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EVALUATION OF STORM WATER TREATMENT BY VEGETATED AREAS ADJACENT TO HIGHWAYS

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Authors:

Misty Scharff, A.P.S.S.c., Caltrans/CSUS Storm Water Program
Anna Lantin, P.E., RBF Consulting, Irvine, CA
David Alderete, Caltrans/CSUS Storm Water Program

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Misty Scharff, A.P.S.S.c.
Office of Water Programs - California State University, Sacramento
7801 Folsom Blvd., Suite 102, Sacramento, CA 95826
Phone: (916) 278-8106 Fax: (916) 278-8140
E-mail: misty.scharff@owp.csus.edu

Anna Lantin, P.E.
RBF Consulting
14725 Alton Parkway, Irvine, CA 92619-7057
Phone: (949) 472-3461 Fax: (949) 586-6531
E-mail: alantin@rbf.com

David Alderete
Office of Water Programs - California State University, Sacramento
7801 Folsom Blvd., Suite 102, Sacramento, CA 95826
Phone: (916) 278-8104 Fax: (916) 278-8140
E-mail: david.alderete@owp.csus.edu

Biographical Sketch of Authors

Misty Scharff has been involved with California State University Sacramento performing research on erosion and sediment control for the California Department of Transportation since 2000. She received her bachelor's and master's degrees in soil science from the California Polytechnic State University, San Luis Obispo, were she assisted in numerous erosion control research studies. She has been a member of IECA since 1996.

Anna Lantin is a senior associate with RBF Consulting, Irvine, California. Her focus is storm water management involving water quality BMP design and research, hydrology, and hydraulics. She received her bachelor's degree in Civil Engineering from the Colorado State University, where she also performed post-graduate work in Civil Engineering. She is a licensed, professional civil engineer in the states of California and Arizona. She has over 12 years of engineering experience with water resources projects.

David Alderete has been involved with California State University Sacramento performing research on storm water treatment technologies for the California Department of Transportation since 2000. He received his bachelor's degree in Civil Engineering from the University of California, Davis. He is a graduate student at the California State University, Sacramento. He has over 8 years of engineering experience with water resources projects.

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Office of Water Programs

California State University, Sacramento

Anna Lantin

RBF Consulting

Abstract

The California Department of Transportation has approved vegetative filter strips as a Best Management Practice to improve water quality in storm water runoff. Design parameters important for a vegetated filter strip's effective performance include: flow velocity, residence time as a function of length and slope, infiltration, and vegetation density. The state agency establishes vegetation adjacent to highways to accommodate a range of functions including: erosion control, aesthetic, safety, environmental mitigation, and storm water pollution prevention. Furthermore, the state agency maximizes the use of vegetated areas for highway improvement projects. Due to the range of functions that vegetated areas adjacent to highways do serve, the design of a vegetated system may not necessarily conform to standard design guidelines for vegetative filter strips.

The state agency initiated a two-year study to assess the treatment effectiveness of existing vegetated areas adjacent to its highways. Eight vegetated areas were equipped with two to five 30-m collection channels to capture highway runoff as it passes through various lengths of the vegetated area and at the edge of pavement. The flow paths between the edge of pavement and the various collection channels ranged from 1.1 m to 13.0 m. The slopes ranged from 5 percent to 52 percent. In the 2001-2002 rainy season, between 14 to 18 storms were monitored at each of the four Northern California test sites. Because of dry weather, only 2 to 8 storms were monitored at each of the four Southern California test sites. As a result of the dry weather, almost all the highway runoff at the four Southern California test sites infiltrated into the vegetated slopes.

Average total suspended solids (TSS) for the eight test sites in the highway runoff measured at the edge of pavement ranged from 30 to 170 mg/L. Preliminary TSS data from the northern sites showed removal rates of 44 to 88 percent, depending on slope and length. As expected, flatter slopes and longer flow paths improved TSS removal. Notable TSS removal was observed even on steep slopes (greater than 30 percent) and short slopes (between 1 to 3 m). Preliminary trends for total metals behave similarly to the preliminary TSS trends. Monitoring is scheduled to continue for another year.

Key Words: storm water treatment; Best Management Practices; highway runoff; biofiltration strips.

Introduction

Similar to other transportation agencies, the California Department of Transportation establishes vegetated areas adjacent to roadways for erosion control. These vegetated areas also accommodate other functions, including: safety, improved aesthetics, environmental mitigation, and treatment of storm water runoff. The state agency has identified a number of technically feasible Best Management Practices (BMPs) for treatment of storm water runoff to comply with its statewide National Pollutant Discharge Elimination System Permit. Included in this list are biofiltration strips, also known as vegetated filter strips. Biofiltration strips are areas of perennial grasses through which storm water runoff flows, in the form of sheet flow, before leaving a site or entering a storm sewer system. Pollutants suspended in the runoff or attached to suspended soil particles are removed by filtration, absorption, and gravity sedimentation (NJDEP, 2000).

Over the past twenty years, numerous studies have been conducted to document pollutant removal efficiencies of biofiltration strips. Other studies have investigated the optimal design criteria (e.g., length and slope) and maintenance practices for biofiltration strips. There are currently many kilometers of vegetated areas along California highways. Since these vegetated areas were designed to serve functions other than storm water treatment, the vegetated areas may not conform to optimal design guidelines for biofiltration strips. The Caltrans Hydraulically Designed Biofilter Evaluation Study (CHD Study) is a two-year effort to assess the treatment effectiveness of vegetated areas whose design was based on erosion control and hydraulic functions. The ultimate objective of this study is to determine if following existing design guidelines results in vegetated areas that perform adequately as biofiltration strips for storm water treatment. In this paper, preliminary results for total suspended solids (TSS) from the first season's monitoring will be presented.

Methodology

California contains over 24,000 km of state and federal highways. The site selection process involved an initial inspection of vegetated right-of-ways along these highways. The study required that each test site be at least 60 m in width (parallel to the roadway and perpendicular to runoff flow) and 8 m in length (down the slope following the flow path of storm water runoff). Eight test sites, or vegetated areas, were selected representing a mixture of rural and urban locations. Four test sites are located in Northern California, and four test sites are located in Southern California. The eight test sites purposely include the extremes in test conditions. Slopes vary from 5 to 60 percent. Average annual rainfall varies from 254 to 1,016 mm. Characteristics of the eight test sites are summarized in Table 1.

A generic schematic of a test site is presented in Figure 1. At each test site, one to four 30-m concrete collection trenches were constructed into the slope of the vegetated area. Each collection trench captures storm water runoff after it has passed through the vegetated area between the highway and collection trench. One additional concrete collection trench at each site captures storm water runoff at the edge of pavement. Test sites with slopes greater than 35 percent have one collection trench at the edge of pavement and one collection trench at the toe of the slope. A photograph of a test site with a slope greater than 35 percent is displayed on the left side of Figure 2. At the test sites with a slope less than 35 percent, one collection trench is located at the edge of pavement and the remaining collection trenches are located at intervals of approximately 2 m, 4 m, 6 m, and 8 m from the edge of pavement. A photograph of a test site with multiple collection trenches is displayed on the right side of Figure 2.

Table 1. Summary of Test Sites

Site No.	Location (City)	Freeway	Slope (%)[1]	Average Annual Rainfall (mm)	Average Annual Daily Trips (AADT)	Number of Collection Trenches[2]	Distance of Collection Trenches from Edge of Pavement (m)
Northern California							
1	Sacramento	I-5	5 / 33	437	75,000	4	1.1, 4.6, 6.6, 8.4
2	Cottonwood	I-5	52	1,001	38,500	1	9.3
3	Redding	SR-299	10	1,001	11,800	3	2.2, 4.2, 6.2
4	San Rafael	US-101	50	912	151,000	1	8.3
Southern California							
5	Yorba Linda	SR-91	14	358	226,000	4	1.7, 4.9, 7.6, 13.0
6	Irvine	I-405	11	325	237,000	3	3.3, 6.0, 13.0
7	Moreno Valley	SR-60	13	262	106,000	4	2.6, 4.9, 8.0, 9.9
8	San Onofre	I-5	8 / 13	262	124,000	3	1.3, 5.3, 9.9

Notes:

1 The Sacramento and San Onofre test sites have changes in the slopes. The change in slope at the Sacramento test site is located approximately 1.5 m from the edge of pavement. The change in slope at the San Onofre test site is located approximately 5 m from the edge of pavement.

2 Number shown does not include the edge of pavement collection trench.

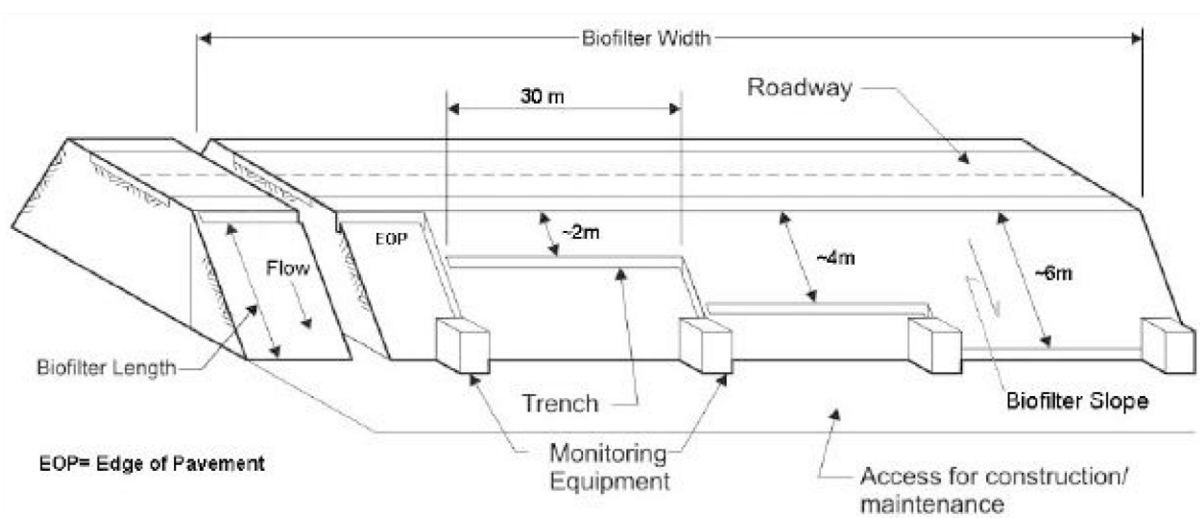

Figure 1. Schematic of Collection System

Figure 2. Cottonwood and Redding Test Sites.

The CHD Study utilizes automatic water quality sampling equipment that can be controlled remotely. The sampling equipment measures the storm water runoff flow captured in each collection trench. A 60-degree trapezoidal flume, with a depthmeasuring device, is located at the end of each collection trench. One monitoring station is placed at each collection trench. A monitoring station contains a data logger and control module; a flow meter; an automated peristaltic sampler; a cellular modem; interface electronics; power supply; and a tipping bucket rain gauge. The sampling equipment creates composite samples of storm water runoff in a flow-proportioned manner. The concentrations of constituents in these composite samples represent the "event mean concentrations" for the storm event sampled. The minimum constituent list for water quality monitoring included conventionals (e.g., TSS, conductivity, pH), nutrients (e.g., TKN, total phosphorus), and total and dissolved metals (e.g., copper, lead, and zinc), as detailed in the Caltrans Guidance Manual: Storm Water Monitoring Protocols (Caltrans, 2000).

The monitoring season for the first year of the CHD study was defined as October 1, 2001, through April 15, 2002. Weather forecasts were tracked and documented throughout the entire monitoring season. Storm events monitored were based on rain events forecasted to deposit at least 5 mm of rain, and were to be preceded by at least 24 hours, preferably 72 hours, of dry conditions.

Preliminary Results

Three of the four test sites in Southern California were located near metropolitan Los Angeles. The fourth test site in Southern California was located near metropolitan San Diego. Precipitation in Southern California during the 2000-2001 monitoring season was below average. Los Angeles and San Diego received only 30 and 29 percent, respectively, of their average annual rainfalls (DWR, 2002). Consequently, the number of storms successfully monitored in Southern California ranged from 2 to 8, depending on the site. Furthermore, most of the successfully monitored storms in Southern California only produced collected storm water runoff samples from the edge of pavement. Precipitation in Northern California was approximately average. The number of storms successfully monitored in Northern California ranged from 14 to 18, again depending on the site.

Preliminary results for total suspended solids (TSS) are presented in Table 2. Due to the small number of storm events sampled in Southern California, the Southern California data are not presented in this paper. However, TSS concentrations measured at the edge of pavement for the Southern California test sites are presented for comparison to the Northern California test sites. To determine treatment efficiency, the water quality characteristics of samples collected from the concrete collection trenches constructed into the slope were compared to those of samples collected at the edge of pavement for each storm event.

At the Southern California test sites, TSS concentrations at the edge of pavement ranged from 95 mg/L to 170 mg/L. Edge of pavement TSS concentrations at the Northern California test sites ranged from less than 30 mg/L to 68 mg/L. The difference in TSS concentrations at the edge of pavement between Northern and Southern California may be attributed to factors such as a difference in annual rainfall totals or the difference in traffic volumes.

Table 2. Summary of Selected Northern California Test Site Data

Test Site	Collection Trench at EOP 0 m	Collection Trench Located 1 m to 3 m	Collection Trench Located 3 m to 6 m	Collection Trench Located 6 m to 8 m	Collection Trench Located 8 m to 13 m
Number of Water Quality Samples Collected at Each Collection Trench					
Redding	14	11	13	11	NA
Cottonwood	14	NA	NA	NA	13
San Rafael	18	NA	NA	NA	16
Sacramento	16	15	13	11	14
Average TSS Concentration (mg/L) at Each Collection Trench					
Redding	30	15	4	5	NA
Cottonwood	68	NA	NA	NA	14
San Rafael	60	NA	NA	NA	21
Sacramento	57	32	18	34	13
Estimated TSS Concentration Reduction (%) at Each Collection Trench Compared to EOP Collection Trench					
Redding	—	50	87	83	NA
Cottonwood	—	NA	NA	NA	79
San Rafael	—	NA	NA	NA	65
Sacramento	—	44	68	40	77

Note:
NA - collection system does not exist at distance away from edge of pavement

Discussion

The results presented in Table 2 are preliminary. As previously mentioned, the study will continue for another monitoring season. Preliminary trends based on the TSS data are discussed below. The preliminary trends for total metals (e.g., copper, lead, and zinc) also follow the preliminary TSS trends assessed below. The preliminary trends for dissolved metals and nutrients do not follow the preliminary TSS trends.

Antecedent Dry Period. As previously mentioned, the first year of the CHD study recorded less than average rainfall in Southern California. Monitored storm events in Southern California ranged from 5.1 mm to 25.4 mm. The less-than-average rainfall in Southern California was accompanied by longer-than-normal dry periods between storms. These antecedent dry periods ranged from 5 days to 2 months. As a result, complete infiltration of the runoff occurred during all of the monitored storm events at the four CHD sites in Southern California. None of the downslope trenches collected any samples. The fortunate aspect of 100 percent infiltration is that none of the pollutants in the storm water runoff was released to local water bodies. The unfortunate aspect was that there were no data to judge the treatment effectiveness of these vegetated areas.

Vegetation Type and Density. Each CHD site exhibited established vegetation selected as part of the state agency's standard erosion control practices. There was site variation among species established. Vegetation species and density were documented twice at each test site during the first monitoring season, winter and summer. Results from the vegetation documentation are summarized in Table 3 and provided below (Caltrans, 2002).

Table 3. Summary of Vegetation

Site No.	Location (City)	Freeway	Winter Vegetative Coverage (%)[1]	Winter Vegetative Height (cm)[1]	Spring Vegetative Coverage (%)[1]	Spring Vegetative Height (cm)[1]
1	Sacramento	I-5	90-98	7-12	93-96	23-94
2	Cottonwood	I-5	70	12	79	31
3	Redding	SR-299	71-92	5-9	90-98	27-40
4	San Rafael	US-101	83	16	87	36

Notes:

1 A vegetation assessment was conducted at the eight test sites in February 2002 (Winter) and April 2002 (Spring).

Vegetation at the Sacramento test site consists mainly of ruderal species, dominated by non-native annual grasses and broadleaf herbs, growing among a relatively vigorous stand of native purple needlegrass (Nassella pulchra). Vegetation at the Cottonwood site consists mainly of ruderal species, dominated by non-native annual grasses and broadleaf herbs. Vegetation at the Redding test site consisted mainly of ruderal species, dominated by non-native grasses and broadleaf herbs. Vegetation at the San Rafael test site consists mainly of ruderal species, dominated by non-native annual and perennial grasses, and broadleaf herbs.

Slopes of Vegetated Areas. The Redding CHD site, with a 10 percent slope, recorded the highest reduction in TSS concentration. The resulting reduction in TSS concentration is approximately, 87 percent. In general, a flatter slope will result in lower flow velocities which will enhance sediment deposition and minimize erosion of the soil.

The preliminary results also indicate that steeper slopes, greater than 30 percent, also show notable TSS removal. The Cottonwood and San Rafael CHD sites have slopes at 52 and 50 percent, respectively. The average edge of pavement TSS concentrations for the Cottonwood and San Rafael CHD sites are 68 mg/L and 60 mg/L, respectively. The average toe of slope TSS concentrations for the Cottonwood and San Rafael CHD sites are 14 mg/L and 21 mg/L, respectively. The reduction in the average concentration for the CHD sites is 79 and 65 percent, respectively. The preliminary TSS removal for the CHD Study vegetated areas with steep slopes is approximately comparable to dry extended detention basins which can remove 70 to 80 percent of TSS (USEPA, 1983).

Length of Vegetated Areas. Based on the preliminary data, a notable increase in TSS removal occurred within the first 3 m of strip length. At the Redding CHD site, storm water runoff flows through a vegetated area 2.2 m in length to the first collection trench. At the Redding CHD site, the edge of pavement average TSS concentration was calculated at 30 mg/L and the average TSS concentration in the first collection trench was calculated at 15 mg/L. The resulting reduction in TSS concentration is 50 percent. At the Sacramento CHD site, storm water runoff flows through a vegetated area 1.1 m in length to the first collection trench. The edge of pavement average TSS concentration was calculated at 57 mg/L and the TSS concentration in the first collection trench was calculated at 32 mg/L. The resulting reduction in TSS concentration is 44 percent. One implication of the notable TSS removal within the first 3 m is that as the number of highway lanes gets expanded, the reduction in vegetated area length may not have an adverse impact on the treatment effectiveness of the vegetated area.

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