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Case Study: The Design of a Bioretention Area to Treat Highway Runoff and Control Sediment

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CASE STUDY: THE DESIGN OF A BIORETENTION AREA TO TREAT HIGHWAY RUNOFF AND CONTROL SEDIMENT

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ABSTRACT

The California Department of Transportation (Caltrans) has initiated a number of pilot projects to assess the performance and applicability of various storm water "green" Best Management Practices (BMPs). Green BMPs include vegetated swales and filter strips, constructed treatment wetlands, wet detention basins, and bioretention areas. One pilot project includes a 3-year study to design, construct, and investigate the water quality performance of a bioretention area BMP. In general, bioretention areas are soil and plantbased storm water treatment systems developed in the late 1980s in Prince George's County, Maryland. Pollutants are removed through biological and physical processes. To date, little performance data has been documented.

The pilot site is located in southern California along State Route 73. The BMP is an on-line system with a drainage area of approximately 1.6 ha (4.0 ac). The BMP includes two pretreatment devices to help remove litter and sediment. Storm water runoff is ponded to a depth of 150 mm (6 in). The ponding area will be planted with Creeping Wildrye, Salt Grass, Mexican Rush, and Clustered Field Sage. The bioretention area consists of a 75 mm (3 in) organic layer, a 1.2 m (4 ft) planting soil layer, a 0.3 m (1 ft) sand layer, and a 0.3 m (1 ft) gravel layer with a PVC underdrain system. The BMP will be installed with automated samplers at influent and effluent points. Water quantity and quality data from flow-composite samples of storm water runoff will be collected and evaluated during representative storms over a 3-year period.

The BMP incorporates design recommendations from available literature on sizing, configuration and vegetation selection. However, deviations in design were necessary to fit within the existing basin footprint. Additionally, the design included cooperation with U.S. Fish and Wildlife Service, California Department of Fish and Game, California Department of Health Services, and a Native American Tribal Council. This paper presents a lessons learned discussion on the design methodologies and challenges of this project.

Key Words: bioretention area; storm water treatment; BMPs

INTRODUCTION

Over the past six years, the California Department of Transportation (department) has initiated a number of pilot projects to assess the performance and applicability of various proprietary and non-proprietary storm water BMPs. In the fall of 1998, the department initiated a 3-year pilot project in southern California that included the design, construction, and monitoring of various storm water "green" BMPs. These green BMPs include vegetated swales and filter strips, and a wet detention basin. In addition to the investigation of these green BMPs, the department has recently initiated a study to design, construct, and investigate the water quality performance of a bioretention area BMP. The objectives of the pilot study include: documenting the design, construction, and maintenance costs; documenting maintenance requirements; and conducting influent and effluent water quality monitoring to investigate the performance of the BMP.

A bioretention area is a soil and plant-based storm water treatment BMP developed in the late 1980s in Prince George's County, Maryland (PGCM). The volume of water to be treated, referred to as the water quality volume (WQV), is ponded to a depth of 6 in within a basin that contains plants and an organic mulch layer. The ponded water infiltrates through an organic mulch layer and a planting soil layer, and into the in situ material underlying the bioretention area or into an underdrain collection system. The BMP traps particles which have been eroded from project sites. Pollutants are removed through biological and physical processes. The soil is designed to adsorb heavy metals, nutrients and hydrocarbons. The microorganisms in the soil are intended to cycle and assimilate nutrients and metals and degrade petroleum-based solvents and other hydrocarbons. Additionally, the planting soil filters the larger particles that do not settle out in the pretreatment area located upstream of the BMP. Bioretention areas can be used in a variety of settings from commercial parking lots to residential areas and can vary in size from single cell to multiple-cell systems.

BIORETENTION PILOT PROJECT OVERVIEW

Bioretention BMPs have been frequently used in the eastern United States to treat storm water runoff from small impervious areas, such as parking lots, or to treat storm water runoff from small residential lots. The purpose of this project is to apply the bioretention concept: (1) in the southern California climate, i.e., a short wet season and dry summers and (2) to the transportation environment, i.e., slightly larger drainage areas adjacent to freeways.

The pilot project included the following three general steps: (1) literature search; (2) siting of the BMP; and (3) design of the BMP. The purpose of the literature search was to identify design guidance in current use by practicing engineers. Siting for the BMP consisted of applying siting criteria from the design guidance to various candidate sites to select a preferred site. Once a preferred site was selected, design of the BMP started with hydrologic and hydraulic modeling of the preferred site. This modeling was conducted to simulate peak inflows and outflows and create inflow and outflow hydrographs. Finally, the design guidance was applied to the preferred site to generate the bioretention BMP design. Plans and specifications were prepared in accordance with department's standard protocols.

LITERATURE SEARCH

Design guidance from the Center for Watershed Protection (CWP) was selected for this project (Claytor and Schueler, 1996). The CWP design guidance was selected because it provides details on the individual design components of the bioretention BMP for storm water treatment. The

CWP design guidance was partially adapted from PGCM Design Manual for the Use of Bioretention in Stormwater Management (PGCMDER, 1993).

SITING

A project site is typically given and a storm water practitioner assesses which BMP can be applied to the project site. For the various department pilot studies, a BMP type is given and the practitioner assesses which site within an area can be best utilized for that BMP. The siting recommendations (Claytor and Schueler, 1996) applied to this project are listed in Table 1. The bioretention BMP had to be located within the department's right-of-way (ROW) along a freeway. Out of 12 candidate sites, a preferred site was selected based on the siting recommendations in Table 1.

DESIGN

The original bioretention design consists of the following components: (1) pretreatment; (2) ponding area; (3) organic layer; (4) planting material; (5) planting soil; (6) sand bed layer; (7) underdrain collection system; and (8) bypass structure (Claytor and Schueler, 1996). During the completion of the bioretention design, PGCM updated its 1993 design guidance manual for bioretention BMPs (PGCMDER, 2002). As a result, there are a number of changes between

Table 1 Bioretention Siting Recommendations.

Criteria	Description
Space	The size of the bioretention area should be at least 5 percent of the tributary drainage area.
Dimensions	The bioretention area should be at least 4.6 m (15 ft) wide by 12.2 m (40 ft) long.
Length-to-Width Ratio	The bioretention area should have a length-to-width (L:W) ratio of at least 2:1.
Drainage Area (DA)	The bioretention area should treat no more than 0.4 ha (1.0 ac) of tributary drainage area. If the tributary drainage area is larger, then multiple bioretention areas should be constructed or a portion of the runoff should be diverted around the BMP.
Head	At least 2.0 m (6.5 ft) of head is required to allow the bioretention area to operate by gravity. Storm water is ponded at a depth of 0.2 m (0.5 ft). The ponded storm water infiltrates through 1.2 m (4.0 ft) of planting soil, through a 0.3 m (1.0 ft) sand layer, and through a 0.3 m (1.0 ft) gravel layer before entering the underdrain collection system.

the original CWP design guidance and the 2002 PGCM design manual.

One of the key issues addressed in the 2002 PGCM design manual was premature clogging observed in a number of full-scale installations. After an evaluation of the new design criteria and discussion with PGCMDER staff, the decision was made to redesign the bioretention BMP to reflect the updated design guidance from PGCM. The redesign removed the sand bed layer, modified the planting soil mixture and reduced the planting soil depth.

The components of the final bioretention design are described below. A cross-section of the bioretention area is presented in Figure 1. An illustrated plan view of the project site is presented in Figure 2. Following the description of the design components is a brief discussion of the deviations from the design guidance and the resource agency coordination required for this project.

Pretreatment

There are two pretreatment components selected for this design project: a bioswale and a litter removal device (LRD). The purpose of the bioswale is to reduce the amount of sediment that enters the bioretention area. The LRD serves two functions: (1) concentrate the gross solids to one point for ease in cleaning; and (2) provide energy dissipation. The bioswale will be 15 m (49.2 ft) long and 610 mm (24 in) deep. The slope is set at 1.5 percent. The LRD will be placed in the bioswale. The LRD is 8.2 m (27.0 ft) long with a 600 mm (24 in) diameter. The LRD utilizes modular well casings with 5 mm x 64 mm (0.2 in x 2.5 in nominal) louvers to remove trash from storm water runoff.

Ponding Area

The ponding area provides surface storage for the WQV. Sediments not removed in the pretreatment components will settle out within the ponding area. Storm water runoff will be ponded to a depth of 152 mm (6 in). The surface area is designed at 0.09 ha (0.22 ac).

Organic Layer

An organic layer consisting of fine shredded hardwood mulch will be applied over the top of the bioretention area. The purpose of the organic layer is to filter finer particles from the storm water runoff and maintain soil moisture in the planting soil (CWP, 1996). The mulch layer should be: well aged, stockpiled or stored for at least 12 months; uniform in color; and free of other materials, such as weed seeds, soil, roots, etc. The mulch should be applied to a maximum depth of 76.2 mm (3 in).

Planting Material

The purpose of the planting material is to encourage diverse biological and bacteriological activity in the soil and to establish a diverse plant cover that will aid in the treatment of storm water runoff through the uptake of pollutants (CWP, 1996). Table 2 lists the recommended vegetation for this project.

Vegetation selection also requires adaptation to the highway environment. Vegetation must be able to withstand periods of saturation and drought. Also, potential pollutant build-up is a concern for plant viability. Where possible, plants native to the area of the project site were selected for use. An erosion control mix will be hydroseeded onto the side slopes to reduce potential erosion during the plant establishment period. While hydroseeding will be used on the side slopes, plugs will be used in the bioretention area to increase plant viability and decrease establishment time. Planting plugs may also decrease potential weed competition. Plants will only be irrigated during the establishment period. No fertilizers will be used because of their promotion of weedy grasses.

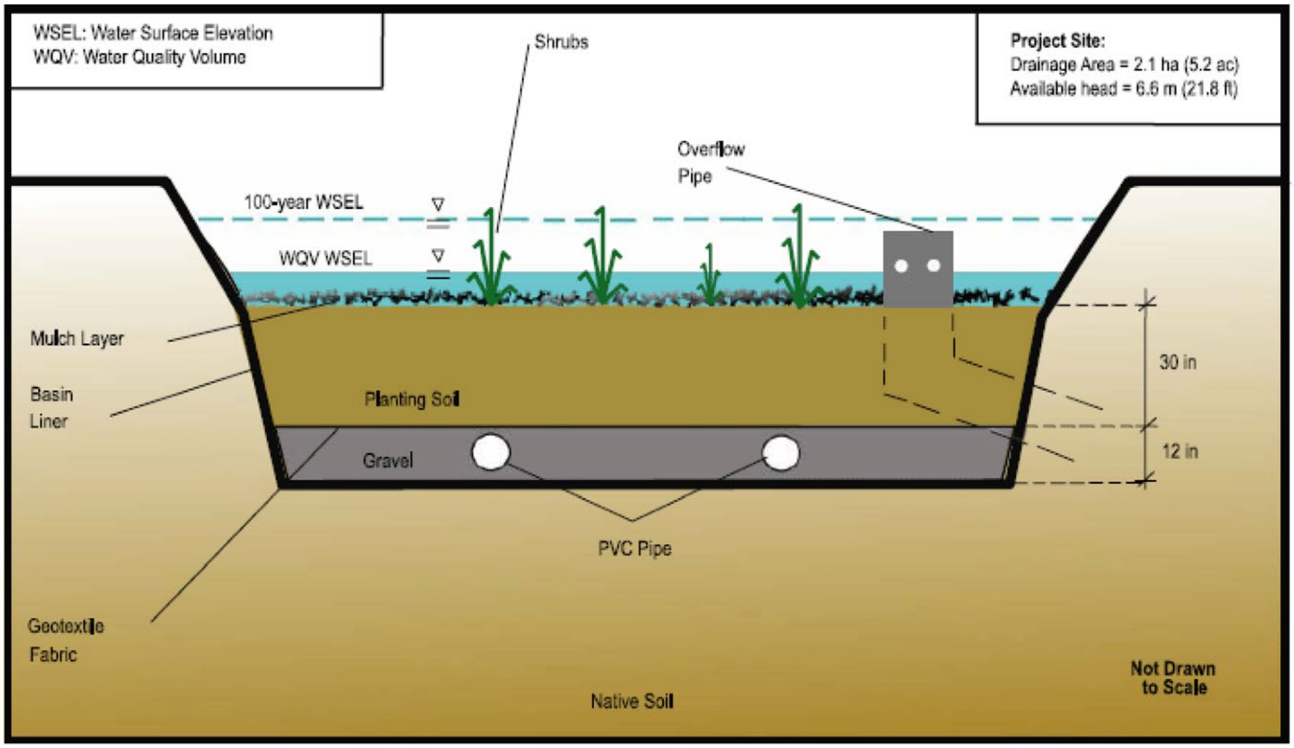

Figure 1. Cross-sectional view of bioretention area.

Table 2. Recommended Vegetation.

Botanical Name (Common Name)	Minimum Percent Germination	Application Rate
Leymus triticoides Pilger (Creeping wildrye)	40	8 kg/ha (7.1 lb/ac)
Distichlis spicata (Salt grass)	30	5 kg/ha (4.5 lb/ac)
Carex praegracilis W. Boot (Clustered field sedge)	N/A	3 kg/ha (2.7 lb/ac)
Cyperus eragrostis Lam. (Tall umbrella sedge)	40	0.8 kg/ha (0.7 lb/ac)
Juncus mexicanus Wild. (Mexican rush)	N/A	2 kg/ha (1.8 lb/ac)
Juncus phaeocephalus Engelm. (Brown-headed rush)	N/A	1.5 kg/ha (1.3 lb/ac)

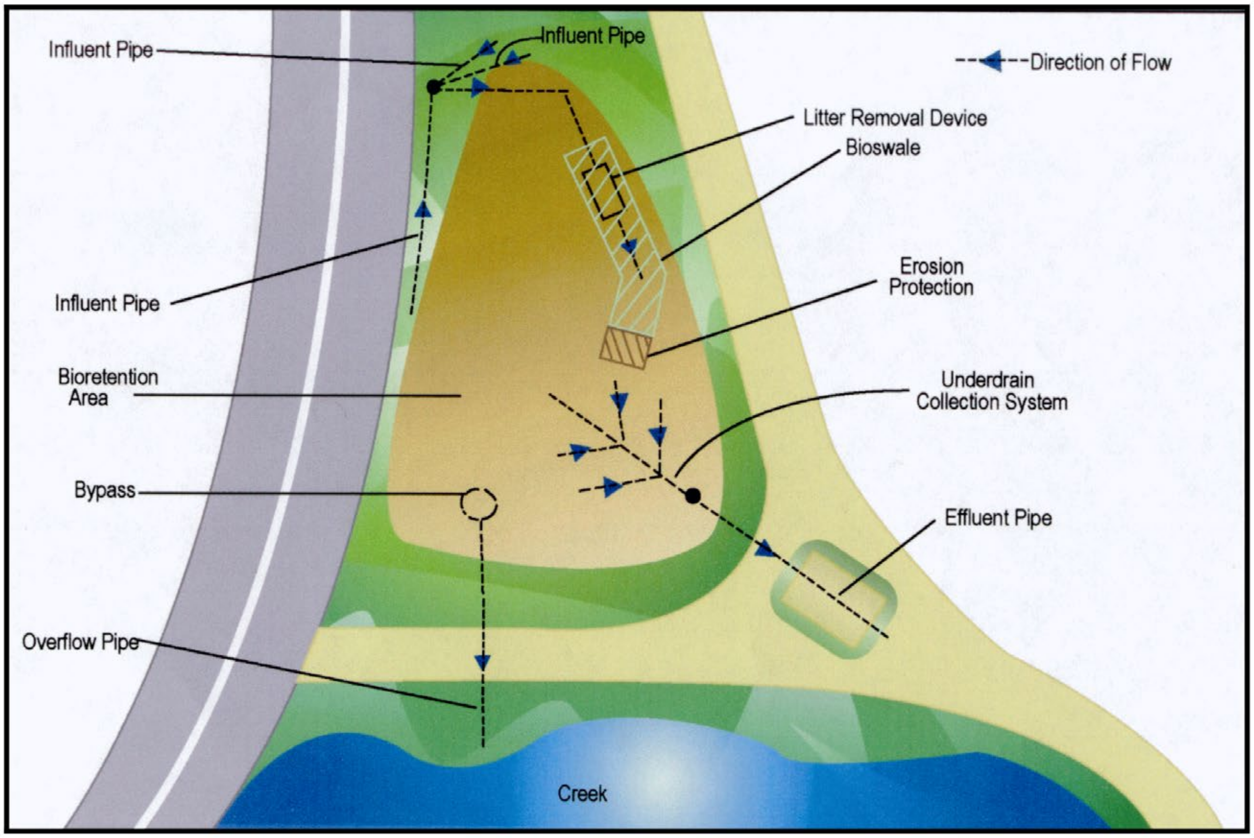

Figure 2. Illustrated plan view of project site.

Table 3. Planting Soil Characteristics.

Parameter	Value
pH range	5.2 to 7.0
Organic Matter	1.5% to 4.0%
Magnesium	39.2 kg/ha (35 lb/ac), minimum
Phosphorus (P_2O_5)	84.0 kg/ha (75 lb/ac), minimum
Potassium (K_2O)	95.3 kg/ha (85 lb/ac), minimum
Soluble Salts	≤500 ppm
Clay	10% to 25%
Silt	30% to 55%
Sand	35% to 60%
Permeability	≥0.31 m/d (1.0 ft/d)

Planting Soil

The planting soil provides bedding and nutrients for the planting material in the bioretention area. The planting soil will have the characteristics presented in Table 3.

Underdrain Collection System

The underdrain collection system collects the storm water runoff that has filtered through the planting soil. The underdrain collection system consists of 150 mm (6 in) perforated PVC pipe laterals placed in a 305 mm (1 ft) gravel layer. The PVC laterals are perforated every 152 mm (6 in) with three holes evenly spaced around the pipe circumference. The PVC laterals are typically spaced at a maximum of 3 m (10 ft) in the underdrain gravel.

Bypass Structure

Bioretention areas can be constructed as either on-line or off-line treatment systems. For an off-line treatment system, storm water runoff flows in excess of the design storm are routed around the bioretention area through a diversion structure. For an on-line treatment system, storm water runoff flows in excess of the design storm are routed into the bioretention area but through a bypass structure. The bypassed flows are not treated. A bypass structure routes storm water in excess of the WQV into a 900 mm (36 in) reinforced concrete pipe (RCP). The bypass structure will be fitted with a debris rack/litter cage.

Deviations from the Design Guidance

While applying the original design guidance (Claytor and Schueler, 1996) to the project, a few deviations were required to fit the bioretention BMP into the project site. These deviations are summarized below:

Claytor and Schueler, 1996	Recommends that a bioretention BMP be used as a water quality control practice only.
Bioretention BMP	Due to space constraints, a separate flood control basin could not be constructed in parallel to the bioretention BMP to detain flows greater than the design storm. As a result, the bioretention BMP will be used as a water quality control practice and for flood control.

Claytor and Schueler, 1996	Recommends the bioretention BMP be constructed as an off-line device, with the following exceptions: • drainage area is less than 0.20 ha (0.5 ac); and • insufficient room to divert runoff in excess of the WQV.
Bioretention BMP	As stated above, a separate flood control basin could not be constructed. As a result, the bioretention BMP will be constructed as an on-line device.

Claytor and Schueler, 1996	Recommends the use of a Pea Gravel Overflow Curtain Drain for overflow and to slow the velocity of the storm water runoff
Bioretention BMP	The bioretention design does not utilize a Pea Gravel Overflow Curtain Drain for overflow. Runoff in excess of the WQV is routed through a bypass stand-pipe. A litter removal device is utilized in this design. This litter removal device slows the velocity of the storm water runoff before entering the bioretention.

Claytor and Schueler, 1996	Recommends a maximum ponding depth of 6 in.
Bioretention BMP	The WQV is designed to pond to a depth of 6 in. However, because the BMP is constructed as an on-line device, storm events larger than the design storm will result in ponding depths greater than 6 in for short periods of time.

Claytor and Schueler, 1996	Recommends that the plant material selection should be based on the goal of simulating a terrestrial forested community of native species. The intent is to establish a diverse, dense plant cover to treat storm water runoff and withstand urban stresses from insect and disease infestations, drought, temperature, wind, and exposure.
Bioretention BMP	For the climate in this region, the project would utilize plants that could withstand periods of drought and periods of inundation. The selection of plants for this project focuses on native species.

Resource Agency Coordination

The design effort required cooperation with U.S. Fish and Wildlife Service (USFWS), California Department of Fish and Game (CDFG), California Department of Health Services (DHS), and a Native American Tribal Council. Primary cooperation took place with the CDFG due to the presence of an endangered species, the California Gnatcatcher (Polioptila californica). The Gnatcatcher utilizes Coastal Sage Scrub (CSS) as its primary nesting area. Due to the presence of CSS at the pilot site, mitigation was necessary to account for the loss of habitat required for the retrofit. The CSS area was not identified until mid-way through the design phase. As a result, the mitigation area was negotiated and lands purchased offsite. The construction schedule was also dramatically shortened, from September 1 to March 1, to avoid interfering with the nesting season for the Gnatcatcher. The USFWS protocol for nesting birds was followed to ensure survival.

Additional negations took place with the Native American Tribal Council when the pilot area was determined to contain ancestral remains. Archeological monitoring is scheduled during the construction process. Any remains or artifacts unearthed will be removed from the site and reburied according to the Tribal Council's protocols.

Negotiations were also made with the DHS to ensure that the bioretention area does not contain standing water long enough to breed mosquitoes. DHS considers mosquitoes a serious health risk due to the recent California outbreak of West Nile Virus. The agency was consulted and allowed to review the design plans for the bioretention basin to ensure the design would provide for a basin which drained within 72 hours. Once the bioretention BMP is constructed, the local vector control district will provide vector monitoring of the BMP for one year.

NEXT STEPS

Now that a final design has been prepared, the plan for the bioretention area will move into the construction phase. The construction schedule is dramatically shortened due to the bird nesting season, which makes construction during the wet season necessary. Once construction is complete, a plant establishment period will be necessary. Influent and effluent water quality monitoring will be performed for a period of three years. Constituents to be monitored include: hardness, total dissolved solids, total suspended solids, conductivity, total organic carbon, dissolved organic carbon, nitrate, total kjeldah nitrogen, total phosphorous, dissolved ortho-phosphate, and total recoverable and dissolved metals (arsenic, cadmium, chromium, copper, lead, nickel, zinc). Observational monitoring will also be performed. Notable observations will include plant survivability and die off, erosion, maintenance concerns, and vigor of the bioswale.

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