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California State University, Sacramento (CSUS)

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Design and Permitting Challenges of Highway Constructed Treatment Wetlands

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Authors:

Catherine Beitia, Caltrans/CSUS Office of Water Programs
Anna Lantin, RBF Consulting, Irvine
Laura Larsen, RBF Consulting, Irvine
David Alderete, Caltrans/CSUS Office of Water Programs
Misty Sharff, Caltrans/CSUS Office of Water Programs

Disclaimer:

Storm Water Program
CSUS Office of Water Programs
6000 J Street, Modoc Hall, Room 1001, Sacramento, CA 95819-6025

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DESIGN AND PERMITTING CHALLENGES OF HIGHWAY CONSTRUCTED TREATMENT WETLANDS

Catherine Beitia

Office of Water Programs
California State University, Sacramento
7801 Folsom Blvd., Suite 102
Sacramento, CA 95826

Anna Lantin, PE and *Laura Larsen*, PE

RBF Consulting
14725 Alton Parkway
Irvine, CA 92619-7057

David Alderete and *Misty Scharff*, APSSc

Office of Water Programs
California State University, Sacramento
7801 Folsom Blvd., Suite 102
Sacramento, CA 95826

BIOGRAPHICAL SKETCHES

Catherine Beitia

Catherine Beitia has been involved with the California State University Sacramento performing research on storm water treatment technologies and vector control for the California Department of Transportation since 2000. She received her bachelor's degree in Biological Sciences from the University of California, Davis, and is currently a graduate student at the University of California, Davis.

Laura Larsen, PE

Laura Larsen is a professional civil engineer with focus on storm water management involving Best Management Practice design, hydrologic/hydraulic analyses, and comprehensive runoff management plans. She obtained her education from California State Polytechnical University, Pomona, Calif., 1998 B.S., and from UCLA, M.S. 2000. She has extensive experience in storm water management projects including water quality research studies, BMP design, construction oversight, BMP implementation, water quality monitoring, operation and maintenance, and BMP performance data analysis.

Anna Lantin, PE

Anna Lantin is a senior associate, professional civil engineer with focus on storm water management involving water quality BMP design and research, hydrology, and hydraulics. She obtained her education from Colorado State University, 1990 B.S., and post-graduate in Civil Engineering. Her 13 years of engineering includes extensive experience in storm water management, flood-control projects in the southwestern region of the United States including planning, design, sediment transport analyses, surface water quality BMP research, and floodplain management. She is a licensed professional civil engineer in the states of California and Arizona and is a member of the IECA.

David Alderete

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.

Misty Scharff, APSSc

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, where she assisted in numerous erosion control research studies. She has been a member of IECA since 1996.

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ABSTRACT

Over the past several years, the California Department of Transportation (Department) has initiated a number of pilot projects to assess the performance and applicability of various storm water Best Management Practices (BMPs). Included in the list are constructed treatment wetlands and wet detention basins. In the fall of 2001, the Department initiated a multi-year pilot study to design, construct, and investigate the water quality performance of one constructed treatment wetland and one wet detention basin in southern California as part of a storm water BMP retrofit project. The two study sites have the potential to provide habitat for two species of concern: the southwestern willow flycatcher and the least Bell's vireo. In addition, the sites are located adjacent to a Native American burial ground. Each 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 three-year period.

In general, a constructed treatment wetland and a wet detention basin are designed with a permanent pool of water with varying depths and vegetation coverage. Additionally, both of these BMPs rely on physical, biological, and chemical processes to remove pollutants from storm water runoff. Sedimentation processes remove particulates, organic matter, and metals. Biological uptake removes dissolved metals and nutrients. Chemical processes include chelation, precipitation, and adsorption. The collection and storage of storm water runoff is important to help reduce the erosive potential and to allow soil particles to settle.

This paper presents a lessons learned discussion on: (a) the design methodologies used for the constructed treatment wetland and the wet detention basin; (b) the federal, state, and local permitting challenges for deploying both BMPs; and (c) construction challenges. A literature search was conducted to identify design guidelines for both BMPs currently used by practitioners. The pilot sites incorporate design recommendations from available literature on sizing, configuration, terrain-fitting, and vegetation selection. Consultation was made with a number of agencies to discuss potential issues which may develop during construction and future maintenance of the BMPs. Consultations with the U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, California Department of Fish and Game, California Department of Health Services, the Juaneño Band of Mission Indians, and the Gabrielino/Tongva Tribal Council were required before the BMP designs could be completed.

Key Words: constructed wetland; water quality; BMPs; storm water; treatment wetlands

INTRODUCTION

Over the past several years, the California Department of Transportation (Department) has initiated various pilot projects to assess the performance and applicability of multiple storm water Best Management Practices. Two of the BMPs assessed for performance include the constructed treatment wetland (CTW) and wet detention pond. In 1998, the Department designed, constructed, and tested a wet detention pond as part of the BMP Retrofit Pilot Program in southern California. In 2001, the Department embarked on a multi-year pilot project to design, construct, and investigate the water quality performance of a CTW and wet detention pond along State Route 73 (SR-73) in southern California. In 2002, the Department embarked on another project to design, construct, and test a CTW near the San Francisco–Oakland Bay Bridge. This paper primarily focuses on the design and permitting challenges from the 2001 project in southern California. For the SR-73 project, water quantity and quality data from flow-composite samples of storm water runoff will be collected over a three-year period. Other factors such as maintenance thresholds, the ability to produce vectors, and cost to construct and maintain these wetland-type BMPs will also be investigated.

Constructed treatment wetlands and wet detention ponds provide natural filters for storm water and allow sedimentation. By allowing storm water to deposit sediment into a specified basin, downstream water quality and erosion control is improved. Constructed wetlands provide integrated ecological functions by combining water reuse, habitat restoration, sedimentation, and aesthetic value to the landscape.

In general, a constructed treatment wetland and a wet detention pond are designed with a permanent pool of water with varying depths and vegetation coverage. Additionally, both of these BMPs rely on physical, biological, and chemical processes to remove pollutants from storm water runoff. Sedimentation processes remove particulates, organic matter, and metals. Biological uptake removes dissolved metals and nutrients. Chemical processes include chelation, precipitation, and adsorption. The collection and storage of storm water runoff is important to help reduce the erosive potential and to allow soil particles to settle.

Additionally, cultural, archeological, and permitting issues served as a challenge to the Department. Consultation was required with various resource agencies such as the U.S. Army Corp of Engineers, U.S. Fish and Wildlife Service, California Department of Fish and Game, California Department of Health Services, the Juaneño Band of Mission Indians, and the Gabrielino/Tongva Tribal Council to determine jurisdiction, investigate vector concerns, and preserve Native American burial grounds.

A literature search was conducted to gather current design guidelines for both types of BMPs used by practitioners. Design factors from the literature search were incorporated into the pilot sites. However, site characteristics and hydrology were the driving force in choosing a design methodology.

Since the two sites are pilot projects, other factors that will determine the applicability of these BMPs for statewide Department use include the maintenance effort required, and the ability to produce vectors. Although these two don't seem to be related, in fact they are interdependent. If wetland-type BMPs are properly maintained, habitats that attract vectors will not proliferate; vice versa, abundance of vectors will remain low if wetlands/wet ponds are properly maintained. Vectors, such as mosquitoes, have the ability to carry vector-borne diseases such as West Nile Virus, and can affect public health. Plants used in the wetland/wet detention pond BMPs were selected with vector control in mind, while still maintaining filtration capabilities to reduce erosion downstream.

As mentioned earlier, if properly maintained, wetlands should keep vector production to a minimal level. Based on the Department's prior experience with a wet pond located off La Costa Blvd. and I-5 in San Diego, initial maintenance thresholds were developed. Although the Department has an idea of what maintenance is required, these pilot projects will attempt to refine maintenance thresholds on a statewide level.

CULTURE AND ARCHAEOLOGY

During the environmental planning phase of the project, it was determined that there is potential for culture and archaeology impacts associated with the construction of the basins. Both basins are located in a region of Orange County where documented American Indian settlement had occurred. Involvement of the two Native American tribes was required during the BMP design phase and is anticipated during the construction phase.

PERMITTING REQUIREMENTS

A constructed wetland is defined by the U.S. Environmental Protection Agency (EPA) as "A wetland intentionally created from a non-wetland site for the sole purpose of wastewater or storm water treatment. These wetlands are not normally considered water of the United States or water of the State" (EPA, 1993). Resource agencies were consulted regarding the requirements for implementation and maintenance of the treatment wetlands and wet basins. It was determined that the sites were not currently within jurisdictional waters of the United States. Under the definition of the waters of the United States in both federal environmental agencies, there is an exemption for waste treatment systems. The exemption reads, "waste treatment systems, including treatment ponds or lagoons designed to meet the requirements of the CWA (Clean Water Act)….are not waters of the United States." Routine maintenance of the basins would be needed during the life of the BMP. For the SR-73 wet detention pond and wetland sites, the California resource agency and the Department engaged in a Streambed Alteration agreement (Section 1601) to allow for maintenance of the basins with conditions to avoid adverse impacts to birds and wildlife resources, limiting maintenance activities within a specific time period to avoid the bird nesting season.

SITING

During the summer of 2001, the Department initiated a statewide reconnaissance study (Caltrans, 2001) to identify and select sites suitable for the design, construction and testing of CTWs within the transportation environment. The reconnaissance study was a collaborative effort between the Department and the regulating agency, the California State Water Resources Control Board (SWRCB). Approximately 1,100 miles out of a total of approximately 16,000 miles were evaluated.

The reconnaissance study consisted of four main steps. First, preliminary siting criteria were developed and passed along to Department district staff. The preliminary siting criteria included availability of perennial water, avoidance of jurisdictional status, and minimum site area and dimensions. The local knowledge of the Department district staff was used to identify specific highway segments that could potentially contain sites to meet the preliminary siting criteria. The identified sites were organized geographically into an initial list for site visits. Second, site visits were conducted to assess how well each site met the preliminary criteria. From the site visits, a list of sites for further consideration was developed. Third, available as-built plans were reviewed for the sites on the list for further consideration. The as-built plans helped assess the drainage area characteristics. Finally, each criterion for each site was given a score based upon professional judgment. The remaining sites were ranked based upon the total score calculated.

Overall, a reconnaissance of 1,100 miles of highway segments resulted in a potential list of 24 sites. These 24 sites were reduced to 12 sites through the screening process. The remaining 12 sites were ranked by calculating a total score, as discussed above. The top three sites, listed in Table 1, were incorporated into projects for the design, construction and testing of CTWs.

One observation from the reconnaissance study was the unexpected small number of sites available to install a CTW. There were two primary reasons for the small number of sites. First, the Department did not want to install CTWs in areas where the CTWs come under the jurisdiction of the environmental agencies, which would result in a lengthy permitting process. As a result, CTWs would need to be located in upland areas. Second, most areas within the Department right-of-way do not have an available source of perennial water to sustain vegetation during the summer months.

HYDROLOGY AND DESIGN

The water quality volume (WQV) was estimated based on 38 mm/hectare (0.6 in/acre), the average for the area. The specified WQV is for paved/roadway runoff (impervious) areas, and adjustments are made for pervious areas where appropriate. The basins at 1080R and 765L currently function for both flood control and water quality. For the purpose of hydrologic analysis, water quality volume within the basin is assumed as dead storage (i.e., water quality volume is in addition to the flood control storage volume). The basins are designed to drain to the permanent pool elevation, drain within 24 hours, and have the ability to convey the 25-year storm. Table 2 summarizes the hydrologic parameters for each site.

Table 1. Results of Reconnaissance Study.

Rank	Site Location	Project
1	Eastbound I-80 I-80 / I-580 / I-880 Interchange	San Francisco–Oakland Bay Bridge BMP for Replacement of Eastern Span
2	Southbound SR-73 El Toro Road Off-ramp (Basin 765L)	CSF BMP Replacement Project
3	Northbound SR-73 Bonita Canyon Drive On-ramp (Basin 1080R)	CSF BMP Replacement Project

Table 2. Hydrologic Summary.

Parameter	Wet Pond	Constructed Wetland
WQV	3814 m^3	347 cm
Drainage Area	25 ha	2.3 ha

Wet ponds (a.k.a., storm water ponds, retention ponds, wet basins, wet detention ponds) are constructed basins that have a permanent pool of water throughout the year (or at least throughout the wet season). The primary difference between constructed wetlands and wet ponds is a greater average depth and peripheral vegetation rather than complete cover. Wet ponds and constructed wetlands treat incoming storm water runoff through settlement and biological uptake. The primary pollutant removal mechanism is settlement of suspended sediments. Pollutant uptake, particularly nutrients, also occurs to some degree through biological activity in the pond. Wet ponds are among the most widely used storm water practices. While there are several different versions of the wet pond design, the most commonly adapted is the extended detention wet pond, where storage is provided above the permanent pool in order to detain storm water runoff and promote settling.

Permanent Pool Size

There are several variations of the wet pond design, including constructed wetlands, and the wet extended detention ponds. There also are a number of methodologies for determining the appropriate permanent pool volume for each type depending on the objectives of the facility. Most prominent are the two methodologies described in detail by WEF/ASCE (1999) associated with sediment and phosphorus removal:

- Solids-settling design method relies on the solids-settling theory and assumes that all pollutant removal is because of sedimentation.
- Lake eutrophication model design method provides for a level of eutrophication by accounting for the principal nutrient removal mechanisms.

In addition to theoretical models for permanent pool sizing, many cities and other regulatory entities have published recommendations for the size of the permanent pool include the following:

Wetland:

- CASQA (2003) suggests that the permanent pool volume be twice the water quality volume.
- Urbonas, 1992 (ref. Young et al., 1996), states: The wetland pond should provide a minimum permanent storage volume equal to three-fourths of the water quality control volume. The full water quality capture volume should be provided above the permanent pool.

Wet Basin/Wet Pond:

- CASQA (2003) suggests that the permanent pool volume be twice the water quality volume.
- Schueler, 1987 (ref. Young et al., 1996), had several alternatives:

    i. 13 mm (0.5 in) of runoff over the contributing watershed area
    ii. 13 mm (0.5 in) of runoff over the impervious portion of the contributing area
    iii. Permanent pool equivalent to a variable depth of runoff distributed over the watershed area
    iv. Average of two weeks of retention within the pond (about four times the volume of runoff generated by the mean storm over the watershed area).

- Washington State Department of Transportation, 1995 states: Permanent pool equal to the runoff volume of the 6-month design storm.
- Denver Urban Drainage and Flood Control District (Urbonas et al., 1992) states: The design of the wet pond includes a permanent pool equal to 1.0 to 1.5 times the water quality volume.
- King County (1996) requires that the permanent pool be three times the volume of runoff from the mean annual storm mean.

Differences in the required water quality volume in different jurisdictions also mean that two facilities designed to the same standard (i.e., twice the water quality volume) may have quite different sizes relative to the average storm size at each location. Despite the critical role played by the permanent pool in pollutant removal, there is surprisingly little empirical data relating pool volume (as normalized by area and average storm size) and performance. Consequently, additional research to develop the relationship between pool volume and performance is warranted. The SR-73 treatment wetland and wet detention pond will be monitored. Each water quality monitoring station will measure flow and take flow-weighted, composite water quality samples that will be shipped to a certified lab for analysis. Additionally, one of the stations at each basin will be equipped with a rain gauge to measure rainfall. A Sampling and Analysis Plan will be prepared prior to the beginning of the monitoring effort.

In an earlier unpublished study conducted in the San Diego area, a wet pond was constructed at La Costa Blvd. and I-5. This pond had a permanent pool volume equal to three times the water quality volume. Because the water quality volume selected at that time was much larger than now required by the regulating agency, the permanent pool was approximately 7.7 times the mean storm runoff volume. The goal in this project is to document the performance of a much smaller system to determine if more compact facilities that would be appropriate for space constrained right-of-ways would offer substantial pollutant removal. Consequently, the following permanent pool volumes that have been selected for these sites are summarized in Table 3.

VECTOR CONTROL

Many vectors (mosquitoes, rodents, ticks, and fleas) carry vector-borne diseases, such as malaria, West Nile Virus, dog heartworm, Lyme Disease, and plague. For the Department, the most problematic of these vectors has been mosquitoes, as they require standing water to complete their life cycle from larvae to adult. As wetlands and wet ponds contain permanent pools of water to provide for treatment through settling, vector control has long been a concern of the Department to continue with BMP design while still minimizing impacts to public health. Dense vegetation provides harborage and shelter for mosquitoes. Based on the La Costa wet pond experience in San Diego, an annual vegetation harvest was implemented primarily to reduce the production of vectors and maintain access. Vegetation became so dense that the local vector control agency could not gain access to the waters (see Figure 1).

Table 3. Summary of Permanent Pool Sizing Criteria.

BMP	Cited Criteria	Permanent Pool Volume to Water Quality Volume Ratio
Constructed Wetland	CASQA, 2003	2:1
	Denver Urban Drainage Flood Control (Urbonas et al., 1992)	0.75:1
	Selected for SR73 Wetlands Project	0.75:1
Wet Basin/Wet Pond	King County, 1996	3:1
	Schueler, 1987 (Young et al., 1996)	1 to 4:1 (approx.)
	CASQA, 2003	2:1
	Denver Urban Drainage Flood Control (Urbonas et al., 1992)	1 to 1.5:1
	Selected for SR73 Wet Detention Pond Project	1:1

Selected design features for the pretreatment, treatment, vegetation coverage, and side slopes are summarized in Table 4.

Table 4. Selected Design Features.

Design Criteria	Selected Design for the Constructed Wetlands	Selected Design for the Wet Pond
Pretreatment	• A sediment forebay/small pool (typically about 10% of the volume of the permanent pool) will be incorporated to allow for pretreatment • Design features will be incorporated to ease maintenance of both the forebay and the main pool of ponds. Maintenance access will be provided.	• A sediment forebay/small pool (typically about 10% of the volume of the permanent pool) will be incorporated to allow for pretreatment • Design features will be incorporated to ease maintenance of both the forebay and the main pool of ponds. Maintenance access will be provided.
Treatment	• 0.75:1 (permanent pool to volume treated) ratio • Basin is designed with a length-to-width ratio of at least 1.5:1. In addition, the design will incorporate features to lengthen the flow path through the pond, such as underwater berms/baffles designed to create a longer route through the pond.	• 1:1 (permanent pool to volume treated) ratio • Basin is designed with a length-to-width ratio of at least 1.5:1.
Vegetation	• Vegetation coverage is at least 50%.	• Vegetation coverage is at least 25%.
Permanent Pool Depth	• 0.5 to 1.2 m	• 1.2 to 2.4 m
Pond Side Slopes	• Basin side slopes will vary between 1:2 and 1:4 (H:V) to meet safety and maintenance requirements. • A vegetated buffer will be provided around the pond to protect the banks from erosion and provide some pollutant removal before runoff enters the pond by overland flow. • Ponds will incorporate an aquatic bench (i.e., a shallow shelf with wetland plants) around the edge of the pond.	• Maximum pond side slopes 1:2 (H:V) • Pond design will incorporate an aquatic bench (i.e., a shallow shelf with wetland plants) about 2 m wide within the pond.

Source: Urbonas, B.R., et al., 1992; Young, G.K., et al., 1996, FHWA-PD-96-032; CASQA, 2003.

Figure 1. La Costa Wet Basin, March 1999 and June 2003.

Dense vegetation also prevented access to mosquitofish (*Gambusia affinis*) to biologically control mosquito larvae. Although biological and chemical control was used at La Costa, recommendations by the local vector control agency in San Diego were provided to the Department to ensure that vegetation doesn't continue to be problematic. In the design of the wet basin in Orange County, these recommendations were incorporated to prevent vector harborage, and thus production. Side slopes became steeper to prevent vegetation outgrowth and enhance access for aquatic predators, and open areas of water became deeper. Additionally, plants were selected that may require the least amount of management and that possess simple leaves. Mosquito oviposition may be hindered by less vegetation surface area in which to attach.

Because of its inherent design to contain a permanent pool of water, efforts by the local vector control agency in Orange County will again be used to monitor and abate sites CSF System 765L and 1080R. A mosquito production study will take place to determine if the wetland and wet detention pond are producing a large abundance of mosquitoes. Based on the design recommendations provided by the San Diego vector control agency and the care utilized to select "mosquito predator-friendly" vegetation, the production study will help determine if the changes in design were useful in preventing mosquito production and increasing mosquito predator abundance.

MAINTENANCE

Maintenance thresholds were developed for the La Costa wet pond in San Diego. As an initial attempt, these defined maintenance activities will be used at CSF Systems 765L and 1080R. As the pilot project progresses, actual maintenance required will be used to further define the thresholds. Maintenance activities defined in the plan are listed in Table 5.

Table 5. Maintenance Thresholds for Wet Ponds.

Maintenance Activity	Maintenance Indicator	Measurement Frequency
24 hour drawdown	Exceeds 24 hours	Once during wet season
Burrow inspection	Burrows, holes, mounds	Annually after vegetation harvest to prevent erosion
General maintenance inspection	Inlet/outlets damaged or hindered by debris, erosion, vandalism, etc.	Once in the dry season, once in the wet season
Vegetation harvest	Mosquitofish cannot freely access emergent vegetation zones	Annually in the dry season, avoid nesting season
Access road maintenance	Access to BMP is prevented	Annually in the dry season

CONSTRUCTION ISSUES

Based on the La Costa wet pond experience, the main issues during construction of the wet pond were centered around constructability and unknown field conditions. Groundwater was expected during the excavation and was encountered. Dewatering was accomplished by gravity drainage to a settling pond, where the water was pumped to a Baker™ tank prior to being discharged to the adjacent creek. Because intercepted groundwater was the primary source to sustain a permanent pool, a pond liner was installed. Construction of the pond liner proceeded without incident but required specialized experience and subgrade preparation. Similar conditions may be expected for the two sites in Orange County. Subsurface groundwater has been encountered at the two sites in Orange County. Installation of an impermeable liner may be necessary to sustain a permanent pool. The subgrade surface grading would need extra care to ensure a smooth homogeneous surface to preclude damage to the impermeable liner.

Anticipated construction for the sites will begin September 2004. Monitoring of the basin will commence after the vegetation establishment period. Sites will be monitored for a period of three years for water quality performance, operation, maintenance, and vector production.

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