soil permeability. Fifteen in-field borings and permeability tests were conducted at the pre-screened sites in Los Angeles and San Diego counties, but only four viable infiltration sites were found. Clay soils are common in Southern California, and some locations have relatively high groundwater. Either condition can eliminate infiltration from consideration.

Media filters, infiltration trenches and drain inlet inserts were used for maintenance station and park and ride locations. Biofilters (swales and strips) and infiltration basins, extended detention basins, wet ponds and CDS units were used for freeway sites.

BMP DESIGN

A Scoping Study was developed as an overall framework for the pilot program. The Scoping Study identified design guidelines, maintenance, and water quality parameters to be measured during the operation phase of the project. The primary design references for the Scoping Study were the Caltrans *Storm Water Quality Handbooks: Planning and Design Staff Guide*, (CDM, 1997) and *Evaluation and Management of Highway Runoff Water Quality*, (Young, et. al., 1996). The Scoping Study provided the basic criteria for the design of the pilot projects; however, final design criteria were set by the site designer based on the specific opportunities and constraints at each site.

The devices in this study are both proprietary and non-proprietary. Design criteria for non-proprietary devices described in the Scoping Study were developed in accordance with the current state-of-the-art technology for BMP design by incorporating the most current research findings. The design objective was to maximize both the treatment capacity and performance of the BMP within the constraints for each site. Design criteria for non-proprietary devices are shown in Table 3.

Proprietary devices used in the Retrofit Pilot Program were developed by private companies and may be patented or in the patent process. The manufacturers have the responsibility for final design of their respective proprietary devices. The site designer provided inlet and outlet piping and general site layout. Proprietary devices used in this project include:

- StormFilter™ Perlite/Zeolite media filter (Stormwater Management)
- FossilFilter™ drain inlet insert (KriStar Enterprises, Inc.)
- StreamGuard™ drain inlet insert (Foss Environmental)

- Continuous Deflective Separation, CDS™ device (CDS Technologies, Inc.)

Table 3. General Design Considerations for Non-Proprietary BMP Devices

BMP Type	Primary Considerations	Other Design Considerations
Extended Detention Basin	Capture volume, detention time, length:width ratio.	Side slope ratio, maintenance access, basin shape, inlet/outlet type, use of forebay, on-line or off-line.
Infiltration Basin	Infiltration rate, drain time, volume, groundwater separation, proximity to adjacent structures.	Basin shape, side slope ratio, maintenance access, use of forebay, vegetation type, inlet configuration, on-line or off-line.
Wet Basin	Volume, ratio of permanent pool volume to water quality volume, drain time.	Basin shape, side slope ratio, maintenance access, use of forebay, littoral zone, vegetation type, inlet/outlet configuration, permanent pool source, on-line or off-line.
Infiltration Trench	Infiltration rate, drain time, volume, groundwater separation.	Trench shape, dimensions, rock matrix specifications.
Biofilter (strips and swales)	Residence time, maximum velocity, slope (strips), minimum dimensions (strips).	Shape/configuration, length, vegetation type.
Sand Media Filter - Austin	Volume, detention time for settling, surface loading rate.	Dimensions, maintenance access.
Sand Media Filter - Delaware	Volume, surface loading rate.	Dimensions, maintenance access.
Media Filter – StormFilter™ with Perlite/Zeolite	Volume, number of cartridges required for treatment.	Dimensions, maintenance access, drainage head.
Multi-Chambered Treatment Train (MCTT)	Capture volume, detention time for settling, filter surface loading rate.	Dimensions, maintenance access, filter media.
Oil Water Separator	Peak flow rate, method of coalescing.	Circular or rectangular configuration, dimensions, fabrication material.

All BMPs were designed to treat the runoff from a 1-year 24-hour storm for Los Angeles or San Diego area. Most of the devices are volume based, requiring a runoff volume to be computed for design. Some are flow based, requiring a peak discharge for design. The design rainfall varies with location, but was typically 2.54 cm for Los Angeles sites and averaged 3.81 cm for the San Diego sites.

CONSTRUCTION

The projects were constructed using the traditional design-bid-build process. The lowest qualified bidder was awarded the contract. Roughly six construction ‘packages’ were bid, with most packages worth between $1 million to 1.5 million per the engineer’s estimates. The smallest construction package was worth about $85,000. The engineers that developed the plans, specifications and estimates provided construction management services for the projects to ensure that they were constructed per the drawings.

Construction costs for adding structural BMPs to existing infrastructure are relatively high. Issues such as traffic control, limited work space, conflicts with existing improvements, unsuitable soils, unknown buried manmade objects, and construction that occurs at many different locations all conspire to inflate the cost of retrofit BMPs compared to new construction.

No right-of-way was purchased for this project and purchasing right-of-way to construct the BMPs would have greatly increased the project cost. Regardless of land cost, retrofit costs for some devices may be as high as ten times that of the same device constructed as a part of new construction. Some of the factors that affect construction cost, project schedule, and ongoing operations at existing facilities are presented below.

Construction Issues

Construction issues included the unavailability of standard details, fabrication delays, material specification and material availability. The contractor had some difficulty during construction because they had little experience with the construction of the devices, and lacked an understanding of the tolerances required for the various elements. One example was the construction of an extended detention basin outlet that was too high by about 2 cm, causing low flow drainage difficulties between the basin inlet and outlet. Standard details would have been helpful in fabricating some of the elements such as outlet structures, vaults, equipment access hatches, underdrain systems etc.

Some of the devices required special fabrication, such as the tube settlers for the MCTT. In several instances, there were delays in receiving the fabricated elements, or fabrication errors that caused construction delays.

Material specification was a problem for some of the proprietary devices. Caltrans does not normally allow the specification of proprietary devices, using instead a generic specification that would allow for a range of alternative materials. Such a process was incompatible with the construction of proprietary devices and exceptions were made for this project. A disadvantage was that device manufacturers tended to substitute materials and design specifications after the drawings were complete, requiring changes in the field to accommodate the new product configuration.

Finally, some material was not available locally. Sand that met the project specifications for the sand filters was not available. Similarly, rock that matched the project specifications for the infiltration trench backfill was not available. Suitable substitutes were found but time and effort were expended conferring with the design engineer to define a suitable substitute material.

Unknown Field Conditions

Perhaps the most significant problems encountered were as a result of unknown field conditions. A geotechnical investigation, including exploratory borings, as appropriate, was completed for each site as a part of the design process. Generally only one or two borings were completed for a site because the sites were relatively small. However, many cases of unsuitable materials, difficult excavation, buried manmade objects, undocumented utilities, and hazardous materials were encountered. These problems were probably not considerably more prevalent than in an average redevelopment project, but they did add significant expense to many of the facilities.

The disposal of inert material in surplus areas of highway right-of-way is not an uncommon practice, and the ‘as-built’ process may not document the existence of such materials. In one case, rubble from a previously demolished bridge was discovered buried at an extended detention basin site. This required the over-excavation of the unsuitable material and disposal in a landfill at considerable cost.

It was also common to discover conflict with existing utilities at the maintenance stations. Utilities at the stations were often poorly documented since easements are not generally required. In two instances, public utilities (water and gas lines) conflicted with proposed BMP locations in maintenance stations. The presence of these utilities was not shown on the station as-built drawings.

Impacts to Existing Facilities

The construction of projects along active freeways, in maintenance stations and park-and-ride lots posed challenges for construction staging and operations. Frequently, the order of construction work at maintenance stations was dictated by station operations, which can change from week to week. For freeway BMP projects, lane closures and construction traffic entering highways were a public inconvenience.

Parking spaces were lost at the park-and-ride lots as a result of BMP construction. Some of the losses were temporary and associated with construction needs such as stockpiling excavation material. Parking spaces were permanently lost where the BMP required more area than was available in landscape and buffer areas.

Some of the projects were constructed in the coastal zone, requiring a coastal development permit. One of the biofilter sites was constructed as a change order to an existing project in the same vicinity, in an attempt to obtain economies from the ongoing construction. The biofilter was subject to the terms of the coastal development permit for the project. The design had to be significantly modified during construction to avoid several existing trees rather than remove them per the original plan, since they would be subject to a 5:1 replacement ratio under the terms of the coastal development permit for the larger project. Significant cost savings was not realized by combining with the larger project as a result. This type of situation may not be uncommon as an example of the problems that may arise in combining retrofit projects with other ongoing construction.

Construction Cost Summary

Preliminary construction cost ranges for the projects are provided below. Actual construction costs will be compiled once the contracts and change orders have been closed out and all installations are completed. It should be noted that some of the costs shown in Table 4 include items related to monitoring, such as concrete pads, equipment enclosures and flumes. These costs are mostly minor, usually less than one or two percent of the estimated construction cost, except for drain inlet inserts. The cost of monitoring facilities exceeded the cost for construction of the inserts themselves because reconstruction of the drainage was necessary for monitoring purposes. Analysis of the construction cost data to determine pilot study related costs is required to determine the deployment cost of the BMPs.

Table 4. Range of Estimated Costs and Drainage areas[1]

Device Type	Estimated Construction Cost[1]	Drainage Area (ha)
Ext. Detention Basin	$166,000 - $855,000	11.9 – 33.1
Infiltration Basin	$241,000 – $273,000	7.9 – 10.4
Wet Basin	$694,000	10.4
Media Filter	$231,000 - $479,000	2.0 – 6.9
Biofiltration Swale	$59,000 - $156,000	0.5 – 5.9
Infiltration Trench/Bio Strip	$196,000 - $218,000	4.2
Drain Inlet Insert[2]	$32,000 - $44,000	0.5 – 4.0
Biofiltration Strip	$100,000	1.2
CDS	$62,000	2.7 – 6.2
Oil/Water Separator	$178,000	2.0
MCTT	$375,000 - $893,000	2.7 – 11.4

1 Construction costs include items that are monitoring related, such as flumes.
2 The drainage system for DIIs was significantly modified to isolate effluent for flow monitoring.

Costs such as design and construction management can usually be estimated by the estimated construction cost, so design and construction management cost are not presented. Also, some costs are not measured in dollars, but rather in lost area available for uses such as public parking or maintenance activities.

OPERATION AND MAINTENANCE

Detailed operation, maintenance and monitoring manuals were prepared for each site location. A Maintenance Indicator Document (MID) was also prepared to detail the maintenance required for each type of device, the frequency for the maintenance (if it is a recurring activity), and the threshold conditions that require a maintenance action (for occasional activities). All maintenance activities are being carefully documented to determine costs. So that the pilot experience can be translated to other sites, the actual time spent on maintenance activities is also being recorded. These records will be valuable for determining the practicability of BMP devices. Table 5 presents a summary of annual operations and maintenance costs observed to date. The hours reported include contract management and oversight, but excludes travel time. Further analysis is needed to determine what appropriate long term hours are required for each technology. Because some BMPs have not reached the initial threshold required for major maintenance items, the true annual average may be higher. However, for biofilters (strips and swales), sod was established over the summer months and initial watering costs may have elevated the annual O&M cost of these BMPs. The wet basin hours are relatively high due to annual vegetation removal.

Several operation and maintenance issues have arisen since many of the BMPs entered service in January of 1999. Over the course of developing the MID, important issues regarding performance, safety, disease vectors, endangered species and wetlands have emerged.

Table 5. Average Annual O&M Person-hrs for 99-00 Season (Excluding Travel Time).

Device Type	Average Annual Person-hrs To Date
Infiltration Trench	70
Pearlite/Zeolite Canistar Filter	72
Sand Filters	93
Drain Inlet Insert	118
Ext. Detention Basin	136
Oil Water Separator	139
MCTT	172
Infiltration Basin	193
Biofiltration Strip	202
Biofiltration Swale	211
Wet Basin	570
CDS™	NA (installed summer 00)

Performance and Safety

In some cases, the level of maintenance has an immediate effect on the performance of the device. Through the first months of operation and maintenance of the drain inlet inserts, it became apparent that a much higher level of maintenance was necessary than first expected, just to keep the inserts from clogging and bypassing flows from some storms as small as a tenth of an inch. The inserts were being clogged mostly by leaves that would get blown into the insert during dry weather or washed in during storms. The solution was to increase the cleaning of inserts to once before and once during each storm event. The use of inserts at highway locations was not considered because of safety considerations of maintenance workers near the traveled way.

Public Health Concerns - Disease Vectors

Mosquitoes are the primary vector of concern for BMP installations. Those BMPs that maintain a pool of standing water (i.e. CDS, Delaware Filter, MCTT, and wet basin) are of particular concern. The issue is especially sensitive at the wet pond, where aquatic vegetation provides harborage for mosquitoes. Removal of vegetation has allowed the continued efficacy of mosquito fish as vector control. Aggressive vector monitoring and abatement is carried out by local vector control agencies. Mosquito breeding abatement has been carried out using Golden Bear™ oil, Altosid (a mosquito specific synthetic juvenile hormone) and mosquito fish (*Gambusia affinis*). The use of Golden Bear™ oil is avoided due to a concern for impacts to water quality monitoring results from residual oil. A study on vector production at the BMPs and a national survey is being led by State of California, Department of Health Services, Vector Borne Disease Section.

Endangered Species and Wetlands

Endangered and protected species can take harborage in some types of BMPs and potentially limit maintenance access and operation. Several steps have been taken to reduce this possibility, including the installation of nets at sand filters (to prohibit least tern nesting), and installation of Mylar strips (to deter sensitive bird species nesting).

Wetlands issues have been addressed by agreement with the US Army Corps of Engineers. Some types of BMPs can take on wetlands characteristics over time. Should BMPs become jurisdictional areas, maintenance and operation of the device could be compromised. The US Army Corps of Engineers and the USEPA issued a letter indicating that if the projects were maintained per an established maintenance schedule, the BMPs would not become jurisdictional even if they exhibit wetlands characteristics. However, the site could not be a jurisdictional wetland prior to BMP construction.

WATER QUALITY CHARACTERISTICS

The monitoring data collected consists of event mean concentrations (EMCs), samples (aliquots) per event, flow, total volume, grab sampling concentrations, and empirical observations such as erosion, weather, short-circuiting, and water appearance. Due to space constraints, only a statistical summary of the water quality data will be presented here. BMP water quality removal efficiencies can be described by both the ability of a BMP to reduce the concentration of pollutants in surface water, and the ability for a BMP to reduce pollutant load (BMPs that infiltrate water have a higher load reduction efficiency than an EMC reduction efficiency). Water quality samples are taken from the BMP influent and effluent (as applicable) to determine the pollutant removal across the device.

Method of Data Collection

Storm water samples are attempted during at least four storms per year, with the goal of sampling eight storms over a two-year period, weather permitting. The minimum separation dry period required between sampled storm events is 48 hours. For many BMP installations, more than four storms were captured in the 99/00 wet season. The wet season for these studies is defined as September through April.

During the storm events, influent and effluent samples were taken using automated sampling equipment. Flow was measured by as pipe flow or in a variety of flumes that best suited site specific conditions. The samplers were triggered to pump an aliquot (the individual volumes that are combined for one composite sample) into a collection bottle each time a specified volume of water was measured by the flow monitoring equipment.

Method of Analysis

EMCs were analyzed from flow weighted composite samples. The constituents analyzed and the methods used are shown in Table 6.

Table 6. Water Quality Parameters and Methods of Analysis

Parameter	Detection Limit (mg/l)	Method (USEPA)
Total Suspended Solids	1	160.2
Zinc	0.001	289.2/200.8
Lead	0.001	239.2/200.8
Copper	0.001	220.2/200.8
Nitrate nitrogen	0.01	353.3
Total Kjedahl nitrogen	0.1	351.3
Total Phosphorus	0.002	365.2
Fecal Coliform	200 CFU	SM 909C
Total Recoverable Petroleum Hydrocarbons	0.25 to 0.75	8015 mod/ext.

Pollutant Removal Efficiencies and Characteristics

Most BMPs have been tested for the complete 99/00 wet season and the first portion of the 00/01 season. The BMPs are performing similar to published values, and removal efficiencies are shown in Table 6. Note that negative removal are reported as negative values. Removal efficiencies for each constituent and device type were computed using the relationship:

$$\text{Efficiency (\%)} = [(\text{Loading in} - \text{Loading out})/\text{Loading in}](100)$$

The loading in and loading out are summed for all storms in the data set for each particular BMP type so that the numbers reported in Table 7 are average pollutant removal numbers for the entire volume of water monitored by each type of BMP and not an average removal on a storm-by-storm basis. These numbers can be useful in comparing performance to other types of BMPs and for planning purposes in addressing allocated load reduction requirements. However, for the immediate effect on receiving water beneficial uses, it may be more appropriate to look at the change in EMC. Devices that rely on infiltration to reduce load, such as biofilters, will not have as great efficiency in reducing EMC concentrations. For this reason, effluent characteristics are reported to allow comparison to water quality standards. The available data collected for constituent removal across the devices indicates that the BMP effluent may not meet water quality standards for the receiving waters. Efficiency and effluent characteristics are presented in Table 7. Constituents that were monitored by a single grab sample at influent and effluent are not presented because grab samples may not represent the overall water quality characteristics for a given storm.

A common shortcoming of the BMPs tested is low nutrient removal. Nutrients continue to be a pollutant of concern throughout the nation, and yet the BMP technologies tested do not consistently remove the different forms of nutrients analyzed (nitrate, TKN, Total P). The BMPs may show different removal characteristics for nutrients, as well as other constituents, as the devices mature.

Table 7. Summary of Water Quality Performance Characteristics.

BMP Constituent	Removal Efficiency %			Effluent EMC		
Extended Detention Basins (5 installations, 36 total events)	Average	Low	High	Average	Low	High
TSS	67	-21	98	41.54	12	190
Total Cu (ug/L)	69	16	90	21.43	6.8	50
Total Pb (ug/L)	73	-11	96	31.10	5.5	140
Total Zn (ug/L)	85	43	99	103.77	23	260
Dissolved Cu (ug/L)	38	-26	84	11.80	4.7	29
Dissolved Pb (ug/L)	61	-2	93	2.20	1	8.1
Dissolved Zn (ug/L)	56	-85	92	52.49	13	175
Nitrate-Nitrogen(mg/L)	50	-5	98	0.93	0.2	4.2
TKN (mg/L)	40	-159	100	2.05	0.5	8.9
Total P (mg/L)	45	-222	87	0.40	0.03	0.86
Perlite/Zeolite StormFilter (1 installation, 9 storm events)	Average	Low	High	Average	Low	High
TSS	51	-11	84	82.2	34	170
Total Cu (ug/L)	84	25	96	51.8	29	72
Total Pb (ug/L)	72	29	78	28.2	11	59
Total Zn (ug/L)	74	15	91	286.0	84	410
Dissolved Cu (ug/L)	42	10	87	21.9	12	37
Dissolved Pb (ug/L)	33	-15	89	2.8	1	5.4
Dissolved Zn (ug/L)	40	8	56	128.9	68	280
Nitrate-Nitrogen (mg/L)	13	-18	42	0.8	0.3	1.9
TKN (mg/L)	29	-21	47	2.3	0.8	5.3
Total P (mg/L)	28	-88	62	0.4	0.1	0.5
Media Filter (Sand-Austin) (5 installations, 30 total events)	Average	Low	High	Average	Low	High
TSS	89	27	100	8.42	1	26
Total Cu (ug/L)	57	-67	94	10.57	3.2	39
Total Pb (ug/L)	84	64	98	3.54	1	19
Total Zn (ug/L)	81	59	100	30.70	1	160
Dissolved Cu (ug/L)	27	-80	81	8.03	2.4	27
Dissolved Pb (ug/L)	51	21	85	1.04	1	1.4
Dissolved Zn (ug/L)	68	5	99	20.99	1	110
Nitrate-Nitrogen (mg/L)	-17	-213	86	0.84	0.16	2.4
TKN (mg/L)	60	7	90	1.34	0.14	6.2
Total P (mg/L)	55	10	91	0.26	0.032	1.3
Media Filter (Sand-Delaware) (1 installation, 8 total events)	Average	Low	High	Average	Low	High
TSS	69	0	95	67	6	250
Total Cu (ug/L)	53	-5	83	14.11	1.8	31
Total Pb (ug/L)	79	50	91	5.94	1.1	14
Total Zn (ug/L)	93	87	97	40.21	7.7	61
Dissolved Cu (ug/L)	45	22	86	5.6	1	13
Dissolved Pb (ug/L)	33	13	89	1.05	1	1.4
Dissolved Zn (ug/L)	92	80	99	22.15	1	51
Nitrate-Nitrogen (mg/L)	-20	-166	70	0.66	0.2	1.7
TKN (mg/L)	58	32	84	1.15	0.43	2.4
Total P (mg/L)	53	-23	70	0.33	0.091	0.58

BMP Constituent						
Wet Basin	Removal Efficiency %			Effluent EMC		
(1 installation, 5 events)	Average	Low	High	Average	Low	High
TSS	96	85	99	12.0	4.0	28.0
Total Cu (ug/L)	100	63	100	18.6	13	31
Total Pb (ug/L)	99	97	100	5.3	1.1	11.0
Total Zn (ug/L)	95	76	98	51.0	36.0	92.0
Dissolved Cu (ug/L)	17	-35	73	16	12	27
Dissolved Pb (ug/L)	81	26	98	2.4	1.0	4.1
Dissolved Zn (ug/L)	22	-69	77	46	33	85
Nitrate-Nitrogen (mg/L)	-18	-288	98	2.1	0.033	8.2
TKN (mg/L)	38	-73	74	2.4	1.6	3.5
Total P (mg/L)	58	-59	68	1.2	1.1	1.5
Bioswales[1]	Removal Efficiency %			Effluent EMC		
(5 installations, 12 events)	Average	Low	High	Average	Low	High
TSS	50	-263	100	22	5	37
Total Cu (ug/L)	43	-84	100	15.62	8.6	23.0
Total Pb (ug/L)	57	-165	100	26.35	9.6	75.0
Total Zn (ug/L)	67	-188	100	53.3	28.1	93
Dissolved Cu (ug/L)	35	-9	100	11.28	5.1	17.2
Dissolved Pb (ug/L)	54	-30	85	9.02	1	24
Dissolved Zn (ug/L)	56	-44	100	32.80	16	56
Nitrate-Nitrogen (mg/L)	20	-33	100	0.75	0.4	1.9
TKN (mg/L)	35	-18	100	1.87	0.1	4
Total P (mg/L)[2]	3	-191	100	0.68	0.2	2.7
Biostrips	Removal Efficiency %			Effluent EMC		
(3 installations, 11 total events)	Average	Low	High	Average	Low	High
TSS	86	52	99	16.1	1	28
Total Cu (ug/L)	90	13	99	5.5	1	10
Total Pb (ug/L)	89	26	99	3.5	1	8.7
Total Zn (ug/L)	85	33	97	29	4.2	37.3
Dissolved Cu (ug/L)	84	4	99	4.5	1	14.7
Dissolved Pb (ug/L)	75	4	98	1.4	1	2.7
Dissolved Zn (ug/L)	81	42	97	22.2	3.2	51
Nitrate-Nitrogen (mg/L)	46	-7	95	0.4	0.1	1.2
TKN (mg/L)	54	9	94	1.7	0.1	4.2
Total P (mg/L)[2]	-29	-17851	88	0.6	0.2	2.7
Multi-Chambered Treatment Train (MCTT)	Removal Efficiency %			Effluent EMC		
(2 installations, 8 total events)	Average	Low	High	Average	Low	High
TSS	89	23	94	5.8	1.5	8.7
Total Cu (ug/L)	67	20	81	4.2	1.6	8.2
Total Pb (ug/L)	67	46	94	2.4	1	8.2
Total Zn (ug/L)	90	72	97	11.9	4.9	25
Dissolved Cu (ug/L)	66	-13	79	2.7	1.3	5.5
Dissolved Pb (ug/L)	32	2	65	1	1	1
Dissolved Zn (ug/L)	87	62	98	10.1	1	19
Nitrate-Nitrogen (mg/L)	-14	-19	36	1.7	0.4	8.6
TKN (mg/L)	55	31	71	0.8	0.4	1.6
Total P (mg/L)	63	31	86	0.1	0.1	0.2

1 Bioswales had 100% load removal during events with 100% infiltration (no effluent).
2 Cause of phosphorus export is unknown, but may be related to material and fertilizer used to establish sod.

Data Quality Assurance and Quality Control

Field and laboratory QA/QC protocols comply with the minimum guidelines in the Guidance Manual: Stormwater Monitoring Protocols (1997). Analytical quality assurance for this program includes the following:

- Calibration of analytical instruments.
- Use of Standard Reference Materials (SRMs).
- Complete documentation of sample tracking and analysis.

Internal laboratory quality control checks included the use of method blanks, matrix spike/matrix spike duplicates, duplicates, laboratory control spikes and SRMs. Control limits for spike recoveries and relative percent differences (RPDs) were defined by the project data quality objectives (DQOs) in the Guidance Manual (1997); however, the pilot study laboratories developed their own acceptance criteria, which differed only slightly from the Guidance Manual.

DISCUSSION

Thus far, the BMP Retrofit Pilot Program has provided useful information relative to the construction and operation of conventional structural storm water BMPs in highway environments. When the study is completed in 2002, detailed information will be available as to the costs and benefits of each type of device, as well as documentation regarding operational issues. Until then, the practicability of retrofitting existing infrastructure with structural controls is unclear.

The BMPs constructed as a part of this study appear to be performing consistent with published literature values. None of the devices however, appear to have the capability of meeting water quality standards for receiving waters, and it is unknown whether they can meet load reduction allocations associated with TMDLs.

There are significant operational constraints on the devices that must be considered for any application. Vector, endangered species and wetlands issues can each result in maintenance impacts. The device may become a public nuisance if vectors are allowed to breed, and maintenance may be prohibited if the device harbors endangered species or becomes a jurisdictional wetland. A comprehensive maintenance and operation program is mandatory to ensure the devices can be operated effectively.

The water quality performance characteristics summarized are for information purposes. The utility of the information is for the reader to assign. Of course many more details about the study are necessary to determine the quality and applicability of the data for other circumstances – much more than could be included in this paper. A complete summary of the report is being compiled. Also, work to assemble the data and make it publicly available is underway. For updates on this and other Caltrans storm water activities, go to http://www.dot.ca.gov/hq/env/stormwater/index.htm.

ACKNOWLEDGEMENTS

This BMP pilot study was funded by the California Department of Transportation, Storm Water Program. The following consultants where key participants: Brown and Caldwell, Montgomery Watson, and RBF Consulting for design, construction, and oversight; Law Crandall, Larry Walker and Associates, and Kinnetic Laboratories Inc. for operation, maintenance, and monitoring; and Richard Watson and Associates was instrumental in siting the BMPs. The California Department of Health Services is assisting in vector studies.

REFERENCES

Caltrans, 1997, *Guidance Manual: Stormwater Monitoring Protocols*, California Department of Transportation, Sacramento, CA Storm Water Unit, Doc. # CTSW-RT-97-019.

Caltrans, 1998, *Scoping Study, District 11*, California Department of Transportation, Sacramento, CA, Storm Water Unit, Doc. # CTSW-RT-98-026

Caltrans, 1998, *Scoping Study, District 7*, California Department of Transportation, Sacramento, CA, Storm Water Unit, Doc # CTSW-RT-98-026.

Caltrans, 1997, *Caltrans Storm Water Quality Handbooks: Planning and Design Staff Guide,* California Department of Transportation, Sacramento, CA, Storm Water Unit, Doc # (CTSW-OT-008-v1).

Young, G.K., et al., 1996, *Evaluation and Management of Highway Runoff Water Quality,* Publication No. FHWA-PD-96-032, U.S. Department of Transportation, Federal Highway Administration, Office of Environment and Planning.