Guide to Phytoremediation Of Highway Runoff

How To Integrate Permanent Vegetative Design Features Into Highway Drainage To Minimize Pollutant Levels In Highway Runoff

November 2001

Disclaimer

The Guide should not be construed as policy of Caltrans. The Guide is intended to be used as a guidance document to demonstrate application of phytoremediation in highway storm water runoff drainage designs. While the storm water runoff treatment systems described in this manual may also serve the purpose of compliance with Caltrans permit requirements, use of any of the practices described herein for compliance purposes should be should be verified with Caltrans and appropriate regulatory agencies.

Although this document was prepared for Caltrans District 4, the phytoremediation methods described in the Guide are broadly applicable to all of California. Vegetation selection will differ in other Major Land Resource Areas.

Report Preparation

This Guide was originally prepared by the San Francisco Estuary Project under contract to Caltrans. TDC Environmental, WRECO, and Geoff Brosseau prepared the original text and drainage design examples in the Guide. Caltrans has updated the text to reflect changes in regulatory requirements and related Caltrans policy that occurred as the original manual was being finalized by the San Francisco Estuary Project.

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1.0 Introduction

Properly designed and maintained highway vegetation has significant potential to reduce pollutant levels in highway storm water runoff. Both the physical nature of the drainage design and the specific plant species selected contribute to the ground cover's ability to remove pollutants from runoff. This guide shows how to integrate highway drainage and vegetation management to enhance the treatment of highway storm water runoff.

The most important processes for highway runoff pollutant removal are infiltration, filtration, and sedimentation. Vegetation promotes infiltration two ways: it slows storm water flow, increasing time for water to infiltrate, and plant roots tend to keep soil porous, enhancing infiltration rates. Vegetation with fine leaves and/or dense root masses (*e.g.*, grasses) provides physical filtration of fine particulate matter. By slowing flows, vegetation enhances sedimentation rates—and then tends to bind the pollutants and sediments in place.

While the concepts in this guide are broadly applicable, site-specific climate, soil conditions, drainage context, and regionally suitable vegetation will influence the appropriateness and effectiveness of treatments in a given geographic area. This guide focuses on Caltrans District 4; that focus determined the selection of the examples, the plant species, and some of the specific recommendations for planting and maintenance.

Under state and Federal water quality mandates, Caltrans may be required to treat highway storm water runoff to remove pollutants. Caltrans has received a permit issued by the State Water Resources Control Board—the National Pollutant Discharge Elimination System Permit (NPDES Permit)—that details specific requirements for highway storm water runoff treatment. The Caltrans *Storm Water Management Plan* describes procedures and practices that should be used to remove pollutants from storm water runoff in accordance with NPDES Permit requirements. The *Project Planning and Design Guide* provides procedures for incorporating practices required by the NPDES Permit into highway project designs.

As this guide was being prepared, Caltrans was in the process of determining specific design standards for storm water treatment facilities. While Caltrans *Storm Water Management Plan* supports the use of vegetation-covered soil areas for treatment of storm water runoff, it is likely that the design details in this guide will not be consistent with final Caltrans design standards, which will be detailed in Appendix D of the *Storm Water Management Plan* (and subsequent documents required by the NPDES Permit) and in a revised *Project Planning and Design Guide* The most recent Caltrans storm water management documents should be consulted prior to designing any product intended to address NPDES Permit requirements for treating storm water runoff.

1.1 How to Use This Guide

The purpose of this guide is to provide training, resources, examples, and tools for Caltrans hydraulic engineers and landscaping architects to use in identifying and selecting permanent measures for highway projects that remove pollutants from highway runoff. Selection of such features can be integrated into the Caltrans project development process (see Figure 1).

This guide is organized into the following sections:

Section 2.0 Information Needs—This section identifies the information necessary for the design process (*e.g.,* soil type, precipitation, major land resource area, groundwater table level, hydrograph).

Section 3.0 Examples—This section provides design concepts for highway drainage conditions. The scenarios for design concepts under specific field conditions illustrate available measures and treatments and train the guide user how to identify opportunities based on site-specific conditions. The examples consist of generic schematic drawings of typical drainage elements modified or enhanced for pollutant removal capability.

Section 4.0 Glossary—This section includes definitions of terms and acronyms.

Section 5.0 Resource List—This section includes a list of Caltrans storm water resources, design resources, other water quality resources, and phytoremediation resources.

This guide is not intended as a prescriptive document that requires all projects be designed with the ideas presented here—but it does present a design philosophy and approach that should be seriously considered for all projects. The example scenarios cover just a few of the more typical District 4 highway drainage situations. The examples present conceptual highway drainage designs and note specific measures and treatments that can be incorporated into each design to enhance pollutant removal. Highway design and maintenance constraints (such as driver safety, fire safety, and maintenance requirements) are also considered and addressed. It is envisioned that each Caltrans project team will adopt or adapt those design concepts and specific measures and treatments that work best for each project.

This guide is not intended as a prescriptive document that requires all projects be designed with the ideas presented here—but it does present a design philosophy and approach that should be seriously considered for all projects.

1.2 Basic Principles

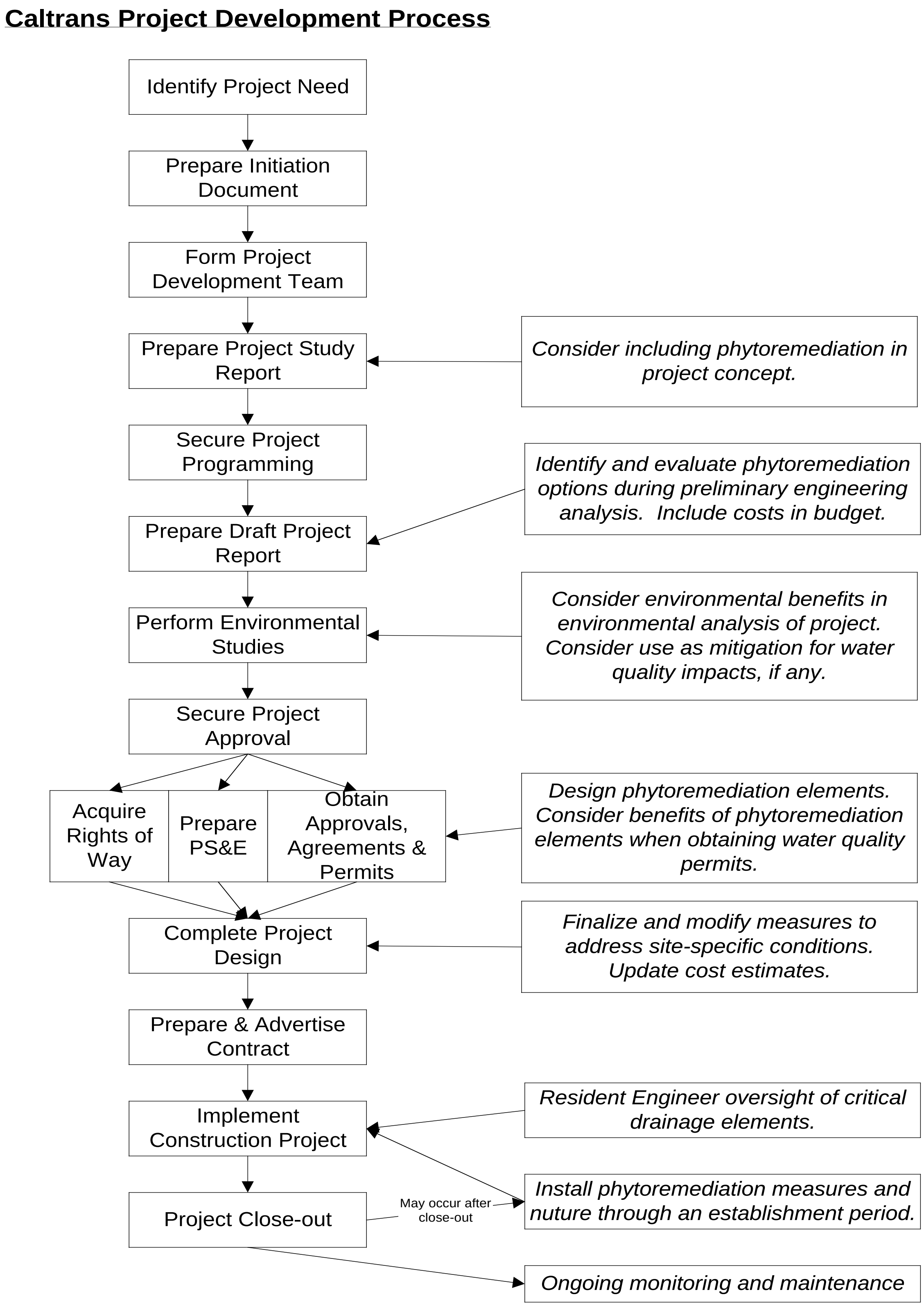
1.2.1 Storm Water Runoff Quality Management

The management of storm water runoff has changed in the last 20 years. The following excerpt from an American Society of Civil Engineers (ASCE) manual of engineering practice sums up why this occurred:

> *The quality of [urban] stormwater was largely ignored in the design of [urban] drainage systems until about 1980. Previously, the focus was on efficient surface drainage and flood control, namely the effects of relatively large storm events. However, a number of engineers and scientists were becoming aware that runoff from smaller, frequently occurring storm events was the cause of many observed negative effects in the nation's streams, lakes, estuaries, wetlands, and other receiving water systems downstream of, and within, the urban and urbanizing areas. Stream banks experienced accelerated erosion, stream habitat was degraded or lost, lakes and estuaries eutrophied at a faster rate, and the water quality in the receiving waters showed noticeable degradation during and sometimes after wet weather events.*[1]

[1] Annotated excerpt from *Urban Runoff Quality Management*, 1998, ASCE Manual and Report on Engineering Practice No. 87 and Water Environment Federation Manual of Practice No. 23.

Figure 1. Integrating Stormwater Runoff Phytoremediation into the Caltrans Project Development Process



To address these negative impacts, the field of storm water runoff management expanded to address both the quality of runoff as well as the quantity. Research in the 1990s demonstrated that small storms add up. Because of their frequency, small storms (*i.e.*, two year recurrence interval or less), produce the vast majority of total runoff over time. In the Bay Area, small storms account for approximately eighty percent of total annual runoff. By targeting these small storms, runoff can be managed for water quality through relatively small water quality systems. In this way, managing frequent small storms can address a large part of the storm water pollution problem.

With this awareness, engineers now consider and design for water quality treatment of small storms, because of their frequency and cumulative impacts, as well as for safely managing the flow from infrequent large rainfall events.

The methods used to manage runoff from small storms to protect water quality depend on the pollutants in the runoff and the pollution problems in the creek, river, bay, or ocean shore area where the runoff eventually flows. In Caltrans District 4, the metals and toxic organic pollutants in highway runoff are of special concern, because these pollutants have been found to adversely affect the habitat in San Francisco Bay (see Table 1, on the next page). Highway runoff contains relatively high fractions of metals in the dissolved form, which is the most important form environmentally. Other common pollutants in highway runoff, like sediments, petroleum products, and trash, are always a concern because they can have serious impacts on creeks, rivers, and beaches.

In District 4, water quality treatment strategies that collect only large sediment particles are unlikely to be very effective at removing most pollutants in highway runoff, since such strategies allow the pollutants of greatest concern—dissolved pollutants and pollutants associated with very fine particulate matter—to pass through. On the other hand, strategies that involve runoff infiltration or filtration through soil and dense root masses are promising for highway runoff control, as such measures provide effective removal of dissolved pollutants and fine particulate matter.

1.2.2 Phytoremediation

Phytoremediation is the use of living plants to remove pollutants from soil and water. The performance of the specific measures illustrated in the examples is enhanced through phytoremediation. Table 2 provides definitions of the basic types of phytoremediation and their relationship to highway runoff pollutants of concern.

1.3 Frequently Asked Questions

Because this approach is focused on managing storm water quality as opposed to storm water quantity and the approach to managing quality is different than the conventional storm water management approach of conveying water offsite as quickly as possible – it often raises questions. A few of the most frequently asked questions are below:

Won't these designs interfere with highway safety?

The overriding concern for all drainage design is safety, safety for the public in the handling of storm runoff, safe placement and design of the drainage features, and safe access to the drainage features by maintenance forces. Facilities for phytoremediation of storm water runoff are placed off of the traveled way and can be designed to avoid many potential safety hazards for both Caltrans maintenance forces and the public. For example, shallow slopes on an extended detention basin minimize hazards for errant drivers. Including maintenance access in designs eliminates the need for maintenance lane closures.

Table 1. San Francisco Bay Area Highway Storm Water Runoff Pollutants of Concern

Pollutant	**Reason**	**Major Sources in Highway Runoff**
Copper	San Francisco Bay impairment	Brakes, eroded soils
Lead	Elevated levels in highway runoff	Historic use in gasoline
Mercury	San Francisco Bay impairment, Bay fish consumption warning	Diesel vehicle tailpipe emissions, air deposition, erosion of debris from historic mines
Nickel	San Francisco Bay impairment	Eroded soils, gasoline vehicle tailpipe emissions (catalytic converters)
Zinc	Elevated levels in highway runoff	Tires
Sediments	Potential impairment of creeks, carries other pollutants to water bodies	Highway construction, erosion (especially of non-vegetated areas), vehicles (tires, brakes, tailpipe emissions)
Polyaromatic hydrocarbons (PAHs)	Linked to toxicity in Bay water samples	Gasoline and diesel vehicle tailpipe emissions
Dioxins/furans	San Francisco Bay impairment, Bay fish consumption warning	Diesel vehicle tailpipe emissions, air deposition
Petroleum products	Potential impairment of creeks, local effects	Drips and spills
Nutrients	Impairment of some rivers, creeks and bays in District 4	Roadside vegetation management
Pesticides	Urban creek and San Francisco Bay impairment	Roadside maintenance and vegetation control
Trash/debris	Aesthetic concern	Litter, construction debris

Sources: Santa Clara Valley Urban Runoff Program, 1997; Woodward Clyde Consultants, 1994; Caltrans, 1997; Spellisey, 2000; Woodward Clyde Consultants, 1992; San Francisco Bay Regional Water Quality Control Board, 2000; Jarman, 1995; Claremont Graduate University, 1998; Bateman, 1998.

Table 2. Relationship of Phytoremediation Processes to Highway Runoff

Process	**Definition**	**Highway Runoff Pollutants**	**Applicable for Highway landscaping?**
Phytostabilization	Presence of plant roots can modify soil either physically (preventing erosion) or chemically to immobilize pollutants.	Copper, Lead, Nickel, Zinc, PAHs, possibly dioxins	Yes, most broadly applicable of the phyto-remediation processes.
Phytoextraction	Pollutants can be taken up by plants and stored in the plant itself (can be in foliage or roots, depending on the plant). “Hyperaccumulators” take up unusually large amounts of specific metals. In “rhizofiltration, pollutants are extracted from water by aquatic plants (tend to stay in the root zone.)	Copper, Lead, Nickel, Zinc	Yes, if vegetation is removed from site (not Caltrans’ general practice). Most feasible where pollutants are stored in foliage.
Phytodegradation and Rhizodegradation	Plants can break down pollutants through metabolic processes, the action of compounds (such as enzymes) produced by the plants, or plant-related microbial activity in the root zone.	PAHs, petroleum products	Yes, but does not address most highway runoff pollutants.
Phytovolatilization	Plants can take up pollutants from the soil and then release the pollutant (or a modified form of it) from foliage into the air.	Mercury	No (not practical)

What is the design basis for the permanent vegetative design features in this guide?

The design basis is generally accepted principles based on trial and error, not detailed scientific testing of each design element. The science of storm water runoff treatment is relatively young so the body of knowledge is still evolving. Nevertheless, the bases for the designs presented in this guide reflect the latest understanding of storm water runoff treatment. Researchers across the country, including Caltrans, are conducting more detailed scientific tests of storm water runoff treatment. At the same time, the American Society of Civil Engineers has assembled a database of treatment system tests, which is being updated on a regular basis with the latest information (see Section 5, which provides details about this database and other available design resources). Further optimization of designs will occur as additional testing is done.

The Manning's n values[2] *look about 10 times higher than normal—are they wrong?*

In a well-designed grassy swale, the water quality flow will be a very shallow flow that does not exceed the height of the grass. Therefore, the flow will encounter significant resistance. Large Manning's *n* values are used for these very shallow flows in vegetated or grassy swales. References suggest *n* values in the range of 0.2 to 0.3 for the shallow flows, rather than more common *n* values of 0.035 for larger open channels where flow depth is greater than the height of the grass. Additionally, the velocity of the flow has an impact on the Manning's *n* value. Even a higher velocity shallow flow will tend to bend tall grasses over, thus lowering the Manning's *n* value. To account for these different factors, the recommended reference for determining the Manning's *n* value in vegetated channels is the *Urban Drainage Design Manual, HEC-22,* U. S. Department of Transportation, FHWA-SA-96-078, November 1996. Section 5.1.5 of that manual describes an iterative method for establishing the depth of flow and the Manning's *n* value.

These design procedures seem backwards—why is it important to manage small storms so carefully, and why don't these facilities treat flows from larger storms?

Storms that generate the most pollutant-laden runoff are small storms, early season storms, and storms after a dry spell (California SWQTF, 1993). During the later parts of larger storms or on later days during a series of storms, pollutant levels in runoff are generally lower, since most pollutants will have been washed off by earlier storms or in the early part of the storm. Focusing on the most polluted flows—the smaller flows and initial flows from larger storms—is the most cost-effective approach.

Aren't these measures going to interfere with management of the peak design flow?

No. Features can be designed with sufficient hydraulic capacity to handle both the peak design flow and the water quality flow or water quality volume. If necessary, drainage facilities can be designed to direct larger flows directly to the ordinary drainage system.

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[2] The Manning coefficient of roughness *n* is an empirical value. It is a factor in Manning's equation, a hydraulic equation used to estimate flow velocity or capacity of an open channel or culvert.

When should a water quality flow rather than a water quality volume be used for design?

Facilities that treat storm water runoff while the runoff flows through them—like swales—should be designed for the water quality flow. Facilities intended to hold a certain volume of water—like detention and retention basins—should be designed for the water quality volume. Water quality flow and water quality volume criteria appropriate for a project site can be obtained from local Caltrans District Hydraulics or Water Quality staff.

Shouldn’t these facilities be larger?

No. Sizing storm water runoff treatment facilities to handle greater than the water quality flow or water quality volume is generally not considered cost effective. The exception is that anticipated sedimentation in the storm water treatment facilities should be accounted for in the design. For example, the American Society of Civil Engineers (ASCE) recommends that volume-based treatment systems like extended detention basins should have a minimum of 20% additional volume. Grassy swale designs should function properly with 150 mm of sedimentation.

How long should water be allowed to pond in an extended detention basin or infiltration basin?

Determining the ideal basin residence time involves several trade-offs. From the water quality perspective, a long holding time enhances the pollutant removal in an extended detention basin, and provides for treatment of a larger quantity of water in an infiltration basin. Unfortunately, standing water provides a location for mosquito breeding. To prevent mosquito breeding, agencies typically follow an informal guideline to avoid presence of undisturbed standing water for more than 72 hours. When designing storm water treatment facilities, designers typically incorporate a margin of safety into the design; they typically target a 24 to 40 hour residence time, with a maximum residence time (at the full treatment volume of the facility) of 48 hours.

Occasionally, basins may experience longer periods of inundation than the design residence time. This can happen when two significant storms are close enough in sequence that the basin cannot drain completely prior to the subsequent storm. Each winter, District 4 experiences one or more 2 to 3 day rain events, and/or one or more series of sequential storms less than 48 hours apart. During such events, a basin may fill and not completely empty within 48 hours (inundation periods could last as long as 10 days in the worst cases).

The basin surface disturbances from each rain event and the cold weather associated with such isolated events should prevent mosquito-breeding problems, which should not occur unless undisturbed standing water exists for more than 3 to 4 days.

Won't these facilities be maintenance intensive?

The designs of the examples presented in this guide have integrated many elements intended to minimize the maintenance needs of these features. Nevertheless, some maintenance will be required to ensure proper operation of the systems and to keep the vegetation healthy. In its *Storm Water Management Plan*, Caltrans has recognized that maintenance will be a major issue for vegetated storm water runoff treatment systems. In the *Storm Water Management Plan*, Caltrans has committed to address this issue (Section 5.5.1):

> "By January 1, 2002 Caltrans will have developed and begun implementation of interim operations and maintenance procedures for vegetated systems design and constructed based on storm water quality treatment design standards. By June 1, 2003 final operation and maintenance procedures based on Caltrans research studies ([*Storm Water Management Plan*] Section 7) will be developed and implemented."

Wouldn't it be less maintenance intensive to omit the sediment collection features recommended for swale and basin entry points?

No. These features greatly reduce long-term maintenance costs because it is far less costly to remove sediments collected in sediment collection features than it is to remove sediments accumulated in vegetation. The most expensive maintenance required for a vegetated storm water treatment system is to remove sediments from the vegetation when sediments collect in the system to the point that they affect the function of the system. (This is costly because removing sediments from vegetated areas requires replanting where the soil is disturbed.) Including sediment collection features in designs can dramatically reduce the frequency of such major maintenance.

2.0 Information Needs

2.1 Drainage Design Elements and Criteria

The drainage design for each treatment feature will include both standard design elements and elements particular to the limitations and goals of the treatment feature. Similarly, there are common and particular drainage design criteria for each of the treatment features.

In using this guide, it is important to remember that a drainage design should be examined within the context of drainage needs both upstream and downstream of the project site. Designs need to be compatible with the overall drainage design for the highway or interchange. Design flow rates and volumes described in this guide are intended to serve only areas within the highway right-of-way. Including management of storm water runoff from areas outside of the highway right-of-way should be confirmed with Caltrans staff.

The main source for drainage design is the California Department of Transportation *Highway Design Manual* (HDM). All criteria and standards in the *Highway Design Manual* are important to consider in the design of drainage facilities, though local Caltrans Districts should be contacted for applicability to the local areas or supplemental design standards. All drainage designs in this example start with standard designs in accordance with the *Highway Design Manual*.

2.1.1 Hydrology

Two types of runoff events must be considered in the drainage design of the storm water runoff treatment features. For proper and safe drainage design, the peak design flow must be considered. In addition, a smaller water quality event must be the focus of the particular design of the treatment function of a feature.

Peak Design Flow—For most all applications of these storm water runoff treatment features, the Rational Method should be used for the estimation of peak storm runoff (HDM Sections 819 and 832). Generally, only runoff from within the highway right-of-way (R/W) will be considered in the design of the treatment feature, therefore the design peak discharge should correspond to the 25-year storm. A common source of rainfall data is the HYDRO modeling package within the *HYDRAIN – Integrated Drainage Design Computer System* from the Federal Highway Administration (FHWA). If runoff from areas outside of the Caltrans right-of-way is tributary to the treatment feature, the design runoff should correspond to the 100-year storm and would likely be developed by using hydrograph methods (HDM Section 819.4) rather than the Rational Method. For design of detention basins and other volume based drainage features serving small watersheds, the Soil Conservation Service[3] Triangular Hydrograph Method is an acceptable method that is appropriate for developing the design storm runoff volumes.

Water Quality Event—The amount of runoff to be treated is defined by either flow or volume based standards, depending on the type of treatment facility being designed.

- The *water quality flow* is defined as the runoff corresponding to a percentage of a selected year return period rainfall intensity. As an example, if the water quality flow was defined as 10% of the 50-year return period rainfall intensity, and if a 15-minute time of concentration has a 50-year return period rainfall intensity of 63 mm per hour, the water quality flow would then be developed using the Rational Method with a rainfall intensity of 6.3 mm per hour.
- The *water quality volume* is defined as the runoff generated from a specified storm event, such as 25 mm of precipitation over a 24-hour period.
- This guide employs an example definition of water quality flow and several common definitions of water quality volume. Caltrans' *Project Planning and Design Guide* will eventually contain Caltrans design standards for water quality flow and water quality volume. Because these definitions are in flux and may be set locally, confirm with local Caltrans District Hydraulics or Water Quality staff the appropriate water quality flow and volume criteria to be used in the project area.

2.1.2 Hydraulics

The primary hydraulic drainage design goals are to limit the amount of storm runoff standing or flowing on the highway or other areas of concern, safe and durable performance, and maintainability. Costs of construction and maintenance are also a consideration. For safety and proper drainage design, the *Highway Design Manual* presents or references all common standards and design criteria.

[3] Now the Natural Resource Conservation Service.

Much of the current trend in drainage design is to use armored facilities or piping systems to convey flow. Redirection of designs to vegetated facilities provides opportunities for storm water phytoremediation. The storm water runoff treatment features will commonly route all or a portion of the design storm runoff across vegetated areas. These vegetated areas will be susceptible to erosion or deposition if not properly designed or maintained. Typical unlined ditch longitudinal slope and velocity design criteria are presented in HDM Sections 834 and 863. Other channel design criteria such as side slope and Manning's *n* values are presented in the HDM. Hydraulic design criteria particular to phytoremediation treatment features will be presented in the individual sections below.

Of note are the large Manning's *n* values used for very shallow flows in vegetated swales. In swales designed for water quality, the vegetation height exceeds the flow depth under the water quality flow conditions. References such as *Open Channel Hydraulics* (Chow, 1959) suggest *n* values in the range of 0.2 to 0.3, rather than more common *n* values of 0.035 for larger open channels where the channel linings (grasses) are not so prominent and flows are deeper than the height of the grasses. (See Section 1.3, Frequently Asked Questions for additional discussion of the Manning's *n* values.)

2.2 Infiltration Characteristics— Hydrologic Soil Groups

The hydrologic soil group strongly influences the choice of storm water runoff treatment options at a particular site. The basic function of some treatment control measures depends on their ability to infiltrate runoff (*e.g.*, swales, infiltration basins) while the function of others (*e.g.*, detention basins, constructed wetlands) does not.

There are four hydrologic soil groups: A, B, C and D. Because group A and B soils possess the greatest infiltration rates (unless soils are compacted during construction), these soil types are generally best suited to storm water infiltration. Unfortunately, District 4 has primarily Groups C and D soils, which possess lower infiltration rates that generally limit use of infiltration for storm water runoff management.

The definition of each hydrologic soil group is given in Table 3. Some soils have compound classifications, such as A/D, reflecting both the natural soil classification (*e.g.*, Group A) and the presence of a feature like a high water table that impedes infiltration.

Most published soil surveys present a listing of the soil types and corresponding hydrologic soil groups. Generally, the original soil type map must be converted to a map of hydrologic soil groups using the published conversions. The Natural Resources Conservation Service (NRCS) has a complete national list of hydrologic soil groups published in NRCS Technical Release 55. Alternatively, a site-specific soil analysis can be used to determine the soil group for the project site.

Soil type information for a particular location may be available in the Caltrans geographic information system. If local soil maps are not available, then information from site geotechnical reports or, if necessary, testing of site soil samples, should be used to identify soil hydrologic groups.

2.3 Plant Selection

Selecting appropriate vegetation for a project site requires an understanding of the soils, climate, water resources, and potential natural vegetation in that location. In 2001, District 4 completed a District-specific seed selection and planting guidance manual, *Seeding Guidance Manual*. That manual can be used to select appropriate plants for storm water runoff treatment facilities (as well as for other highway seeding). The best plants for storm water runoff treatment facilities are long-lived, finely divided perennial grasses or grass-like species that grow well in the soil and climate conditions and with the water resources available at the facility site.

The *Seeding Guidance Manual* employs a system for characterizing natural environments and associated vegetation developed by the U.S. Department of Agriculture Soil Conservation Service (now the Natural Resource Conservation Service), called major land resource areas (MLRAs). The Soils Conservation Service identified MLRAs based on the pattern of soils, climate, water resources, land uses, and types of vegetation in its 1981 publication *Land Resource Regions and Major Land Resource Areas of the United States*, a handbook identifying all MLRAs in the United States. Maps with sufficient details to identify the MLRA for a particular project site are available in the Natural Resources Conservation Service publication *A Vegetative Guide to selected Native Grasses of California* or from the Caltrans geographic information system.

Table 3. Definition of Hydrologic Soil Groups

Hydrologic Soil Group	Soil Group Characteristics	Typical Soil Infiltration Rates (mm per hour)
A	Soils having high infiltration rates, even when thoroughly wetted. Deep, well drained sands or gravels.	8 to 11
B	Soils having moderate infiltration rates when thoroughly wetted. Moderately deep to deep soils with moderately fine to moderately coarse textures.	4 to 8
C	Soils having slow infiltration rates when thoroughly wetted. Soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture.	1.3 to4
D	Soils having very slow infiltration rates when thoroughly wetted. Typically, these soils consist of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, or shallow soils over nearly impervious material.	0 to 1.3

3.0 Examples

This section provides design concepts for highway drainage scenarios. The examples illustrate available measures and treatments, and train the guide user how to identify opportunities based on site-specific conditions. The examples consist of generic schematic drawings of typical drainage elements, modified or enhanced for pollutant removal capability through integrated drainage and vegetation design. The examples use elements consistent with current Caltrans practices and include features that minimize maintenance requirements. Not all of the measures discussed below have been approved for use on highway sections (readers can check the Caltrans *Storm Water Management Plan* for the latest list of approved measures).

Among the number of treatment control measures available to designers, there are four basic storm water runoff options that use phytoremediation to some degree:

- Swales
- Detention basins
- Infiltration basins
- Constructed wetlands[4]

The selection of an appropriate measure to reduce pollutant levels in highway runoff is very site-specific in nature. No one specific measure was identified that would function in all locations. The characteristics of the specific project site should determine the measure that will be used. Site-specific factors that should be considered in selecting storm water runoff management measures include:

- Groundwater level
- Soil type
- Pollutant removal goal
- Climate
- Characteristics of right-of-way area (size, location relative to drainages)

No one specific measure was identified that would function in all locations. The characteristics of the specific project site should determine the measure that will be used.

[4] Constructed wetlands are not a currently approved practice, however, Caltrans is working with water quality agencies to evaluate their potential as a practice for highway runoff management.

Based on these site-specific factors, the Table 4 (on the next page) presents general rules-of-thumb on situations when specific treatment control measures are appropriate to consider and when they may be problematic.

Based on these general rules-of-thumb, of the four storm water runoff phytoremediation options, two types are particularly well suited for near-term implementation in the soil and climate conditions in District 4 (given the Bay Area's generally clay soils and its climate, and the regulatory issues still to be resolved for constructed wetlands):

- Swales—Although they are relatively low cost storm water runoff phytoremediation options, grassy swales remove significant fractions of pollutants in storm water runoff—and they are capable of removing dissolved metals and organic pollutants that are of concern in the San Francisco Bay Area. The swales described in this guide are "dry" swales, designed to drain completely between storms. Swales are designed to receive concentrated runoff at their head end, and convey and treat it at shallow depths and slow velocities; while "filter strips" are broad areas of vegetation for treating sheet flow runoff. A hybrid design–called a "continuous inflow swale"–receives sheet flow runoff continuously along the side slopes as well as at the head end. This guide does not focus on filter strips or continuous inflow swales because of the following limitations:

Table 4. Factors that Affect Selection of Storm Water Management Elements

Factor	**Measures to consider**	**Measures that may be problematic**
Shallow groundwater	∞ Constructed wetlands	∞ Infiltration basins ∞ Extended detention basins (below grade)
Hydrologic soil groups A or B	∞ Infiltration basins ∞ Swales	∞ Constructed wetlands
Hydrologic soil groups C or D	∞ Extended detention basins ∞ Constructed wetlands	∞ Infiltration basins
Goal includes reducing levels of toxic pollutants	∞ Swales ∞ Infiltration basins	∞ Extended detention basins

Table 4 - continued		
Goal includes reducing levels of nutrients	∞ Infiltration basins ∞ Constructed wetlands	Swales (wet)
Wet climate (Northern portion of District 4)	∞ Constructed wetlands ∞ Swales	∞ Extended detention basins
Limited right-of-way	∞ Extended detention basins in interchanges	

- Caltrans (per the HDM and as supported by the report *California Roadsides: A New Perspective*) is moving to install dikes on most highway projects in District 4, which prevent sheet flow.

- What is intended to be sheet flow onto a swale or filter strip often turns into erosive flows at the highway edge so the sheet flow must be converted into frequent, small point flows through the use of dike inlet ports and then reconverted into sheet flow through the use of a flow spreader extending the entire length of the swale or strip.

- The slope area used as the filter strip will have some maximum slope inclination that is a function of soil type, vegetative coverage and maximum flow rate.

- Right-of-way limitations common in District 4 limit the locations where such designs are feasible.

∞ Extended detention basins—Extended detention basins can be used throughout Caltrans District 4 to treat storm water runoff from Caltrans facilities. Extended detention basins collect runoff following a storm event, releasing it slowly over the next day or two. Between storms, the basin is designed to drain completely.

The next sections identify and discuss key aspects of the design, construction, and maintenance of swales and extended detention basins, followed by three examples:

1. Grassy swale in an interchange
2. Grassy swale for a linear highway section
3. Extended detention basin in an interchange

3.1 Safety

Safety is the top priority for highway runoff management. There is always a significant safety concern for errant vehicles that must be considered when designing highway roadside elements. Use of a typical minimum setback from the traveled way of 9 m (the width of the safety clear zone) is recommended.

- Swales—Swales should also be located in a safe place. Since the depth may not be great enough to be considered a hazard to errant vehicles, swales may be placed within 9 m of the traveled way with Caltrans approval.

- Extended detention basins—With a traditional detention basin depth of 1.2 m or more, the basin would have to be physically separated from the traveled way with a barrier. An alternative configuration is to make the basin shallow enough to be acceptable, with a maximum ponding depth of 1.1 m in an area without barrier separation from the traveled way.

Structural protection is also a critical safety issue. Where swales or basins may be located near structures, an engineering evaluation is recommended.

- Swales—Because swales are intended to promote runoff infiltration, swales should be kept a safe distance (at least 3 m) from bridges or other structures.

- Extended detention basins—Similarly, in most cases, infiltration will occur during the drainage period for an extended detention basin, so basin placement should also consider proximity to other structures.

3.2 Drainage Design Elements

3.2.1 Swales

Hydrology—Onsite hydrology design should follow the procedures presented in the Caltrans *Highway Design Manual*. Typically a 10-minute time of concentration will predominate. The flow design should be checked for two conditions, the peak design flow (typically the 25-year event), and the water quality flow (to be provided in the *Project Planning and Design Guide*; confirm with local Caltrans

District Hydraulics or Water Quality staff for the appropriate water quality flow criteria to be used in the project area.) The peak design flow should be used to check the swale for erosion and stability and to ensure adequate hydraulic capacity. The water quality flow should be used for the design of the swale's bottom width and length.

Inlets—Within a typical interchange or reach of highway, the normal drainage system layout can be modified to direct runoff to a defined vegetated swale. Initially the on-pavement, median or off-pavement inlets (which should be located as to avoid flows across surfaces that may erode) should be placed where necessary for proper drainage design. Then, where possible, slight relocations or additional inlets should be considered that benefit the action of the vegetated swales. The pavement inlets could be either AC overside drains, downdrains, or inlets with connecting storm drains with approved aprons.

Swale Longitudinal Slope—The swale longitudinal slope should be in the range of 0.5% to 4%; a 2% slope is considered ideal. Steeper longitudinal slopes should be checked for erosive velocities with respect to the desired vegetative cover (generally slopes above 4% and up to 6% can be used if check dams are installed about every 30 m to break up and slow water quality flows without impeding peak flows and to provide infiltration opportunities; however, check dams will interfere with mowing), and flatter slopes experience poor drainage conditions that affect swale vegetation. Any swale with a slope of less than 2% requires construction of a permeable layer and underdrain system beneath the swale to prevent standing water and protect the vegetation (such underdrains are not intended to contribute to flow conveyance). Underdrains should be avoided where possible, because they add significantly to the construction cost.

Swale Side Slope—Swale side slopes should be flat, in the range of 3 to 1 to 10 to 1. The flat side slopes are intended to maximize the area for infiltration, create a wide and shallow flow path, and allow maintenance access to the swale. The distance between the toe of the slope and the right-of-way may be limited, requiring a small bottom width and steeper side slopes. If the swale is on a side slope, the downhill edge of the swale should be strengthened, so that maintenance activities like mowing cannot damage the swale edge and cause runoff to leave the swale.

Freeboard—A minimum freeboard height of 0.3 m is recommended. Any drainage design should avoid impacts to adjacent property. Consider an additional freeboard allowance for sediment buildup if maintaining freeboard is critical.

Swale Bottom Width—A minimum useful swale bottom width is 0.6 meters (the smallest width that can conveniently accommodate a mower). The bottom width should be limited to 3 m to limit the possibility of flow lines forming along one side of the swale. Wider swales should be partitioned with a berm along the center of the swale (such swales are not recommended due to concerns about the ability to maintain the swale without interfering with the central berm).

Swale Flow Velocity—The velocity on the vegetated swale should be calculated for two conditions: the velocity of the water quality flow and the velocity of the peak design flow. The velocity of the water quality flow should be limited to 0.3 m/s (to provide adequate opportunity for vegetative filtering and infiltration)**,** and the velocity of the peak design flow should be limited to the erosive velocity of the vegetated swale, 1.0 to 1.2 m/s. For calculating the water quality flow, a Manning's *n* value of 0.2 is suggested for vegetated swales with regular mowing and 0.25 for swales with infrequent mowing. For peak design flows deeper than the grasses, an appropriate Manning's *n* value may be closer to 0.035 than 0.2. (See Section 1.3, Frequently Asked Questions for additional discussion of the Manning's *n* values.)

A separate location for potential erosion is at the points where the storm drains outlet onto the swales. The potentially high velocities within the storm drains must be attenuated before being released into the swales. Energy dissipators such as "tee" outlets or flared end sections with riprap pads or impact blocks with a flow redistribution pad are appropriate.

The conditions of the site, particularly the hydrology, may result in peak design flows that are erosive to the swale, while the water quality flows are manageable. In this condition, the peak design flows should be metered onto the swale to limit erosion from the larger peak design runoff flows. The easiest solution is to limit the amount of flow entering the swale.

Minimum Swale Length—The swale should have a minimum length of 30 m to provide adequate residence time for the infiltration and pollutant capture functions of the swale. Optimally, the length will be selected to allow a travel time of at least 10 minutes.

Outlet—The connection of the swale to the downstream drainage facility will generally be in accordance with standard Caltrans drainage design using a drainage inlet or flared end section.

Sediment Control—Minimizing sediment entry into the swale significantly reduces the need for maintenance of the swale itself (removal of sediments in the swale is the single most costly maintenance activity required for a swale's operation). If pre-swale sediment control is omitted from the design, the swale could need to receive significant maintenance (sediment removal and replanting) as often as once a year. Two options exist for locating sediment collection devices: at the inlet location (at highway level) or at the point that water reaches the swale. Providing an inlet sediment removal device (such as a continuous deflective separator) at the pavement level allows the sediment removal to be conducted mechanically (*e.g.*, by a vactor truck); however, such devices have a history of mosquito problems (California DHS, 2001). Alternatively, at the downstream ends of the storm drains, sediment traps could be designed where flow exits onto the swale. These sediment traps could be standard inlets with a depressed invert, a pea gravel diaphragm, or a small lined basin after the energy dissipators. Due to their location, such devices would require manual cleaning. In addition, they would need to be designed to avoid interfering with swale mowing. In order to function properly, pre-swale sediment traps would need to be inspected and regularly maintained.

3.2.2 Extended Detention Basins

Hydrology—Onsite hydrology design should follow the procedures presented in the Caltrans *Highway Design Manual*. Typically a 10-minute time of concentration will be common, but an extended detention basin could handle flows from areas beyond the limits of the interchange, resulting in longer times of concentration. The design should be checked for two conditions, the peak design flow (typically the 25-year event), and the water quality volume (to be provided in the *Project Planning and Design Guide*; confirm with local Caltrans District Hydraulics or Water Quality staff for the appropriate water quality flow criteria to be used in the project area). The peak design flow should be used in the extended detention basin to check for erosion, stability, and capacity to pass (or ability to bypass) the flow. The water quality volume should be used for the design of the extended detention basin.

Inlets—Within a typical highway grade separation interchange, the normal drainage system layout could be modified to direct runoff to the defined extended detention basin. Initially the on-pavement or off-pavement inlets should be placed where necessary for proper drainage design. Then, where possible, slight relocations or additional inlets should be considered that benefit the action of the extended detention basin. The use of baffles, riprap, and other types of energy dissipators is encouraged; the most effective location for these depends on the basin geometry.

Basin Side Slope—It is recommended that the sides of the basin be designed to permit ease of equipment access to the basin floor and for safety considerations. A recommended basin side slope is 5:1 or flatter on the sides of the basin closest to the traveled way, with a maximum slope of 3:1 away from the traveled way.

Basin Bottom Slope—The basin bottom should be nearly flat, but graded to drain to the low-flow channel. During basin operation, the primary concerns are preventing erosion and avoiding re-suspension of materials collected on the basin bottom. For these reasons, steeper bottom slopes (*i.e.*, greater than 3:1) should be avoided. Reducing inflow velocities (*e.g.*, by installing energy dissipators), diverting high flows from the basin, and maintaining vegetative cover also minimize the potential for erosion or re-suspension of collected sediments.

Basin Depth—Basins should not intersect groundwater; however, basins can function with as little as 0.3 to 0.6 meters of separation from the high groundwater level. To protect groundwater quality, particularly in areas with highly porous soils or where groundwater is a source of drinking water, local water quality agencies may restrict or prohibit use of basins where the basin bottom elevation is less than 3 meters above the seasonal high groundwater level. Consult with local water quality agencies before designing basins for such locations.

Low-Flow Channel—Including a low-flow channel in the basin prevents very low flows (such as those that only fill the forebay) from braiding and ponding in the basin bottom, which can damage vegetation and cause erosion. The low-flow channel should be lined with filter fabric and gravel.

Basin Cross Sectional Area—Minimizing the velocity of the flow through the basin can greatly improve the pollutant removal efficiency of the basin. Increasing the basin depth (to the extent possible while addressing vehicle safety) and cross sectional area will help to establish low flow velocities. Basins that taper outward from inlet to outlet are also effective in slowing influent velocities by increasing the cross sectional flow area. In general, the goal is to provide conditions where the velocity of flow through the facility for a typical storm event is less than the settling velocity of the pollutants of concern.

Basin Residence Time—The basin residence time is dependent on many factors: the design flow, the basin length and width, the velocity, the volume of the basin, and the inlet and outlet control structures. A typical target is a 24- to 40-hour residence time, with a maximum residence time of 48 hours. Such a design criterion ensures that water will drain from the basin much sooner than 72 hours, the guideline for avoiding mosquito breeding.[5] The basin residence time can be increased by maximizing the distance between inlet and outlet points, thereby giving greater opportunity for pollutant settling. If the inlet and outlet are too close together, the opportunity for the suspended solids to settle out in the basin is reduced. With a constrained site, like a highway interchange, a tradeoff exists between basin length and maximizing basin capacity (and thus the drainage area that may be served by the basin). In order to increase flow path length, baffles and flow directors may be used.

Outlet—Any drainage design should avoid water surface elevations that encroach on the traveled way. If not bypassed, the basin outlet should be designed to safely convey the design storm, normally the peak flow from the onsite 25-year recurrence runoff. If offsite runoff is tributary to the basin (generally this should be avoided) then the peak 100-year runoff should be considered for the peak design flow. A combination of standard Caltrans inlets or flared end sections could be used to design the basin high water outlet. Extra outlet capacity should be considered to minimize the clogging potential.

It is desirable to avoid routing peak flows through the basin, where possible, to avoid re-suspending sediments. This can be accomplished by diverting only lower flows (up to the water quality volume) to the basin, while routing larger flows directly to the ordinary drainage system.

A secondary low flow outlet should be designed to allow the basin to be completely drained in a 48-hour period. The low flow outlet could be a perforated, small diameter, vertical, non-clogging outlet pipe (75 mm minimum diameter) protected by rock and stone connected to the main outlet drainage facility. An underdrain system is not preferred but may be acceptable under certain conditions. The low flow outlet control should be oversized by 50% with a flow control device added in-line so that over time the draw down rate could be adjusted.

Sediment Control—Minimizing sediment entry into the main basin significantly reduces the need for maintenance of the basin itself (removal of sediments in the main basin is the single most costly maintenance activity required for an extended detention basin's operation). At the principal inlet to the basin (which should be placed in an easy-to-access location), a settling area, or sediment forebay,

[5] Each winter, District 4 experiences one or more 2 to 3 day rain events, and/or one or more series of sequential storms less than 48 hours apart. During such events, a basin may fill and not completely empty within 48 hours (inundation periods could last as long as 10 days in the worst cases). The basin surface disturbances from each rain event and the cold weather associated with such isolated events should prevent mosquito-breeding problems, which should not occur unless undisturbed standing water exists for more than 3 to 4 days.

should be provided. The sediment forebay should be concrete lined or otherwise hardened to facilitate sediment removal. To simplify monitoring, the forebay lining can be marked to indicate the sediment level.

Two common configurations for the forebay include: (1) A shallow, flat entrance to the basin that allows velocities to be greatly reduced and causes particulates to settle out of the water, and (2) A relatively deep area that is separated from the rest of the basin by a berm, with a large surface area acting to reduce velocities and the berm preventing the settled sediment from migrating to the downstream portion of the basin. With either configuration, a low flow outlet should be designed to allow the forebay to completely drain within a 48-hour period (to prevent mosquito breeding). With the berm option for the sediment forebay, the berm should allow slow percolation through it via a narrow pervious zone or a perforated riser pipe to prevent long-term ponded water. So as not to re-suspend sediment in the forebay during the peak design event and allow for adequate sediment storage volume, the forebay volume should be 10% of the main detention basin.

3.3 Plants and Planting Considerations

Vegetation is essential to the operation of a swale—and it enhances the operation of extended detention basins. For swales, grasses slow the water flow and provide the conditions necessary to promote infiltration. For both swales and basins, vegetation tends to bind in place (phytostabilize) the pollutants that settle out or infiltrate into shallow soils. This stabilization enhances the performance of both swales and basins by preventing flush out of accumulated sediments, while it reduces the needed frequency for sediment removal (interference with vegetation growth, swale flow patterns, and reduced swale or basin capacity are the primary reasons for sediment removal). Second, vegetation promotes infiltration into shallow soils because plant roots tend to keep soil porous. For basins, vegetation only slightly enhances infiltration rates—while this limited infiltration probably does not greatly enhance pollutant removal, it can reduce the potential for standing water in the basin bottom.

General Plant Selection Criteria—Plants in grassy swales will need to be able to withstand short periods of inundation. In swales with shallow slopes or clay soils, an underdrain should keep soil from being saturated for more than 48 hours under normal circumstances, at which point the soil drains to field capacity consistent with its soil type and soil depth. The vegetation must be able to withstand nearly as long a summer drought as surrounding vegetation.

For most areas in District 4, extended detention basins designed to drain within 48 hours are anticipated to create approximately the same growing conditions as do the grassy swale structures. Plants in extended detention basins will need to be able to withstand periods of inundation. While generally inundation periods would not exceed 48 hours, sequential rain events could create conditions that would extend the inundation period. In most areas these periods should not exceed 10 days. In the northern part of District 4, or areas of high rainfall frequency, the vegetation may need to survive much longer inundation periods. For these areas, wetland type vegetation may invade the perennial grass species or it may be preferred to establish wetland vegetation in these areas.[6]

Other general criteria that direct plant selection are:

- Best plants are long-lived perennial plants that are finely divided (lots of surface area at ground surface for filtering), dense and deep-rooted.
- Plants should be relatively erect in stature.
- Plants should be planted in mixed stands as opposed to monocultures.
- Where possible, rhizominous and clumping types should be mixed together. Rhizominous plants may be better able to re-colonize areas that have been covered with sediment.
- Trees and shrubs can be located adjacent to swales and basins, but they do not work in the swales or basins themselves.

Planting—Plug plants or specialized sod are considered the top materials for plant establishment. Ideal plug material is 63 mm square by 125 mm deep. Sod composed of the recommended species is not currently grown in California but several sod farms might be induced to experiment with contract growing under the right conditions. Initially native sods would likely be grown on plastic sheets with artificial soils, until growers perfect field lifting of the sod and soil texture interface concerns are addressed.

Temporary Erosion Control Blankets—If plugs or plugs with nurse crop seed are used, the first rain events might severely damage the

[6] Using wetland vegetation may have regulatory consequences that should be considered. Caltrans is currently evaluating the use of constructed wetlands as a storm water runoff treatment option.

plants. Thus, reinforced erosion control blankets or nettings are recommended as initial swale and basin liners. With plug planting, the plants should provide substantial cover after one year and solid cover by the middle of the second growing season.

Recommended Species—Several grass or grass-like species have been selected for initial consideration, assuming a project site located in central District 4:

- *Leymus triticoides* (Creeping wildrye). This plant is slow to establish from seed but is very vigorous when planted from plugs. It takes both wet and drier conditions and is highly rhizominous and thus may be able to withstand some sediment loads. It grows to 0.75 m tall, but timely mowing can keep the height to a maximum of 0.3 to 0.6 meters, making it an excellent candidate adapted to nearly all of District 4. Compatible species for *Leymus triticoides* include *Hordeum brachyanterum* (Meadow barley), *Elymus trachycaulus* (Native slender wheatgrass), and *Deschampsia ceaspitosa* (Tuffed hairgrass).

- Compact species mix. Where more compact plants are preferred, *Carex tumulicola* (Berkeley sedge), *Deschampsia ceasitosa* var. *holciformis* (Pacific hairgrass) and *Agrostis pallens* (Thin grass) are good candidates. These plants are shorter (to 0.4 m) and finer bladed than *Leymus*. They should be plug planted on 225 mm centers and are a mix of clumpers and creepers. They would be relatively ornamental and still be hardy enough to survive the summers without irrigation.

- Fine Fescue species mix. This group of plants could be used for swales in areas with less than 400 mm of annual rainfall. It could also be used for basins in areas with less than 350 mm of annual rainfall or with basin designs that would only occasionally be inundated for a period in excess of 24 hours. They like normal water conditions and could be used where year-round irrigation is utilized as part of the more traditional landscape planting.

Irrigation—Irrigation is essential for consistent and rapid plant establishment. Late summer or early spring plantings are highly preferred. The form and method of irrigation is highly site dependent. Water must be able to be applied slowly enough to not erode the site and in quantities great enough to supply 80-90% of reference evapotranspiration on a weekly basis. At planting, water must be constantly available in the root zone.

Grass Height—The most effective water quality treatment in swales occurs when water depth in a swale does not exceed height of grass (at least during small storms). The appropriate height also depends on the plan species used. For the recommended species, minimum heights for long-term management of healthy plants are 250 to 300 mm.

Soil Stabilization in the Swale or Basin Bottom—Soil stabilization of a swale or basin bottom increases construction cost, but would allow light vehicle access to the area before the bottom has completely dried; this would extend the time period available for mowing and other maintenance of the area and would provide maintenance access to the swale when right-of-way limitations result in placement of a swale at the edge of the right-of-way.[7] For swales with at-swale sediment removal features, soil stabilization could reduce labor required for removing sediment (however, such stabilization would not be sufficient to provide access for heavy equipment like vactor trucks). Examples of soil stabilization include cellular confinement systems and synthetic turf reinforcement mats that would be placed within the grass root zone. For swales, extending the stabilization system for about 0.75 m on each side of the swale is recommended to facilitate equipment access.

3.4 Construction

Grading—Soil should not be compacted when constructing a swale or an extended detention basin. The construction contractor should be able to complete the installation of the swale or extended detention basin elements other than landscaping. Certain swales (ones with slopes less than 2% or with heavy clay soils [Type D]) an underdrain will be required to protect vegetation. If an underdrain is needed, the construction contractor may install the underdrain system under the center of the swale after grading; however, after underdrain installation heavy equipment access to the swale should be limited. Construction of proper grades is critical to the proper function of the swale, and therefore should be carefully overseen by the Resident Engineer.

Planting—The grading contractor will establish the rough grade for the swale or basin before turning it over to the planting contractor. The planting contractor will rip and amend the soil and install the underdrain (unless Caltrans chooses to have the construction

[7] Note that mowing should not be conducted during the wet season unless clippings are collected, as they may be washed into the drain system, potentially contributing to drain blockage, and possibly creating an unacceptable nutrient load in the water body where the drainage flows.

contractor install it), irrigation, soil re-enforcement grids, and a low-flow channel, if the project is an extended detention basin. Then the contractor will fine grade, plant (as described above), and install erosion control protection. If bark is used adjacent to the swale or basin or if the area adjacent to the swale or basin is initially subject to soil erosion, the contractor will need to install control measures (such as fiber rolls on contour) to keep bark and sediments out of the structure. When planting is complete, the contractor will establish and maintain the plants as per current standard landscape practices.

Landscaping Establishment Period—Construction of a swale or extended detention basin should include an establishment period that covers vegetation establishment to ensure the success of the project and to provide a ready mechanism for site-specific adjustments after construction. Either a contractor or Caltrans staff with appropriate expertise could handle this function. For example, a common initial problem for swales is erosion in the swale, which can be corrected through changes in drainage or adding protecting rock.

Initial Inspection/Maintenance—The project must include provisions for initial inspection, maintenance, and oversight of the operation of the swale or basin through at least the first three (and preferably five) years of operation. This essential function may be provided by a contractor or by Caltrans staff with appropriate expertise. In addition to overseeing the maintenance items listed below, this function should include monitoring factors that will determine long-term maintenance requirements (*e.g.*, rates of sediment accumulation in the swale or basin, excessive trash accumulation at inlets, lead concentrations in sediments), and viewing swale or basin operation during at least one storm per season. At the end of this initial period, the a site-specific long-term maintenance plan should be prepared by the personnel responsible for the initial inspection/maintenance, with the goal of maintaining the facility's design and function while minimizing maintenance requirements.

3.5 Maintenance

The long-term success of a treatment feature depends on monitoring the facility and effective maintenance.

Swale Maintenance Checklist

- ❑ Obstructions of the inlet or outlet devices by trash and debris
- ❑ Poor plant health or areas of low plant density (depending on condition, either fertilize with organic slow-release fertilizer [only when conditions prevent release of fertilizer in runoff] and irrigate prior to rainy season or clip short; reseed, sod, or plug plant; and irrigate for 60-90 days prior to likely first rain event)
- ❑ Excessive erosion or sedimentation in the swale (correct grade and replant per above)
- ❑ Condition of the underdrain (standing water or evidence of standing water indicates a need for cleaning)
- ❑ Stability of the side slopes
- ❑ Weed growth in energy dissipators (pull or cut to remove; do not use herbicides; when growth is severe, replace landscaping fabric and rock)
- ❑ Signs of vandalism

Maintenance Access—Normal maintenance access consistent with Caltrans standards (including a vehicle pullout placed to allow access to the swale) should be sufficient for maintenance of a swale system. Placing a swale system in the 3 m setback from the embankment toe to the right-of-way line is possible. Access to the swale would be in the same manner as the slope access, from possibly distant access points, and travel along the right-of-way line. Where the right-of-way is limited, soil stabilization in the swale (Section 3.3) would allow light maintenance vehicles to use the swale itself (rather than adjacent right-of-way) to access portions of the swale that are not immediately adjacent to maintenance vehicle pullouts. For extended detention basins, a maintenance vehicle pullout area should be placed to allow access to the basin, particularly the basin outlet and sediment forebay.

Inspection—Both swales and extended detention basins should be inspected in accordance with the site-specific maintenance plan (see Section 3.4; at a minimum, annual inspections will be needed), evaluating and correcting problems identified when completing the maintenance checklist. Inspecting near the end of the rainy season provides the opportunity to correct any problems prior to the next rainy season.

Mowing—The grassed areas in swales and extended detention basins will need to be mowed at least annually, to a minimum height of 150 to 200 mm. Mowing two to four times per year is preferred because more frequent mowing prevents injury to grasses from cutting off too much of the leaf blade and stands or grasses maintain a greater shoot density, which enhances pollutant removal. Mowing should be conducted often enough that only one-third to one-half of the grass blade is cut off each time (*i.e.*, do not allow the grass to grow above 0.5 m). Designing wide swales and swales and basins with shallow sloped designs without barriers will provide easy access for mowing. Removing clippings[8] is better, but it is possible to leave clippings in place if mowing is conducted in the dry season (however, this may increase the frequency that the swale needs maintenance; see below). Unless soil stabilization is used, mowing should only be done in the dry season, when the swale or basin bottom is dry enough to be capable of supporting a lawn mower (note that soil stabilization extends the mowing season by allowing access before the soil is completely dry, but does not allow mowing during the wet season unless clippings are collected). To avoid compressing the soil, tracked or lightweight vehicles are preferred for mowing if soil stabilization methods are not used.

Extended Detention Basin Maintenance Checklist

- ❑ Obstructions of the inlet or outlet devices by trash and debris
- ❑ Poor plant health or areas of low plant density (depending on condition, either fertilize with organic slow-release fertilizer [only when conditions prevent release of fertilizer in runoff] and irrigate prior to rainy season or clip short; reseed, sod, or plug plant; and irrigate for 60-90 days prior to likely first rain event)
- ❑ Excessive erosion or sedimentation or low spots in the basin (correct grade and replant per above)
- ❑ Cracking or settling of the outlet structure
- ❑ Deterioration of pipes
- ❑ Stability of the side slopes
- ❑ Weed growth in low-flow channel and berm between forebay and main basin (pull or cut to remove; do not use herbicides; when growth is severe, replace landscaping fabric and rock)
- ❑ Signs of vandalism

[8] If grass is only mowed once a year, the amount of clippings would be large and clipping removal would probably be necessary. Clippings removed from a swale or basin can be used as mulch in adjoining landscaping areas that do not drain directly into the swale or basin. This keeps the clippings from clogging the drainage structure or being washed out with runoff.

Underdrain Cleanout—Cleaning should be performed in response to observed drainage problems.

Sediment Removal—Sediments need to be removed relatively frequently from sediment control features at the swale or basin entry, and less frequently in the main swale or basin. Sediment should be removed during the dry season, to minimize handling and disposal cost. Ideally, such cleaning should be conducted in late summer or early fall, prior to the first rains. For the first several years, testing of the sediments to confirm they are non-hazardous is recommended. Lead is the most likely problem pollutant; its levels in the highway environment are decreasing, so elevated lead concentrations in sediments are not anticipated to be a long-term problem.[9] Because site-specific conditions such as watershed land use, type of ground cover in the area, and soil types are important factors in determining how rapidly sediment will accumulate, setting a generic frequency for sediment removal is not possible. Since Caltrans' goal will be to minimize maintenance visits to a site, performance standards are recommended below to set maintenance intervals, rather than recommending a particular maintenance frequency.

- Swale Entry Sediment Control Devices—Annual cleaning must be conducted to ensure that trapped sediments are not washed into the swale.

- Swales—Debris and sediments accumulated in the swale bed must be removed when visible sediment builds up to 150 mm deep at any location or if it causes grass to die. (The sediment depth will be uneven—one way to evaluate its maximum depth will be to look at the unevenness of the swale bottom.) Because site-specific conditions such as watershed land use, type of ground cover in the area, and soil types are important factors in determining how rapidly sediment will accumulate in a swale, setting a generic frequency for sediment removal is not possible. Since Caltrans' goal will be to minimize maintenance visits to a site, a performance standard is recommended to set maintenance intervals, rather than recommending a particular maintenance frequency. Remove sediment by hand (flat bottomed shovel, for small jobs and spot

[9] During the first few years of swale or basin operation, the project team recommends annual testing of sediments in the swale or basin at the same time that testing of the sediments in pre-swale or pre-basin sediment traps is conducted. This will confirm that future sediment disposal will not be a problem, and will allow early identification of the possible but unlikely trend to increasing lead concentration in sediments that might warrant sediment removal before concentrations become too high.

corrections) or mechanically (for large jobs) to bring the swale to an even grade. Reseed, sod, or plug plant the affected portions of the swale, and irrigate for 60-90 days prior to likely first rain event.

- Sediment Forebays in Extended Detention Basins—The basin forebay (entry area) will require more frequent maintenance than the main portion of the basin. A typical maintenance performance standard is that the sediment should be removed when 25 to 50% of the forebay capacity is filled with sediments. A sediment removal marker placed on the forebay lining provides a convenient indicator of the sediment volume. Site-specific conditions determine maintenance frequencies for both the forebay and the main basin; reported sediment removal intervals for forebays in similar systems are from annually to every 5 to 7 years.

- Extended Detention Basins—For the main basin, sediments should be removed when 20% of the basin volume is lost (in order to ensure that the basin treatment capacity does not fall below the water quality volume) or when 25% or more of the vegetation in the basin is covered with sediments. Reported sediment removal intervals for the main basin in similar systems are from every 5 to 7 years to every 25 to 50 years. Once the sediment is removed, the bottom of the main basin and any other disturbed areas will need to be stabilized and re-vegetated to maintain the basin's operating efficiency and to prevent clogging of the outlet piping. If only portions of the basin need to be re-vegetated, reseed, sod, or plug plant and irrigate for 60-90 days prior to likely first rain event. If most of the basin bottom has been disturbed, it will be more appropriate to replant the entire base using procedures similar to those used for the original planting.

Maintaining Vegetation Cover—Maintenance activities should not create the presence of any unvegetated soil areas in the drainage system. Such areas would be subject to erosion, potentially harming the swale or basin, and creating undesirable sediment loads in the runoff.

3.6 Pollutant Removal

From a storm water quality perspective, the ultimate goal of permanent vegetative design features is to reduce pollutants that are discharged to water bodies. Currently, there are two basic regulatory drivers behind this goal–NPDES permits and Total Maximum Daily Loads (TMDLs).

NPDES Permit—As described in Section 1.0 Introduction, Caltrans has received an NPDES Permit that details specific requirements for highway storm water runoff treatment. The permit includes requirements for Caltrans to reduce pollutants in storm water runoff to the "maximum extent practicable" (MEP). However, MEP has not yet been defined by regulatory agencies. MEP is very likely to evolve over time and will likely vary from place to place and from one pollutant to the next. Therefore, if the permanent vegetative design features in this guide are being incorporated into highway drainage designs to comply with NPDES Permit requirements, Caltrans staff should confirm for themselves that the designs meet the appropriate MEP standard.

Currently, regulatory agencies are focusing on the quantity of runoff, not its quality as the way of expressing the MEP standard. As discussed in Section 2.1.1 Hydrology, the quantity of runoff to be treated is defined as either a "water quality flow" or a "water quality volume," depending on the type of treatment facility being designed. This guide employs an example definition of water quality flow and two common definitions of water quality volume (which are the same as the two definitions included in Caltrans' NPDES permit). In general, the designs presented in this guide are at the high end of the types of treatment controls available. So at this point, it is assumed that vegetative-type treatment of the water quality flow and water quality volume will be considered MEP. It is possible that the MEP standard could be raised in the future (including adding a quality of runoff element), but as to if and when the standard may change cannot be predicted at this time.

Caltrans' *Project Planning and Design Guide* will eventually contain Caltrans design standards for water quality flow and water quality volume. Because these definitions are in flux and may be set locally, staff should confirm with local Caltrans District Hydraulics or Water Quality staff the appropriate water quality flow and volume criteria to be used in the project area.

Total Maximum Daily Loads—Clean Water Act (CWA) section 303(d) requires that water bodies not meeting water quality standards be identified ("listed") every two years. In recent years, the U. S. Environmental Protection Agency (U.S. EPA) has listed hundreds of water bodies in California as impaired due to pollutants in storm water runoff. CWA 303(d) listings trigger the need to establish a TMDL, which sets a limit on the "load"(quantity) of a pollutant that can be discharged into the listed water body, and allocates pollutant reductions among dischargers, such as towns, cities, wastewater treatment plants, and potentially Caltrans.

To help staff address storm water issues, Caltrans worked with the California State University Sacramento Office of Water Programs to develop its Water Quality Planning Tool. Available only on the Internet (see Section 5 for details), the tool is a database of water quality standards and possible pollutants from Caltrans facilities. The Water Quality Planning Tool should be checked early in the project development process to determine: (1) whether water bodies in the project area have been listed for specific pollutants and (2) the status of and any requirements of subsequent TMDL efforts. The pollutants of concern in an area and any requirements for their reduction should be considered when selecting an appropriate treatment control.

3.6.1 Swales

Well-designed and properly maintained grass-lined swales provide significant pollutant removal. Swales work well for highway runoff because their ability to remove pollutants is at its peak during storms that generate the most pollutant-laden runoff—small storms, early season storms, and storms after a dry spell. At such times, the swale bottom will be generally dry, allowing maximum infiltration of runoff and associated pollutants. During the later parts of larger storms or on later days during a series of storms the swale bottom will become saturated, reducing the swale’s capability to remove pollutants by infiltration. At such times, pollutant levels in runoff are generally lower (since most pollutants will have been washed off by earlier storms or in the early part of the storm). Table 5 summarizes removals of pollutants in a well-designed and well-maintained grassy swale.

Table 5. Storm Water Runoff Pollutant Removal by Swales and Extended Detention Basins

Storm Water Runoff Treatment Element	Total metals (%)				Dissolved metals (%)				Solids (%)	Organics (%)
	Cu	Pb	Ni	Zn	Cu	Pb	Ni	Zn	Total Suspended Solids (TSS)	Total Petroleum Hydro-carbons (TPH)
Swale	46-89	50-99	88	69-99	19	50	47	82	80-99	75
Extended Detention Basin	29	43	--	29	--	--	--	--	61	--

Notes: "—" means no data; removal likely small. Data are from sites around the U.S. with well-maintained dry swales and vegetated extended detention basins. Caltrans measurements of pollutant removal by basins and swales conducted with somewhat different design parameters showed similar to somewhat higher pollutant removals (Currier, 2001).
Sources: Winer, 2000; Schueler, 1996; and Schueler, 1997.

3.6.2 Extended Detention Basins

In an extended detention basin, the most important process for highway runoff pollutant removal is gravitational settling of suspended sediments.[10] A small portion of the dissolved pollutants in highway runoff may be removed by contact with the basin bottom sediments and/or vegetation. In general, fine metal-bearing particulates and dissolved pollutants in highway runoff are not removed well—extended detention basins do not remove highway runoff pollutants of concern as well as swales or other infiltration measures. Nevertheless, extended detention basins, if properly designed and maintained, can provide significant pollutant removal, as shown in the table above.

By detaining and slowly releasing captured water, extended detention basins also have the benefit of moderating peak flows (except under bypass conditions). Reducing peak flows reduces the potential for downstream flooding and erosion.

3.6.3 Factors Affecting Pollutant Removal

Factors that affect the pollutant removal efficiency of swales and extended detention basins include design elements and maintenance.

Underdrains—The use of an underdrain (necessary for slopes below 2% or in heavy clay soils) reduces residence time of water in the vegetated portion of the swale. If the underdrain is properly designed, it will facilitate a slow drainage of the swale within 12 to 24 hours; however, a poorly designed underdrain has the potential to reduce

[10] Limited infiltration may be provided during the retention time, depending on the soil permeability. Such infiltration enhances pollutant removal. Because clay soils, which are common in District 4, limit infiltration rates, this analysis assumes no pollutant removal from infiltration.

removal efficiencies if it reduces the travel time in the swale to less than 10 minutes.

Maintenance—Maintenance is essential to the operation of the swales and basins. A poorly maintained, but still functional swale will have significantly lower pollutant removal rates. A deteriorated swale (where vegetation has died, sediment accumulation is not stabilized by vegetation, and/or erosion has become significant) will remove few pollutants and may actually contribute sediments and nutrients to runoff. If an extended detention basin is not maintained, eventually it will pass sediments through—or worse, large storms could wash accumulated sediments out of filled, no-longer-vegetated basins. The pollutant removal data in this section do not apply to swales and basins that are not properly maintained.

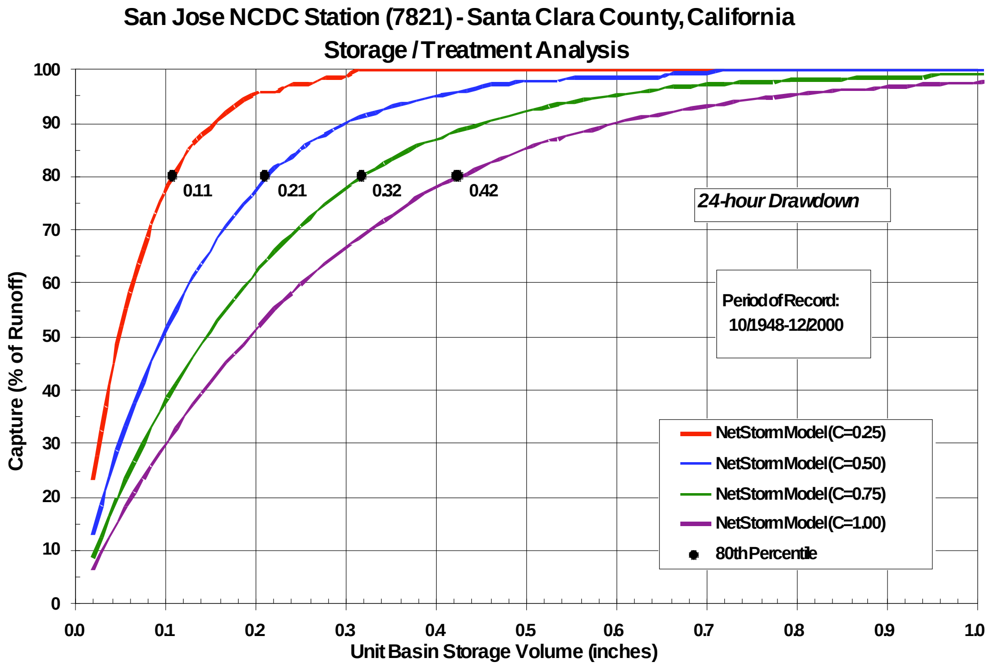
3.6.4. Treatment of "Water Quality" Flow or Volume

Another way of evaluating the effectiveness of a storm water runoff treatment element is to look at the portion of the annual storm water runoff that is effectively treated by the element. If the design procedures recommended in this guide are followed, the selected water quality flow (for swales) or water quality volume (for basins) will determine the fraction of the annual runoff that receives treatment.

Water Quality Volume—For any given location and climatology, a relationship exists between the storage volume of a basin and the percent of annual runoff that can be captured by that volume. Plotting basin storage volumes versus percent of annual runoff captured yields a capture efficiency curve that is unique to the climatology of each location. The one thing the curves have in common is a point of diminishing returns (the so called "knee of the curve"). The knee of the curve is often used to define the "water quality" volume, or the volume of water that facilities should be designed to treat. A review of capture efficiency curves for locations around the state including Oakland (as was done in the *California Storm Water Best Management Practice Handbooks*) shows that the knee of the curve is generally in the range of capturing 80 to 90 percent of the annual runoff. Figure 2 (on the next page) shows an example of a capture efficiency curve.

Studies have demonstrated that pollutant removal capability of a basin generally tracks capture efficiency curves. That is, the more small infrequent storms and the first part of larger storms that can be captured (up to the maximized annual volume), the more the pollution control benefits of a basin are provided in a cost-effective manner.

Figure 2. Example of Capture Efficiency Curve Demonstrating Knee-of-the-Curve or Water Quality Volume Concept



Water Quality Flow—The performance of treatment controls such swales is driven by their ability to handle flow (as opposed to volume, which is the case with treatment controls such as basins and constructed wetlands). Swales should be designed for effective treatment of the peak runoff rate during a "water quality" event, which is at the upper end of common flows—not a peak flow event. The "water quality flow" is selected by analyzing rainfall intensity-duration curves for a given location and climatology. The pollutant removal capability of a swale is generally believed to track the rainfall intensity-duration curves. That is, the more small infrequent storms and the first part of larger storms that can be treated, the more the pollution control benefits of a swale are provided in a cost-effective manner. The curves have a point of diminishing returns (the so called "knee of the curve"). The knee of the curve is commonly used to define the "water quality" flow. Treatment of flows above this level is possible, but generally not believed to be cost-effective.

To provide effective treatment, the swale should pass flows up to the "water quality flow" at less than 0.3 m/s, with a total travel time in the swale of at least 10 minutes. The flow rate is set to maximize the opportunity to infiltrate and filter pollutants and to protect swale vegetation. The 10-minute residence time has been found experimentally to provide effective treatment.

Because these concepts provide a good method of estimating pollutant removal effectiveness for storm water runoff treatment measures, regulatory agencies have started to designate standards for water quality flow and water quality volume. Such standards, which vary by region, can be more stringent than statewide standards. In Section B.5.3 of its *Storm Water Management Plan*, Caltrans has designated water quality volume stands and has indicated the intent to develop water quality flow standards. The standards will be provided in the *Project Planning and Design Guide*. When designing a storm water runoff treatment feature that is intended to address requirements for runoff treatment, confirm with local Caltrans District Hydraulics or Water Quality staff for the appropriate water quality volume and/or flow criteria to be used in the project area.

Example #1: Grassy Swales Incorporated Into an Interchange

This example shows how a grassy swale can be incorporated into the drainage for an overpass and ramp in a highway interchange. The same concepts can be applied to other portions of an interchange. Figure 3 shows the typical grading and drainage design for a loop ramp. Figure 4 shows how the drainage can be modified to incorporate a grassy swale into the interchange drainage. Major elements of the design example illustrated in Figure 3 are:

- The design utilizes typical interchange grading and open spaces to create a long circuitous swale.
- The design maximizes opportunities for storm water runoff from the interchange to be treated by draining through the swale.
- The swale design utilizes typical interchange drainage patterns and facilities and standard or slightly modified Caltrans drainage structures.
- The design example includes elements to minimize common failures in swales (erosion, vegetation failure, and excessive sedimentation).
- The design example includes elements to minimize and simplify maintenance (swale entry sediment collection elements, maintenance access pull-out, and use of appropriate grasses).

Drainage Design Elements

The location for this treatment method example is within a loop ramp of a typical interchange layout. The local street crosses over the highway with approach embankments to the bridge. The embankment grading within the loop ramp is slightly modified to create a bench for a grassy swale with a mild longitudinal slope. Drainage facilities are directed to outlet onto the grassy swale with the runoff eventually discharging to a drainage inlet. The swale is designed with broad sweeping curves to minimize the potential for erosion (tight bends should be avoided).

EX-1-A shows the steps in the general design procedure for a swale. EX-1-B provides the specific design procedures for this example.

- Longitudinal Slope—Selected the ideal slope of 2%.
- Water Quality Flow—For this example, the water quality flow was defined as the runoff based on 10% of the 50-year rainfall intensity.
- Sizing—Bottom width of 0.8 m, with 3:1 side slopes
- Swale Flow Velocity—Design velocity at water quality flow is 0.1 m/s; velocity at peak design flow is 0.33 m/s. Energy dissipators are included in the design to control velocity at swale entry points.
- Minimum Swale Length—in this example, the entire swale is about 200 m long, with the last swale entry point more than 61 m from the end of the swale. At least a 60 m length is necessary to provide the desired 10-minute travel time.

Figure 3. Typical Loop Ramp Grading and Drainage

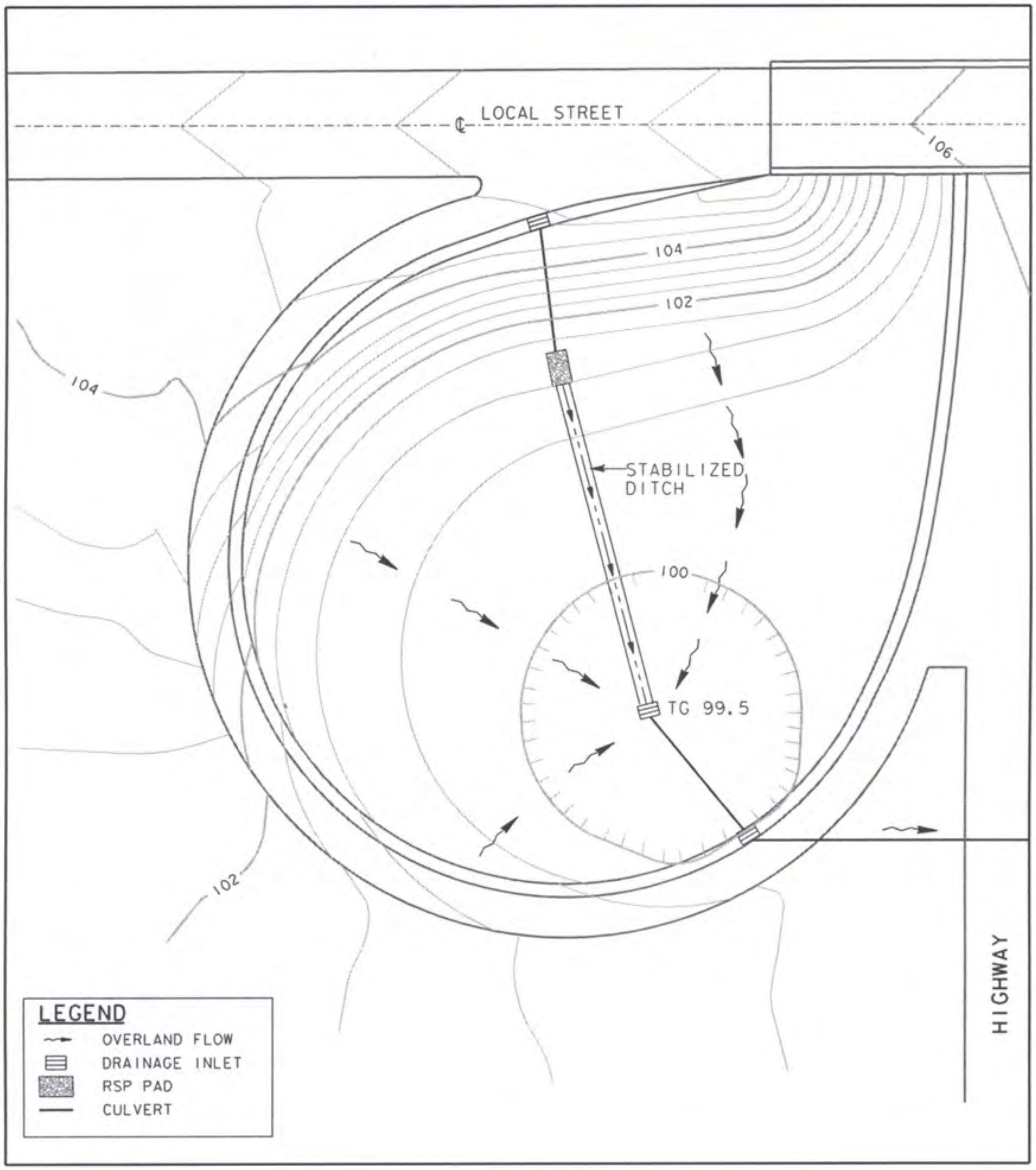
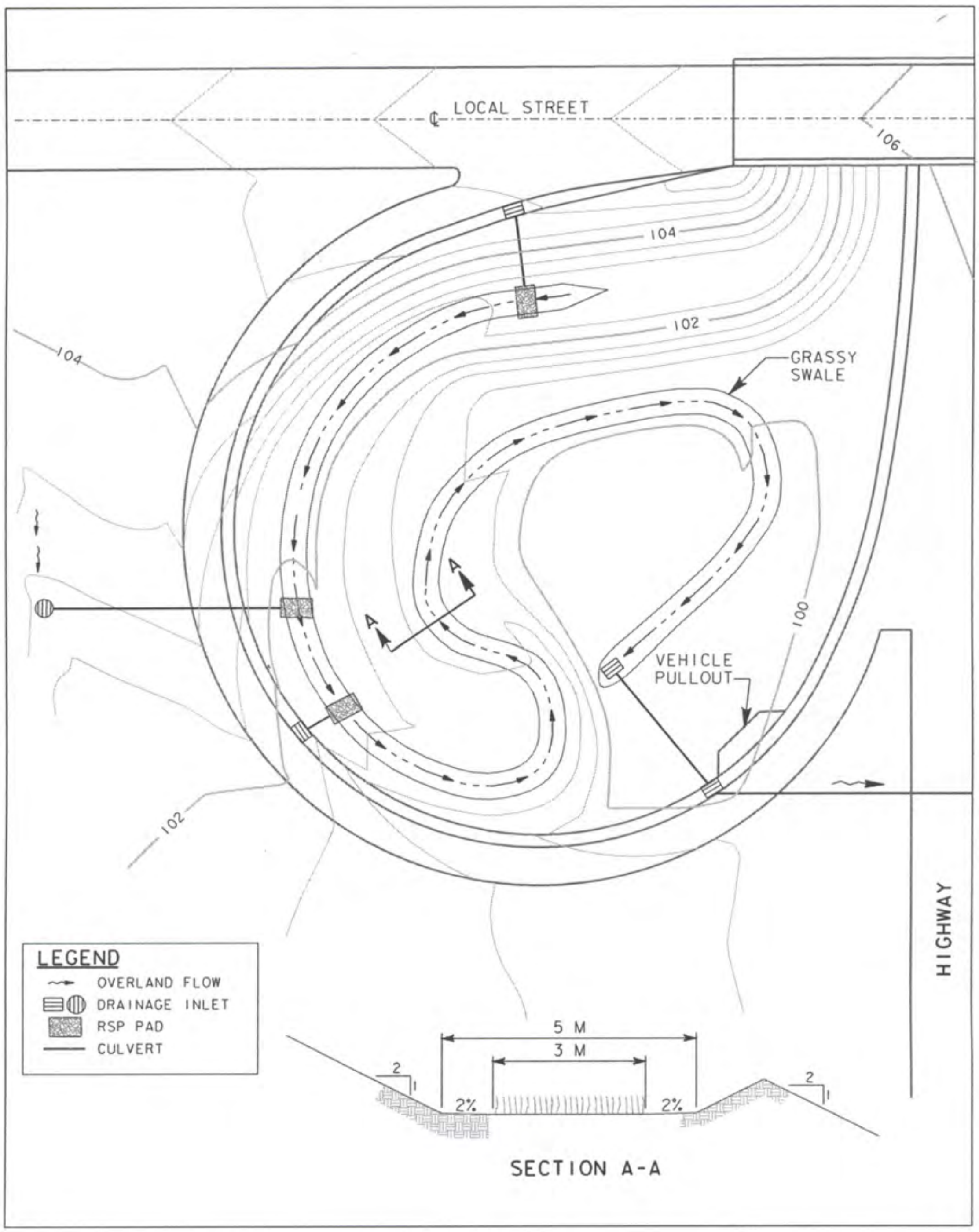


Figure 4. Example #1 - Grassy Swale Incorporated Into an Interchange



EX-1-A

Steps For The Drainage Design Of A Grassy Swale In An Interchange:

1. Layout standard drainage system design for the interchange.
2. Layout grassy swale in the off-pavement areas where pavement flows and other target storm drains can be discharged. Allow for minimum length of the swale to establish a minimum 10-minute travel time for the water quality flow and enough longitudinal slope to discharge to the main interchange drains.
3. Establish the peak design flow and water quality flow along the length of the swale.
4. Select desired vegetation and determine the controlling Manning's *n* values for the peak design flow and the water quality flow.
5. Establish the geometry of the swale (longitudinal slope, bottom width, side slope, depth) and the additional geometry of the swale bench. The geometry should be established using Manning's Equation and the swale design criteria identified above. The swale geometry should consider the peak design flow and the water quality flow.

Manning's Equation $$Q = \frac{1}{n} A R^{0.67} S^{0.5}$$

where: Q = total flow, m^3/s
A = cross-sectional area, m^2
R = Hydraulic radius, m
S = longitudinal slope, m/m
n = Manning's coefficient

6. Prepare a rough grading plan for incorporating the swale into the interchange grading.
7. Incorporate velocity control energy dissipators where flow enters the swale.
8. Design sediment control elements upstream of the swale.

Plants and Planting Considerations

Selecting and establishing the right grasses are essential for the operation of a swale. Planting, species, use of temporary erosion control blankets, and recommended soil stabilization methods for this example are the same as described in Section 3.3.

Construction Cost

Swales are generally considered to be the lowest-cost of the various highway storm water runoff treatment options.

- The costs of the civil elements of the swale, in addition to the drainage elements that would be necessary without the swale, are relatively small. If the project were net import, the project would add expense because it would involve additional fill. If the project is net export, the design could reduce costs. The grading costs would likely be included in the construction; additional costs would be unlikely.
- Landscaping costs would be somewhat higher than typical—estimated to be in the range of about $41,000 to $78,000 for this 200 m stretch of swale (the cost depends on the landscaping method and soil stabilization option selected). A landscaping contractor could construct underdrains designed to protect vegetation (if needed due to the presence of heavy clay soils) for about $59 per linear meter, for a total of about $11,700 for a 200 m stretch of swale.

See EX-1-C for an example landscaping cost estimate for this swale.

Maintenance

- Annual Inspection (see Section 3.5)
- Mowing—Annually or more often (two to four times per year recommended) if needed to maintain optimal height (no less than 150 to 200 mm) and to avoid cutting more than half of the grass blades off at each mowing.
- Pre-swale sediment traps—Annual cleaning
- Underdrain cleanout—Cleaning should be performed in response to observed drainage problems.
- Swale Sediment Removal and Swale Revegetation—Frequency to be determined by inspections. Debris and sediments accumulated in the swale bed must be removed when visible sediment builds up to 150 mm deep at any location or if it causes grass to die.

The most costly maintenance element would be swale sediment removal and revegetation—see EX-1-D for an example. Relative to swale sediment removal and revegetation cost, the cost for annual maintenance activities (inspection, correction of minor problems, annual cleaning of pre-swale sediment traps, and mowing) would be small; for similar swales annual maintenance costs have been estimated to be less than $1 per linear foot ($3.30 per linear meter) of swale (San Francisco Bay RWQCB, 2001).

Pollutant Removal

The design method used in this example bases the swale design on a "water quality flow" that provides treatment to about 80% of total runoff. The design uses the common standards for swale design—keeping flows up to the water quality flow below 0.3 m/s and ensuring a minimum swale residence time of 10 minutes. Designs like this example that employ the water quality flow concept should maximize the value of storm water phytoremediation practices and achieve pollutant removals similar to those in Table 5.

Applicability of this Design Example to District 4 Highways

Designs incorporating a grassy swale into highway drainage should work in most San Francisco Bay Area locations. Two types of locations are problems:

1. Sites with very shallow groundwater (less than 0.6 meters below ground surface)—at such locations, constructed wetlands may be a more appropriate storm water phytoremediation strategy (if Caltrans approves use of constructed wetlands for storm water runoff treatment). In such situations, swales could still be used to manage runoff from the upper portions of the interchange, but would need to terminate and connect to the ordinary drainage system at an elevation well above the groundwater level.

2. Sites with heavy clay soils where water residence time in the swale could exceed 24 hours—Such sites can be addressed through incorporation of an underdrain in the design. Underdrains add expense (and have the potential to reduce pollutant removal efficiency if they are not properly designed). Other storm water phytoremediation designs (*e.g.*, wetlands) should be considered in such locations.

EX-1-B

Swale in an Interchange Example Design

1. Layout the normal drainage system.

   Identify the typical interchange drainage needs, inlet spacing, and the normal discharge points within the interchange.

2. Identify linear swale system layout.

   Layout the grassy swale in the off pavement areas where pavement flows and other target storm drains can be discharged. Allow for minimum length of the swale and enough longitudinal slope to discharge to the main interchange drains. As shown in the attached drawing, portions of the interchange pavement have been diverted down the ramp embankment to the grassy swale located within the loop ramp.

3. Calculate the peak design storm flow.

   Using the Rational Method as defined in the Caltrans HDM, determine the peak 25-year flow to the grassy swale.

   Q_{25} = 0.00275 ciA where: c = 0.60 overall
   i_{25} = 52 mm/hour (t_c of 10 minutes)
   A = 0.81 ha

   Q_{25} = 0.071 m^3/s

4. Calculate water quality flow (WQF).

   No commonly accepted definition of a WQF has yet been established in California. A tentative guideline for estimating purposes for the estimation of the WQF is “the runoff based on 10% of the 50-year rainfall intensity”.

   Q_{WQF} = 0.00275 ciA where: c = 0.60 overall
   i_{50} = 58 mm/hour (t_c of 10 minutes)
   i_{WQF} = 1/10 of i_{50} = 5.84 mm/hour
   A = 0.81 ha

   Q_{WQF} = 0.0085 m^3/s

5. Set Manning’s *n* value.

   Depending on the type of target vegetation and the depth of flow set the Manning’s *n* value for the WQF. Use 0.25 for very shallow flow in grassy vegetation. (See Section 1.3, Frequently Asked Questions for additional discussion of the Manning’s *n* values.)

EX-1-B - continued

6. Calculate the swale bottom width using the WQF.

Using Manning's Equation for a trapezoidal channel the bottom width is defined as:

$b = (Qn/(y^{1.67}s^{0.5}))-Zy$ where: $n = 0.25$ $y = 0.076$ m
$Q = 0.0085\ m^3/s$ $s = 0.02$
$Z = 3$ (side slope per unit rise)

b = 0.87 m, say 0.9 m

Top width = b + 2yZ = 1.4 m

Cross sectional area = $by + Zy^2 = 0.087\ m^2$

Velocity (V) = Q/A = 0.10 m/s

Travel time for a 150 m long swale = 150/V = 1500 seconds = 25 minutes

Swale sections should be at least 60 m long to achieve the minimum 10-minute travel time.

7. Check swale stability using peak design flow.

The peak design flow is 0.071 m^3/s for the 25-year runoff. Assuming a greater flow depth and poor vegetative cover, use a Manning's *n* value of 0.10. A trial and error calculation could be performed to determine the flow depth in the swale, or Table 7-11 of *Handbook of Hydraulics*, King and Brater, 1976 could be used (English units required).

$K' = Qn/b^{2.67}s^{0.5}$ where: b = 3 s = 0.02
Q = 2.5 cfs n = 0.10

$K' = 2.5 \times 0.1/(3^{2.67} \times 0.02^{0.5})$
K' = 0.094

From Table 7-11 D/b = 0.17,
therefore D = 0.51 feet (0.16 m)

Top width = b + 2DZ = 6.06 feet (1.85 m)

Cross sectional area = $bD + ZD^2$ = 2.31 square feet (0.21 m^2)

Velocity = Q/A = 1.1 fps (0.33 m/s)

Travel time for a 150 m long swale = 150/V = 454 seconds = 7.5 minutes

EX-1-B - continued

8. Adjust grading plan to match the requirements of the grassy swale.

9. Place vehicle maintenance turnout adjacent to the grassy swale(and sediment control structure if used).

10. Design energy dissipators.

    At the entrance to the grassy swale, velocities for the WQF should be limited to 0.3 m/s. If the runoff is discharging from a culvert, the entrance velocities could be controlled with the installation of a flared end section, riprap, a culvert “tee” outlet, concrete energy dissipators or other configurations presented in the Caltrans Highway Design Manual. The energy dissipator should also be designed to reduce the velocity of the peak design flow at the entrance to the grassy swale to acceptable levels, typically 0.9 to 1.2 m/s.

EX-1-C

Swale in an Interchange Example Landscaping Cost Estimate

Two cost estimates are provided, one based on use of grass plugs, the other using grass sod. The estimates are based on the following assumptions:

- Both options include same soil preparation—soil preparation is 200 mm deep (if Caltrans allows, ripping another 300 mm deeper would be very beneficial)
- Grass plugs includes coconut blanket and grass overseeding
- Plant establishment is one year
- Grass plug establishment includes watering and weed eradication
- Sod establishment includes watering and not more than two mowings
- Both options based on finish grade provides by others
- Fine grading is by hand and machine work, does not include precision screeding
- Water supply for establishment to be provided onsite
- Cost of water not included
- This estimate assumes construction is completed as scheduled with sod or contract-grown plugs
- If schedule and planting/growing seasons are ideal, establishment period might be shortened, at least for the sod option
- Swale is 200 meters long and 3 meters wide (600 square meters)
- Soil stabilization is provided for the width of the swale and an extra 0.375 m on each side, for a total width of 3.75 m (750 square meters)

Grass Plugs Option

Item	Area (m^2)	Unit Cost ($ per m^2)	Total Cost
Grass plugs with blanket in swale	600	$99.13	$59,480
Total without soil stabilization			***$59,480***
Cellular confinement, 100 mm depth	750	$24.21	$18,160
Total with soil stabilization			***$77,640***

Sod Option

Item	Area (m^2)	Unit Cost ($ per m^2)	Total Cost
Grass sod	600	$68.25	$40,950
Total without soil stabilization			***$40,950***
Turf reinforcement mat (18 mm)	750	$11.84	$8,880
Cellular confinement, 100 mm depth	750	$24.21	$18,160
Total with turf reinforcement mat			***$49,830***
Total with cellular confinement			***$59,110***

Note: Costs are based on 2001 price levels.

EX-1-D

Swale in an Interchange Example Major Maintenance Cost Estimate

This major maintenance cost estimate is based on use of grass sod. The estimate is based on the following assumptions:

- Strip up to 150 mm uneven sediment and vegetation from swale
- Load and haul off strippings, assuming 1 hour truck cycle for hauling (disposal fees are not included; expect $26 to $29 per cubic meter for non-hazardous waste)
- Import, spread and grade up to 50 mm topsoil to recreate original sod-bed grades
- Furnish and place native grass sod
- Furnish and construct PVC above ground irrigation system (built on site) and operate as necessary for a period of 90 days, then remove system
- Water supply to be provided onsite; cost of water not included
- Dry soil conditions
- Swale is 200 meters long and 3 meters wide (600 square meters)

Item	**Area (m^2)**	**Unit Cost ($ per m^2)**	**Total Cost**
Move in and staking	600	$0.98	$590
Strip, load, and haul	600	$6.07	$3,640
Prepare sod bed	600	$3.79	$2,270
Furnish and place sod	600	$34.99	$20,990
90-day temporary irrigation	600	$26.00	$15,600
Total			***$43,090***

Note: Costs are based on 2001 price levels.

Example #2: Linear Highway Section

This example shows how the standard design of a linear highway section can be modified to incorporate grassy swales in the runoff drainage and to prevent erosion from the clear strip when the highway is on a slope. The approach used in this design would also be appropriate for a median or other widening of an existing highway. For a newly constructed highway, it would be possible to drain upper slope flows under the highway for management in the swale system described below. For this highway-widening example, construction of such cross-highway drainage was deemed impractical. Figure 5 shows the typical grading and drainage design for a linear highway section on a slope. Figure 6 shows how the drainage can be modified; Figure 7 shows the upslope edge treatment and the swale design details. Major elements of the design example illustrated in Figures 6 and 7 are:

- Highway runoff is diverted through the roadside dike into a swale prior to its discharge into a drainage structure.[11] The swale is placed within the normal right-of-way setback at the toe of the highway fill. These areas are typically the sites of drainage swales.

- Stabilizing the clear strip prevents erosion from an upslope clear strip. While this slightly reduces runoff infiltration (not a desirable change from the water quality perspective) it provides substantial water quality benefits by eliminating a source of sediments and herbicides in runoff, while maintaining Caltrans' preferred vegetation-free clear strip.

- The design utilizes standard Caltrans drainage structures.

- The design example includes elements that minimize common failures in swales (erosion, vegetation failure, and excessive sedimentation).

- The design example includes elements to minimize and simplify maintenance (swale entry sediment collection elements, maintenance access pull-out, and use of appropriate grasses).

[11] Drainage of highway runoff by sheet flow into the swale would be preferable from a water quality perspective, but was not included as an element of the example for the following reasons: (1) dikes appear to be the standard District 4 practice; (2) dikes were highly rated in *California Roadsides: A New Perspective* as a vegetation control measure that reduces pesticide use (a water quality benefit); and (3) sheet flow conditions are only maintained when the road edge is swept or hand-cleaned regularly—otherwise sediment buildup leads to formation of runoff channels that cause erosion in the swale system.

Drainage Design Elements

Uphill Slope—Stabilization of Clear Strip

At locations like the one in this example, there are few drainage design elements on the uphill slope. The uphill area drains onto the shoulder or a separate drainage ditch located between the shoulder and the toe of the uphill slope. The clear strip, which is just uphill from the toe of the slope, is maintained for safety purposes, and the steeply sloped bare ground is subject to erosion. Soil stabilization prevents erosion, eliminating an ongoing source of sediments in runoff, while improving the appearance of the highway edge. By selecting a stabilization method that is compatible with the adjacent drainage facilities and drainage scheme, runoff from the uphill slope should pass across the stabilized slope and safely flow onto the shoulder or adjacent ditch without causing erosion.

Figure 5. Typical Linear Highway Section Grading and Drainage

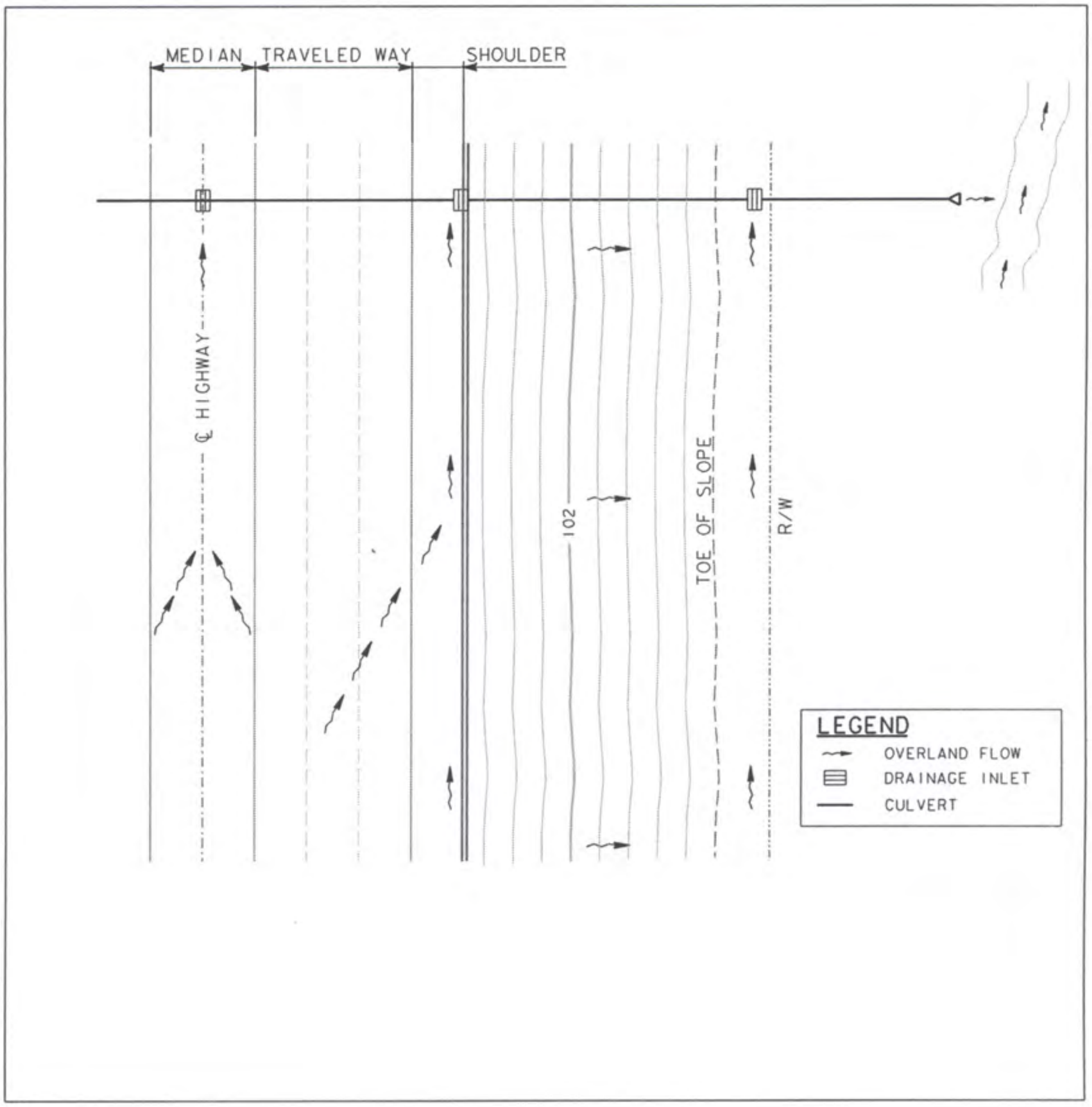


Figure 6. Example #2 - Linear Highway Section

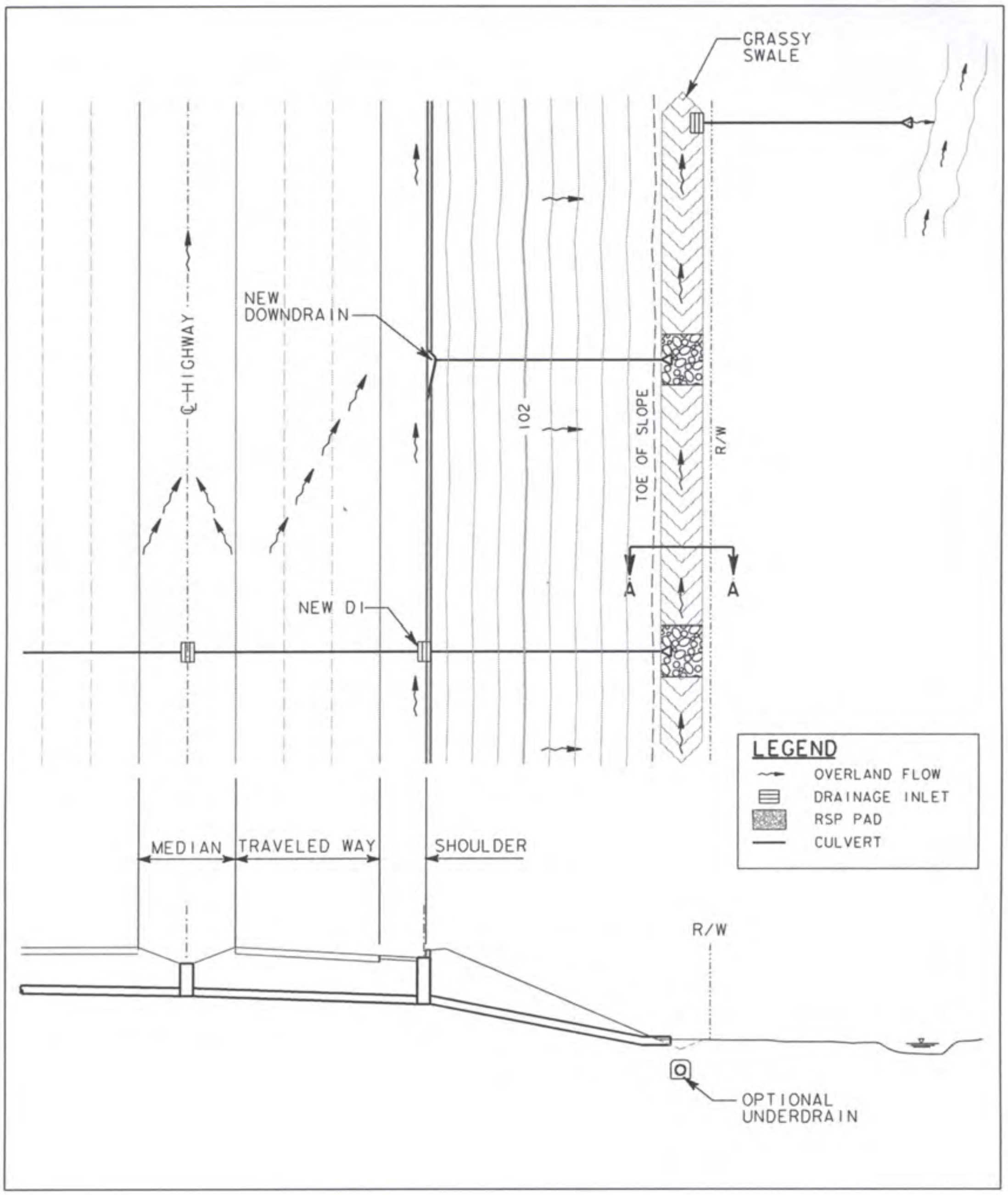
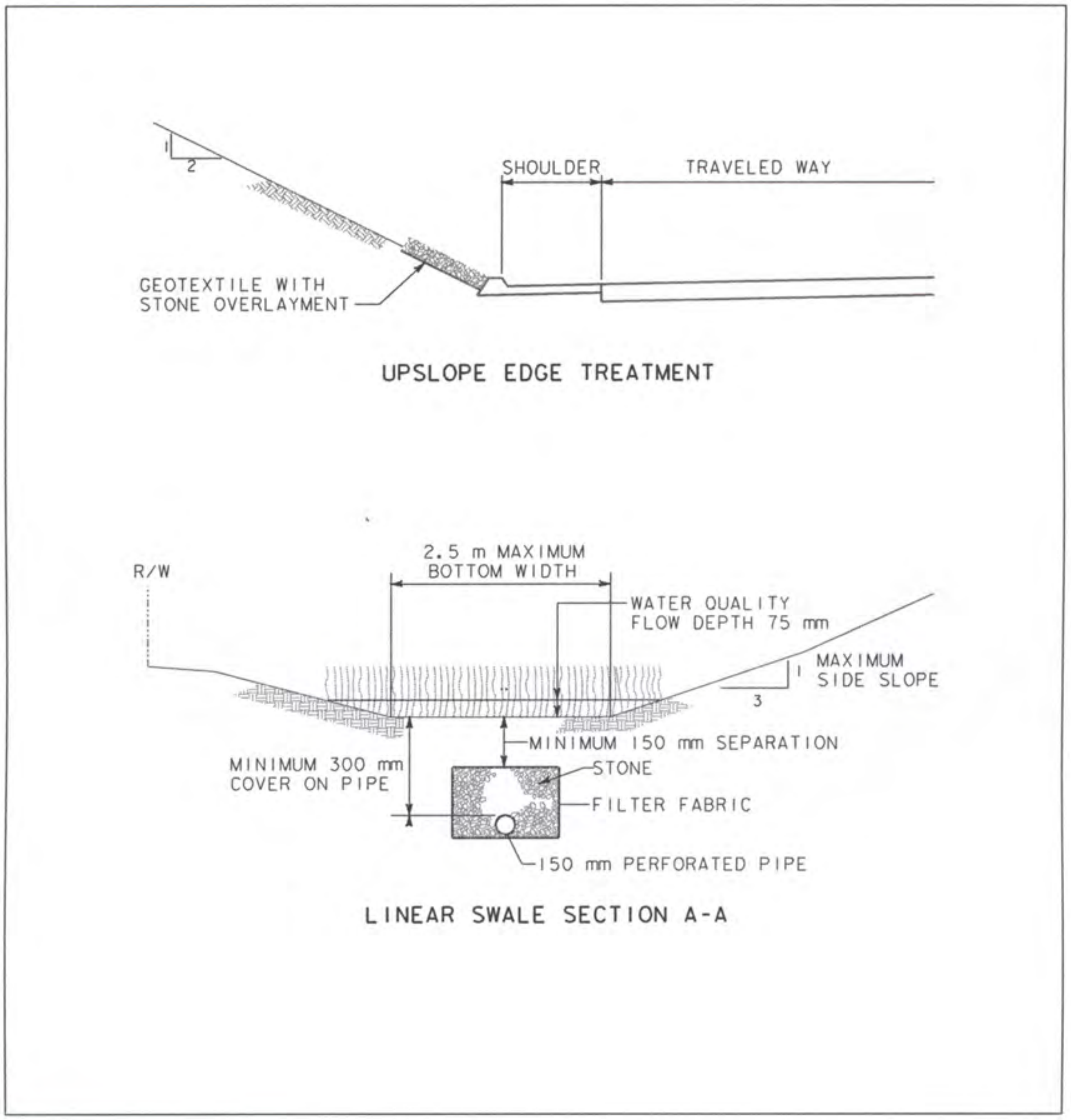


Figure 7. Example #2 - Linear Highway Section Upslope Section and Swale Details



Downhill Slope—Swale

The area of interest is at the foot of the fill slope on the downhill slope of the highway. The focus of this phytoremediation method is to place a linear swale at the toe of the slope, parallel to the highway, which can provide some treatment to pavement runoff. For typical highway pavement drainage design at the top of a tall slope, all pavement runoff will be contained on the shoulder and directed to drainage inlets. The pavement drainage inlets are drained by storm drains to a larger drainage facility that conveys runoff out of the Caltrans right of way. This example shows that it is possible to collect pavement runoff farther upstream of the normal inlet location, convey the runoff to the

EX-2-A

Steps For The Drainage Design Of A Grassy Swale Along A Linear Highway Section:

1. Layout standard drainage system design for the linear highway section including the median or off pavement areas as necessary. For a new highway section, consider installing underground cross-roadway drainage facilities to direct runoff from both sides of the highway into the swale system.
2. Layout swale at the toe of the downside slope where pavement flows and other target storm drains can be discharged. Allow for minimum length of the swale to establish a minimum 10-minute travel time for the water quality flow and enough longitudinal slope to discharge to the main drainage facility.
3. Establish the peak design flow and water quality flow along the length of the swale.
4. Select desired vegetation and determine the controlling Manning's *n* values for the peak design flow and the water quality flow.
5. Establish the geometry of the swale (longitudinal slope, bottom width, side slope, depth). The geometry should be established using Manning's Equation and the swale design criteria identified above. The swale geometry should consider the peak design flow and the water quality flow.

Manning's Equation

$$Q = \frac{1}{n} A R^{0.67} S^{0.5}$$

where:

Q = total flow, m^3/s

A = cross-sectional area, m^2

R = Hydraulic radius, m

S = longitudinal slope, m/m

n = Manning's coefficient

6. Prepare a rough grading plan for incorporating the swale into the linear highway grading.
7. Incorporate velocity control energy dissipators where flow enters the swale.
8. Design sediment control elements upstream of the swale.
9. Determine need to incorporate an underdrain, based on slope (less than 2%) and soil characteristics (infiltration rate less than 0.2 mm per second).

toe of the slope, and discharge to a linear vegetated swale, which then outlets to the larger drainage facility. Such a design does not re-route the flows, so it is consistent with the overall drainage design commonly used for linear highway sections.

EX-2-A *(on previous page)* shows the steps in the general design procedure for a swale. EX-2-B provides the specific design procedures for this example.

- Longitudinal Slope—This example illustrates the likely case that the swale would have a slope of less than 2%, and therefore would requires construction of a permeable layer and underdrain system beneath the swale to protect swale vegetation.

- Water Quality Flow—For this example, the water quality flow was defined as the runoff based on 10% of the 50-year rainfall intensity.

- Sizing—Bottom width of 0.8 m, with 3:1 side slopes

- Swale Flow Velocity—For this example, the design velocity of the water quality flow is 0.1 m/s; velocity at peak design flow is 0.33 m/s. Energy dissipators are included in the design to control velocity at swale entry points.

- Minimum Swale Length—in this example, a minimum 60 m length is used to provide at least a 10-minute travel time.

Plants and Planting Considerations

Selecting and establishing the right grasses are essential for the operation of a swale. Planting, species, use of temporary erosion control blankets, and recommended soil stabilization methods for this example are the same as described in Section 3.3.

Slope Stabilization in the "Clear Strip"—Erosion of soils in the clear strip is particularly prevalent when the clear strip is on a slope. While vegetation is the preferred approach to slope stability from a water quality standpoint, this example operates under the assumption that no vegetation is acceptable to Caltrans in the clear strip. With that limitation, non-vegetative methods to stabilize the clear strip provide water quality benefits by eliminating erosion (a potentially significant source of sediments in highway runoff) and eliminating the use of pesticides to control vegetation in the clear strip.

A variety of available slope stabilization methods were rated in *California Roadsides: A New Perspective,* including asphalt concrete, Portland cement concrete, unit pavements, geotextiles with stone overlayment, herbicidal geofabrics, mat barriers, polymers, enzymes, soil cements, and resin-modified emulsions. Of these methods, the relatively highly rated "geotextiles with stone overlayment method" is notable for its appropriateness to the situation in this example, relatively low cost, and water quality benefits.

Reducing the usual 2.5-meter clear strip width (a very highly rated option in *California Roadsides: A New Perspective*) is recommended in ecoregions where low-fuel vegetation can be planted on the adjoining slope.

Construction Cost

Swales are generally considered to be the lowest-cost of the various highway storm water runoff treatment options.

- The costs of the civil elements of the swale, in addition to the drainage elements that would be necessary without the swale, are relatively small. The grading costs would likely be included in the construction; additional costs would be unlikely. Underdrains, if needed, could be constructed by the civil contractor if Caltrans desires; this example assumes the landscaping contractor would install underdrains.

- Landscaping costs would be somewhat higher than typical—estimated to be in the range of $16,000 to $28,000 per 60-meter stretch of swale, assuming a total landscaping job of about 600 linear meters of swale (the cost depends on the landscaping method and soil stabilization option selected). A landscaping contractor could construct underdrains designed to protect vegetation (if needed due to a low slope or presence of heavy clay soils) for about $60 per linear meter, for a total of about $3,600 for a 60 m stretch of swale. Stabilizing the slope in the clear strip using the geotextile with stone overlayment method would cost about $35,000 for a 600-meter length of clear strip.

See EX-2-C for an example landscaping cost estimate for a 600 linear meter highway section with 600 meters of swale and 600 meters of slope stabilization in the clear strip.

Maintenance

- Annual Inspection (see Section 3.5)
- Mowing—Annually or more often (two to four times per year recommended) if needed to maintain optimal height (no less than 150 to 200 mm) and to avoid cutting more than half of the grass blades off at each mowing.
- Pre-swale sediment traps—Annual cleaning
- Underdrain cleanout—Cleaning should be performed in response to observed drainage problems.
- Swale Sediment Removal and Swale Revegetation—Frequency to be determined by inspections. Debris and sediments accumulated in the swale bed must be removed when visible sediment builds up to 150 mm deep at any location or if it causes grass to die.
- Slope Stabilization in the "Clear Strip"—Eventually the stone overlayment will accumulate dirt and grow weeds and/or the geotextile will begin to fail and allow weed growth (estimated to occur about 4 to 5 years after installation). After that point, weed control will be necessary until the geotextile is replaced.

The most costly maintenance element would be swale sediment removal and revegetation—see EX-2-D for an example of the cost for a 600 linear meter highway section with 600 meters of swale. Relative to swale sediment removal and revegetation cost, the cost for annual maintenance activities (inspection, correction of minor problems, annual cleaning of pre-swale sediment traps, and mowing) would be small; for similar swales annual maintenance costs have been estimated to be less than $1 per linear foot ($3.30 per linear meter) of swale (San Francisco Bay RWQCB, 2001). Replacing the geotextile in the slope stabilization element would cost almost as much as its initial installation (see EX-2-C).

Pollutant Removal

The design method used in this example bases the swale design on a "water quality flow" that provides treatment to about 80% of total runoff. The design uses the common standards for swale design—keeping flows up to the water quality flow below 0.3 m/s and ensuring a minimum swale residence time of 10 minutes. Designs like this example that employ the water quality flow concept should maximize the value of storm water phytoremediation practices and achieve pollutant removals similar to those in Table 5.

Stabilizing the clear strip eliminates an ongoing source of sediments, effectively providing a 100% removal of the eroded sediments.

Applicability of this Design Example to District 4 Highways

Designs incorporating a grassy swale into highway drainage should work in many San Francisco Bay Area locations. Three types of locations are problems:

- Sites with very shallow groundwater (less than 0.6 meters below ground surface)—at such locations, constructed wetlands may be a more appropriate storm water phytoremediation strategy (if approved by Caltrans for treatment of storm water runoff).

- Sites where the swale would need to be located within 3 m of a sound wall or another structure. Because infiltration from the swale has the potential to affect immediately adjacent structures, such situations should be avoided; however, it may be possible to locate swales near structures with certain designs. A site-specific engineering evaluation can be conducted to determine the feasibility of locating a swale near a structure like a sound wall. Alternatives include management of runoff on the other side of the right-of-way (if drainage allows) or diversion to an interchange or other location with expanded right-of-way area.

- For sites with heavy clay soils or shallow slopes, extended water residence time in the swale could be a problem (*e.g.*, exceed 24-48 hours). As shown in the example, these sites can be addressed through incorporation of an underdrain in the design to protect the vegetation. Since underdrains add expense and reduce pollutant removal efficiency, other storm water phytoremediation designs (*e.g.*, constructed wetlands, if approved by Caltrans for treatment of storm water runoff) should also be considered in such locations.

EX-2-B

Swale Along a Linear Highway Section Example Design

1. Layout the normal drainage system.
   Identify the typical pavement drainage needs, inlet spacing, and the normal discharge points along the linear stretch of highway.

2. Identify linear swale system layout.
   Identify areas along the downslope side of the highway before the R/W that are potential sites for a linear swale. Identify if the linear swale site has enough slope available to reach the main drainage facility. Identify tributary areas that can be diverted to the linear swales and not directly to a drainage facility. As shown in the attached drawing, portions of the pavement area have been diverted down the highway embankment to the linear swale located along the highway R/W.

3. Calculate the peak design storm flow.
   Using the Rational Method as defined in the Caltrans HDM, determine the peak 25-year flow to the linear swale.

   $Q_{25} = 0.00275$ ciA where: c = 0.60 overall
   i_{25} = 52 mm/hour (t_c of 10 minutes)
   A = 0.81 ha
   $Q_{25} = 0.071\ m^3/s$

4. Calculate water quality flow (WQF).
   No commonly accepted definition of a WQF has been established in California. A tentative guideline for estimating purposes for the estimation of the WQF is "the runoff based on 10% of the 50-year rainfall intensity".
   $Q_{WQF} = 0.00275$ ciA where: c = 0.60 overall
   i_{50} = 58 mm/hour (t_c of 10 minutes)
   i_{WQF} = 1/10 of i_{50} = 5.84 m/hour
   A = 0.81 ha
   $Q_{WQF} = 0.0085\ m^3/s$

5. Set Manning's *n* value.
   Depending on the type of target vegetation and the depth of flow set the Manning's n value for the WQF. Use 0.25 for very shallow flow in grassy vegetation. (See Section 1.3, Frequently Asked Questions for additional discussion of the Manning's *n* values.)

6. Calculate the swale bottom width using the WQF.
   Using Manning's Equation for a trapezoidal channel the bottom width is defined as:

   $b = (Qn/(y^{1.67}s^{0.5}))-Zy$ where: n = 0.25 y = 0.076 m
   $Q = 0.0085\ m^3/s$ s = 0.02
   Z = 3 (side slope per unit rise)
   b = 0.87 m, say 0.9 m

EX-2-B - continued

Top width = $b + 2yZ$ = 1.4 m
Cross sectional area = $by + Zy^2$ = 0.087 m^2

Velocity = Q/A = 0.098 m/s

Travel time for a 30 m long swale = 30/V = 306 seconds = 5.1 minutes

Swale sections should be at least 60 m long to achieve the minimum 10-minute travel time.

7. <u>Check swale stability using peak design flow.</u>
The peak design flow is 0.071 m^3/s for the 25-year runoff. Assuming a greater flow depth and poor vegetative cover, use a Manning's *n* value of 0.10. A trial and error calculation could be performed to determine the flow depth in the swale, or Table 7-11 of *Handbook of Hydraulics*, King and Brater, 1976 could be used (English units required).

$K' = Qn/b^{2.67}s^{0.5}$ where: b = 3 s = 0.02, Q = 2.5 cfs n = 0.10

$K' = 2.5 \times 0.1/(3^{2.67} \times 0.02^{0.5})$
$K' = 0.094$

From Table 7-11 D/b = 0.17,
therefore D = 0.51 feet (0.16 m)

Top width = $b + 2DZ$ = 6.06 feet (1.85 m)

Cross sectional area = $bD + ZD^2$ = 2.31 square feet (0.21 m^2)

Velocity = Q/A = 1.1 fps (0.33 m/s)

Travel time for a 30 m long swale = 30/V = 90 seconds = 1.5 minutes

8. <u>Adjust grading plan to match the requirements of the linear swale.</u>

9. <u>Place vehicle maintenance turnout adjacent to the linear swale(and sediment control structure if used).</u>

10. <u>Design energy dissipators.</u>
At the entrance to the linear swale, velocities for the WQF should be limited to 0.3 m/s. If the runoff is discharging from a culvert, the entrance velocities could be controlled with the installation of a flared end section, riprap, a culvert "tee" outlet, concrete energy dissipators or other configurations presented in the Caltrans Highway Design Manual.

EX-2-B – continued

11. Design underdrains (if required).
    For swales with a slope flatter than 2%, an underdrain is needed to prevent **EX-**formation of areas of standing water or highly saturated soil (for more than 48 hours), in order to prevent harm to the swale vegetation. The underdrain is intended to protect the vegetation in the swale—not for flow conveyance. A typical underdrain is a 150 mm diameter perforated plastic pipe surrounded by a zone of stone wrapped in a filter fabric, and should be located beneath the active growing zone of the swale (about 200 mm below the surface). Underdrain cleanouts should be placed in locations suitable for maintenance access (*e.g.*, near swale outlet or in other accessible locations).

EX-2-C

Linear Highway Section Example Landscaping Cost Estimate

For the swale portion of this example, two cost estimates are provided, one based on use of grass plugs, the other using grass sod. The cost for stabilizing the uphill clear strip is provided separately. The estimates are based on the following assumptions:

- Both options include same soil preparation—soil preparation is 200 mm deep (if Caltrans allows, ripping another 300 mm deeper would be very beneficial)
- Grass plugs includes coconut blanket and grass overseeding
- Plant establishment is one year
- Grass plug establishment includes watering and weed eradication
- Sod establishment includes watering and not more than two mowings
- Both options based on finish grade provides by others
- Fine grading is by hand and machine work, does not include precision screeding
- Water supply for establishment to be provided within one mile
- Cost of water not included
- This estimate assumes construction is completed as scheduled with sod or contract-grown plugs
- If schedule and planting/growing seasons are ideal, establishment period might be shortened, at least for the sod option
- Swale is 600 meters long and 3 meters wide (1,800 square meters)
- Soil stabilization is provided for the width of the swale and an extra 0.375 m on each side, for a total width of 3.75 m (2,250 square meters)
- A underdrain is required for the length of the swale (600 linear meters)
- The clear strip is 600 meters long and 2.5 m wide (1,500 square meters)

Grass Plugs Option

Item	**Area (m^2)**	**Unit Cost**	**Total Cost**
Grass plugs with blanket in swale	1,800	$101.67/$m^2$	$183,000
Underdrain (150 mm landscaping subdrain)	600 m	$60/linear m	$36,000
Total without soil stabilization			***$219,000***
Cellular confinement, 100 mm depth	2,250	$24.21/$m^2$	$54,470
Total with soil stabilization			***$273,470***

EX-2-C - continued

Sod Option

Item	**Area (m^2)**	**Unit Cost**	**Total Cost**
Grass sod	1,800	$70.00/$m^2$	$126,000
Underdrain (150 mm landscaping subdrain)	600 m	$60/linear m	$36,000
Total without soil stabilization			***$162,000***
Turf reinforcement mat (18 mm)	2,250	$11.84/$m^2$	$26,640
Cellular confinement, 100 mm depth	2,250	$24.21/$m^2$	$54,470
Total with turf reinforcement mat			***$188,640***
Total with cellular confinement			***$216,470***

Clear Strip Stabilization

Item	**Area (m^2)**	**Unit Cost**	**Total Cost**
Geotextile with stone overlayment	1,500	$23.47/$m^2$	$35,200

Note: Costs are based on 2001 price levels.

EX-2-D

Linear Highway Section Example Major Maintenance Cost Estimate

This major maintenance cost estimate is for the swale portion of the example and is based on use of grass sod. The estimate is based on the following assumptions:

- Strip up to 150 mm uneven sediment and vegetation from swale
- Load and haul off strippings, assuming 1 hour truck cycle for hauling (disposal fees are not included; expect $26 to $29 per cubic meter for non-hazardous waste)
- Import, spread and grade up to 50 mm topsoil to recreate original sod-bed grades
- Furnish and place native grass sod
- Furnish and construct PVC above ground irrigation system (built on site) and operate as necessary for a period of 90 days, then remove system
- Water supply to be provided onsite; cost of water not included
- Dry soil conditions
- Swale is 600 meters long and 3 meters wide (1,800 square meters)

Item	Area (m^2)	Unit Cost ($ per m^2)	Total Cost
Move in and staking	1,800	$0.44	$800
Strip, load, and haul	1,800	$3.67	$6,600
Prepare sod bed	1,800	$4.78	$8,600
Furnish and place sod	1,800	$35.78	$64,400
90-day temporary irrigation	1,800	$16.44	$29,600
Total			***$110,000***

Note: Costs are based on 2001 price levels.

Example #3: Extended Detention Basins Incorporated Into an Interchange

The example shows how an extended detention basin can be incorporated into the drainage for an overpass, ramp, and highway section in a highway interchange. The same concepts can be applied to other portions of an interchange. In this example, the basin layout and elements differ from the traditional configuration for an extended detention basin to address safety concerns and to include the typical hydraulic design elements for a highway interchange. The basin is designed to take advantage of the phytoremediation capabilities of the vegetation included in the design, which enhance the appearance and performance of the basin while reducing its maintenance requirements. Figure 8 shows how the typical drainage in an interchange can be modified to incorporate an extended detention basin that treats runoff from the interchange and the adjacent highway section. Major elements of the design example illustrated in Figure 8 are:

Major elements of the design example:

- The design utilizes typical interchange grading and open spaces to for a detention basin.
- The design maximizes opportunities for storm water runoff from the interchange and adjacent highway section to be treated by draining through the extended detention basin.
- The design utilizes typical interchange drainage patterns and facilities and standard or slightly modified Caltrans drainage structures.
- The basin design addresses potential safety concerns by using a minimal basin depth (1.0 m), shallow side slopes, and physical placement at least 9 m from the traveled way.
- The design example includes elements like a sediment collecting forebay, a low-flow channel, and inflow energy dissipators that minimize maintenance and reduce chances of common failures in extended detention basins (*e.g.*, erosion of entry features and excessive sedimentation).
- The design provides overflow protection to prevent flooding and to ensure that treatment of “water quality volumes” of storm water runoff does not interfere with safe management of runoff from large storms.

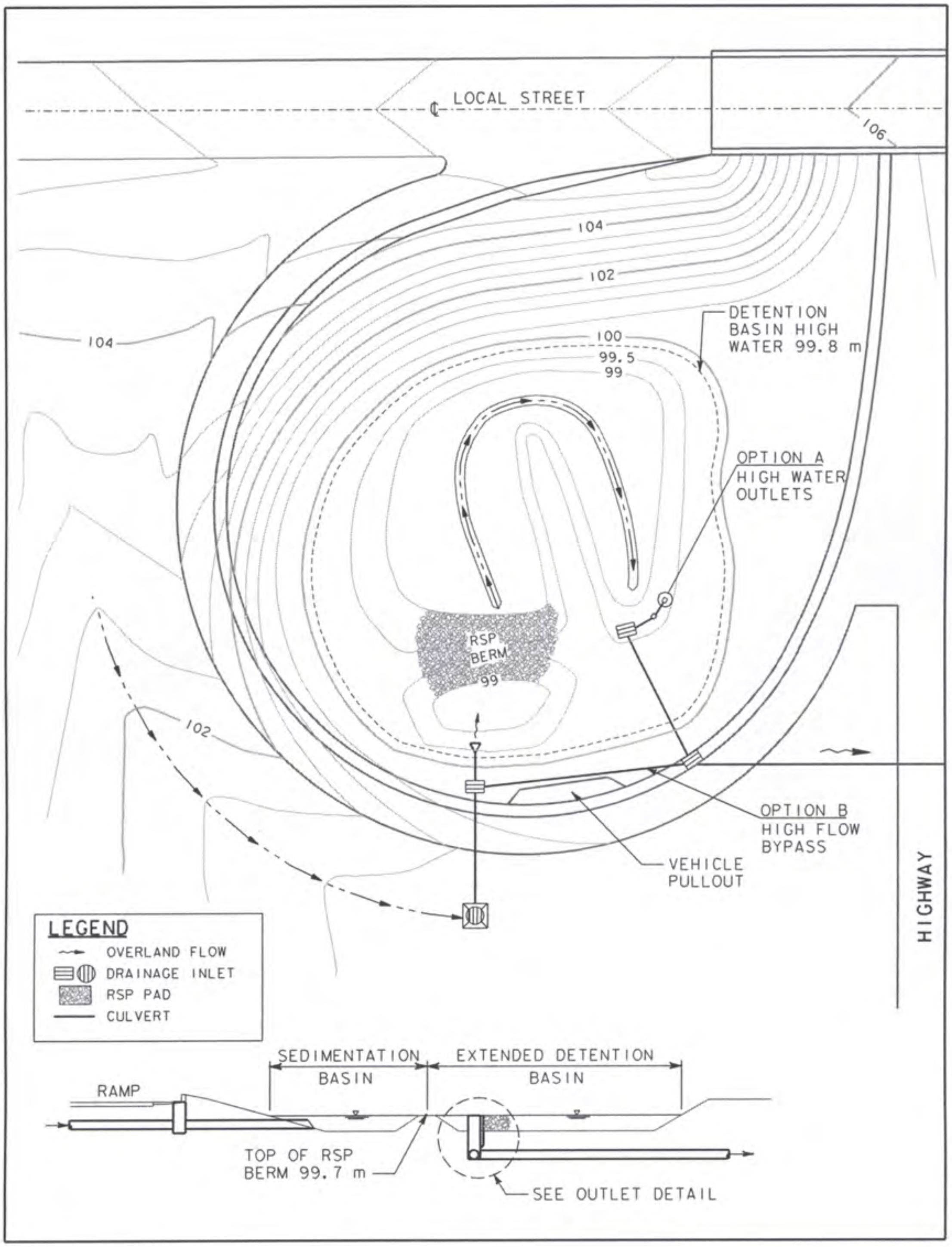
Drainage Design Elements

The location for this treatment method example is within a loop ramp of a typical interchange layout. The local street crosses over the highway with approach embankments to the bridge. The grading within the loop ramp is slightly modified to create a shallow basin and a sediment forebay. Drainage facilities are directed to outlet into the forebay, with runoff flowing into the extended detention basin and eventually discharging to a drainage inlet.

EX-3-A shows the steps in the general design procedure for an extended detention basin. EX-3-B provides the specific design procedures for this example.

- Hydrology—The basin in this example is designed to manage the water quality volume and to pass the 25-year storm. Higher flows should bypass the basin.

∞ **Figure 8. Example #3 – Extended Detention Basin**



EX-3-A

Steps for the drainage design of an extended detention basin in an interchange:

1. Layout standard drainage system design for the interchange, highway mainline including the median, or off pavement areas as needed.
2. Layout initial extent and depth of basin to establish maximum storage volume. A typical basin shape is a length four time the width; use of a central berm can effectively lengthen the basin.
3. From the available basin volume back calculate the runoff area that can be serviced by the basin.
4. Establish the practical drainage watershed limit depending on the slope available, the cost of the tributary drainage facilities, and the capacity of the outlet drainage facility.
5. With the watershed established, determine the peak design flow. Estimate the water quality volume for the watershed. The volume of the extended detention basin should be at least the calculated runoff Water Quality Volume plus 20% minimum for accumulation of sediments.
6. Design the forebay to safely pass the peak design flow or provide a basin bypass for the higher flows. Design the basin high water outlet to safely pass the peak design flow. Design the basin low flow outlet to drain the full basin volume, including forebay, in 48 hours.
7. Layout the extended detention basin in the off pavement areas where pavement flows and other target storm drains can be discharged. Allow for lateral extent of basin, hydraulic fall through the basin and forebay, and outlet connection to the conventional drainage facility. If the basin layout requires (or would allow) incorporating an unlined ditch or swale between the piped drainage facilities and the basin forebay, the design swale should check for erosion of sedimentation. The swale design could incorporate phytoremediation measures.
8. Prepare a rough grading plan for incorporating the extended detention basin into the interchange grading.

EX-3-B

Drainage Design Example: Extended Detention Basin

In this example the intention is to determine the maximum watershed area within the highway R/W that can be treated with an extended detention basin and size the various other elements of the basin. Typically the watershed size will be determined and the extended detention basin sized to treat the resultant WQV.

1. Calculate Available Volume of the Basin (including forebay).

   As shown in the attached drawing, the location of the basin is within the loop ramp of a typical highway interchange creating a maximum basin footprint. The bottom elevation is 100 m and the maximum pool elevation is 101 m. With the routing berm placed in the center of the basin, the surface area of the basin bottom is 0.073 hectares and the area of the maximum pool elevation is 0.22 ha. Including other intermediate area measurements, the basin volume is calculated to be 1490 m^3 using the equation:

$$V_{12} = h/3 \left(A_1 + A_2 + (A_1 A_2)^{0.5}\right)$$

where: V_{12} = volume between base areas 1 and 2

A_1 = surface area of base 1

h = vertical distance between base area 1 and 2

The ASCE recommends that the available basin volume be reduced by 20% to account for sediment buildup between major maintenance events. This makes the basin water quality sizing volume 80% of 1490 m^3 or 1192 m^3.

2. Calculate Water Quality Volume (WQV).

   Two accepted methods for calculating the WQV are presented in Appendix B, Section B.5.3 of the Caltrans *Statewide Storm Water Management Plan* (May 2001). The 2 numerical methods presented in subsection #2 when evaluated for a site in the San Francisco area with a watershed that is 40% impervious give the following estimates for the WQV:

   - The basin sizing method from the *California Storm Water Municipal Best Management Practice Handbooks*, California Storm Water Quality Task Force, March 1993, determines the WQV to be 1045 cubic feet per tributary acre (73 m^3 per tributary hectare).

   - The basin sizing method from the *Urban Runoff Quality Management WEF Manual of Practice No. 23*, published jointly by the water Environment Federation and the American Society of Civil Engineers, 1998, determines the WQV to be 1032 cubic feet per tributary acre (72 m^3 per tributary hectare).

EX-3-B - continued

3. Calculate the Size of the Treatable Watershed.

   Using the more conservative of the two WQV estimates the treatable watershed size is:

   Treatable watershed area = Available basin volume / WQV

   $= 1192\ m^3 / 73\ m^3/ha$

   Treatable watershed area = 16.3 ha.

4. Calculate the Drainage Peak Design Flow.

   Using the Rational Method as described in the Caltrans HDM, determine the peak 25-year runoff for the defined watershed of 16.3 ha.

   $Q_{25} = 0.00275\ ciA$ where: c = 0.60 overall

   i = 38 mm/hour (t_c of 20 min.)

   A = 16.3 ha

   $Q_{25} = 1.02\ m^3/s$

5. Calculate the Size the Sedimentation Forebay.

   Setting the volume of the forebay as 10% of the main basin, and the same depth as the main basin, 1.0 m, the average area of the sedimentation forebay will be 0.014 ha (smaller at the forebay bottom and larger at the high water elevation).

6. Design the Berm between the Forebay and the Detention Basin.

   The spillway crest should be sized for the peak design flow, limiting the depth of flow over the top of the berm to 0.3 m. In the example shown, the forebay berm is placed at the same elevation as the main basin outlet, 101 m. Using the broad crested weir equation with a weir coefficient of c = 2.63, the weir length is determined to be:

   Berm crest length = $Q / (2.63 \times H^{1.5})$ where: H = flow depth on crest

   $= 1.02 / (2.63 \times 0.3^{1.5})$

   Berm crest length = 3.9 m

   The berm should be designed with a low flow outlet (such as a narrow pervious zone or a perforated riser pipe) that allows the forebay to completely drain within a 48-hour period.

EX-3-B - continued

7. Create Circuitous Route through Detention Basin to Outlet.

   See the attached drawing for suggested basin routing. Note placement of interior basin berm to increase the effective length of the basin and the inclusion of the shallow low-flow pilot channel (0.6 m wide with 0.5% grade).

8. Design the Detention Basin High Water Outlet.

   The capacity of the high water outlet should be designed for the peak design flow with a maximum head on the outlet of 1 foot (or other limit as allowed by the particular design). Use weir flow or orifice equations as appropriate to determine the number of standard inlets necessary (The GDO inlet described, is a Caltrans standard inlet with a grated opening 0.9 m by 1.2 m).

Use orifice equation for depth of 0.3 m.

$Q = C A (2 g d)^{0.5}$ where: $C = 0.67$

$g = 9.81 \text{ m/s}^2$

$= 0.67 \times 0.446 (2 \times 9.81 \times 0.3)^{0.5}$ A = open area of grated inlet

$Q = 1.09 \text{ m}^3\text{/s}$ per GDO inlet (GDO inlet open area = 0.9 m by 1.2 m, minus 20% for bars, minus 50% for debris) = 0.446 m^2)

Use 2 GDO inlets.

Use weir equation for depth of 0.3 m.

$Q = c P d^{1.5}$ where $c = 1.66$

P = free perimeter (GDO inlet open perimeter = (1.2 m + 0.9 m) x 2 minus 50% clogging = 2.13 m)

$= 1.66 \times 2.13 \times 0.3^{1.5}$

$Q = 0.60 \text{ m}^3\text{/s}$ per GDO inlet

Use 2 GDO inlets.

EX-3-B - continued

9. Design the Detention Low Flow Outlet.

   The basin low flow outlet should be designed to drain the full volume of the extended detention basin (1490 m^3), which includes the volume of the sedimentation forebay. Assuming no infiltration occurs, over a period of 48 hours this volume of 1490 m^3 should be drained at the average rate of 0.0085 1490 m^3/s. Depending on the infiltration of the native soils, the remainder of the basin volume should be drained with a riser pipe (underdrain is not preferred but may be acceptable under certain

   conditions). The low flow outlet should be connected to the basin high water outlet and then to the main downstream drainage facility. The low flow outlet control should be oversized by 50% with a flow control device added in-line so that over time the draw down rate could be adjusted.

10. Adjust grading plan to match the requirements of the interchange.

11. Place vehicle maintenance turnout adjacent to the sedimentation forebay.

The difference between the water quality volume flow rate and the 25-year storm flow rate could be routed around the basin or routed through the basin with proper basin outlet design.

- Water Quality Volume—For this example, two different water quality volume (WQV) criteria are used; these are values from the Caltrans *Storm Water Management Plan*. Each of the three numerical WQV criteria were used to estimate the WQV for a sample extended basin configuration within an interchange.

- Interchange Drainage Inlets—The example shows how the normal drainage system layout could be modified to direct runoff to the defined extended detention basin in an interchange. Energy dissipators are included at the basin inlet to control velocities.

- Basin slopes—the basin bottom has a slight slope to drain to the low-flow channel. Side slopes are 5:1 or flatter on the sides of the basin closest to the traveled way, with a maximum slope of 3:1 away from the traveled way.

- Safety—To address safety concerns, this example uses a minimum setback from the traveled way of 9 m and a relatively shallow basin (maximum ponding depth of 1.0 m) in an area without barrier separation from the traveled way.

- Basin Residence Time—A berm is used to lengthen flow path, thus increasing residence time.

- Basin Outlet—A combination of standard Caltrans grated inlets comprise the basin high water outlet. The low flow outlet shown in Figure 9 is designed to allow the basin to be completely drained in a 48-hour period. The outlet is a perforated, small diameter, vertical, non-clogging outlet pipe (75 mm minimum diameter) protected by rock and stone connected to the main outlet drainage facility. The design includes an oversized low-flow outlet pipe with separate flow controls to accommodate changes in drainage as the basin fills with sediment. The basin should be protected from higher than design flow rates by one of two methods: (a) bypassing the higher flow rates at the basin entrance, so that the higher flows are routed around the basin; or (b) providing high elevation outlets within the basin to provide extra capacity to pass flows through the basin.

- Sediment Forebay—The sediment forebay is separated from the rest of the basin by a berm that includes a low flow outlet designed to completely drain the forebay within a 48-hour period.

Plants and Planting Considerations

Selecting and establishing the right grasses are important for the operation of an extended detention basin. Planting, species, use of temporary erosion control blankets, and recommended soil stabilization methods for this example are the same as described in Section 3.3. It may be desirable to emphasize use of rhizominous plants, which may be better able to re-colonize areas that have been covered with sediment. In the northern part of District 4, or areas of high rainfall frequency, establishment of wetland vegetation in the basin bottom should be considered.[12]

Construction Cost

Extended detention basins are among the lowest-cost of the various storm water runoff treatment options available.

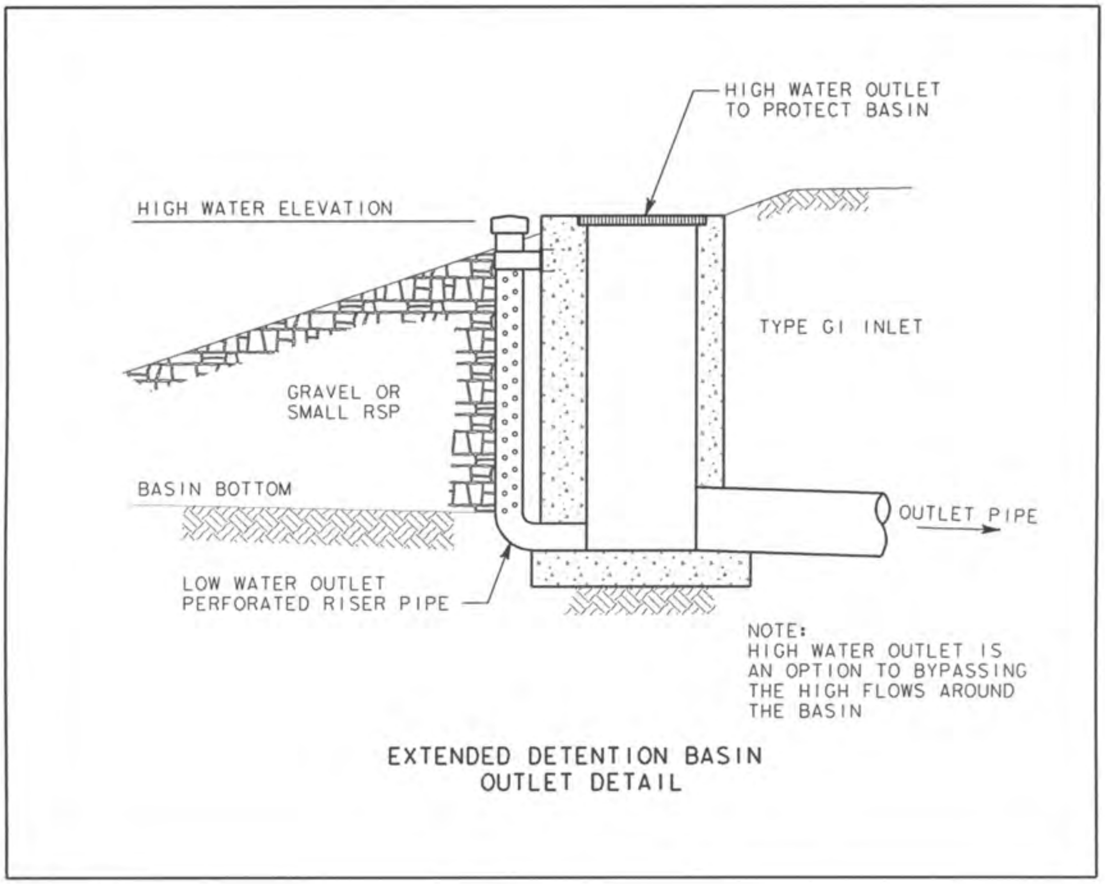
- The costs of the civil elements of the extended detention basin, in addition to the drainage elements that would be necessary without the basin, are relatively small. The grading costs would likely be included in the interchange construction; additional costs would be unlikely unless the excavation for the basin required soil export. The outlet structure would be about $10,000 additional, the forebay lining and base material would be about $9000, and the stone and filter fabric around the inlet and outlet structures would be about $6000, for a total of about $25,000 in addition to the drainage features that would be part of the normal drainage design.

- Landscaping costs would be somewhat higher than typical—estimated to be in the range of $160,000 to $285,000 (the cost depends on the landscaping method and soil stabilization option selected).

See EX-3-C for an example landscaping cost estimate for this basin.

[12] Using wetland vegetation may have regulatory consequences that should be considered. Caltrans is currently evaluating the use of constructed wetlands as a storm water runoff treatment option.

Figure 9. Example #3 – Extended Detention Basin Outlet Structure



EX-3-C

Extended Detention Basin Example Landscaping Cost Estimate

Two cost estimates are provided, one based on use of grass plugs, the other using grass sod. The estimates are based on the following assumptions:

- Both options include same soil preparation—soil preparation is 200 mm deep (if Caltrans allows, ripping another 300 mm deeper would be very beneficial)
- Grass plugs includes coconut blanket and grass overseeding
- Plant establishment is one year
- Grass plug establishment includes watering and weed eradication
- Sod establishment includes watering and not more than two mowings
- Both options based on finish grade provides by others
- Fine grading is by hand and machine work, does not include precision screeding
- Water supply for establishment to be provided onsite
- Cost of water not included
- This estimate assumes construction is completed as scheduled with sod or contract-grown plugs
- If schedule and planting/growing seasons are ideal, establishment period might be shortened, at least for the sod option
- Basin bottom is 730 square meters; side slopes are 1,445 square meters (total of 2,175 square meters)
- Soil stabilization is provided for the basin bottom and side slopes (2,175 square meters)
- Low-flow ditch is 55 meters long and 0.6 m wide (33 square meters)

EX-3-C - continued

Grass Plugs Option

Item	Area (m^2)	Unit Cost ($ per m^2)	Total Cost
Grass plugs with blanket in basin	2,175	$103.19	$224,440
Low-flow ditch	33	$199.09	$6,570
Total without soil stabilization			***$231,010***
Cellular confinement, 100 mm depth	2,175	$25.37	$55,180
Total with soil stabilization			***$286,190***

Sod Option

Item	Area (m^2)	Unit Cost ($ per m^2)	Total Cost
Grass sod	2,175	$71.05	$154,530
Low-flow ditch	33	$199.09	$6,570
Total without soil stabilization			***$161,100***
Turf reinforcement mat (18 mm)	2,175	$12.40	$26,970
Cellular confinement, 100 mm depth	2,175	$25.37	$55,180
Total with turf reinforcement mat			***$188,070***
Total with cellular confinement			***$216,280***

Note: Costs are based on 2001 price levels.

EX-3-D

Extended Detention Basin Example Major Maintenance Cost Estimate

This major maintenance cost estimate is based on use of grass sod. The estimate is based on the following assumptions:

- Strip up to 200 mm uneven sediment and vegetation from basin bottom
- Load and haul off strippings, assuming 1 hour truck cycle for hauling (disposal fees are not included; expect $26 to $29 per cubic meter for non-hazardous waste)
- Import, spread and grade up to 50 mm topsoil to recreate original sod-bed grades
- Furnish and place native grass sod
- Furnish and construct PVC above ground irrigation system (built on site) and operate as necessary for a period of 90 days, then remove system
- Reconstruct rock-lined low-flow ditch
- Water supply to be provided onsite; cost of water not included
- Dry soil conditions
- Basin bottom is 730 square meters (and is only portion requiring maintenance); side slopes are 1445 square meters
- Low-flow ditch is 55 meters long and 0.6 m wide (33 square meters)

EX-3-D - continued

Item	Area (m^2)	Unit Cost ($ per m^2)	Total Cost
Move in and staking	730	$1.07	$780
Strip, load, and haul	730	$9.36	$6,830
Prepare sod bed	730	$3.44	$2,510
Furnish and place sod	730	$34.41	$25,120
90-day temporary irrigation	730	$34.84	$25,430
Replace rock-lined low-flow ditch	33	$51.27	$1,690
Total			***$62,360***

Note: Costs are based on 2001 price levels.

Maintenance

- Annual Inspection (see Section 3.5)
- Mowing—Annually or more often (two to four times per year recommended) if needed to maintain optimal height (no less than 150 to 200 mm) and to avoid cutting more than half of the grass blades off at each mowing.
- Forebay Sediment Removal—Frequency to be determined by inspections. A typical maintenance performance standard is that the sediment should be removed when 25 to 50% of the forebay capacity is filled with sediments.

Basin Sediment Removal and Basin Revegetation—Frequency to be determined by inspections. Sediments should be removed when 20% of the basin volume is lost (in order to ensure that the basin treatment capacity does not fall below the water quality volume) or when 25% or more of the vegetation in the basin is covered with sediments.

The most costly maintenance element would be basin sediment removal and revegetation—see EX-1-L for an example of the cost for this basin. Relative to sediment removal and revegetation cost, the cost for annual maintenance activities (inspection, correction of minor problems, forebay sediment removal, and mowing) would be small; for similar basins, annual maintenance costs have been estimated to be a few thousand dollars per year (San Francisco Bay RWQCB, 2001)

Pollutant Removal

The design method used in this example bases the extended detention basin volume on a "water quality volume" that provides treatment to about 80% of total runoff volume. Designs like this example that employ the water quality volume concept should maximize the value of storm water phytoremediation practices and achieve pollutant removals similar to those in Table 5. While a properly designed extended detention basin like the one shown in this example can provide significant pollutant removal, extended detention basins generally do not remove highway runoff pollutants of concern as well as swales or other infiltration measures.

Applicability of this Design Example to District 4 Highways

Designs incorporating an extended detention basin into highway drainage should work in most San Francisco Bay Area locations. Even in areas with poor infiltration properties or high water tables, extended detention basins may be a feasible option.

- Sites with very shallow groundwater. Very shallow groundwater will limit the usefulness of basins at a site, as runoff from the highway surface can only be economically treated by a basin that sits below the highway grade. Local water quality agencies may prohibit use of basins where the seasonal high groundwater level is less than 3 m below the basin bottom elevation. Where groundwater is less than 0.6 meters below the basin bottom elevation, it may interfere with basin operation. In such locations, constructed wetlands may be a more appropriate storm water phytoremediation strategy (if approved by Caltrans for treatment of storm water runoff).

- Sites where excavation depth may be limited. Site-specific constraints may include the location of existing subsurface drainage facilities, other existing utilities, shallow groundwater, and the depth to bedrock. These could limit the depth of the basin and thus its capacity to manage runoff from the highway section.

- Areas with very rapidly draining soils (*e.g.*, sand or soil hydrologic group A with excessively rapid drainage). In such locations, extended detention basins must be lined to prevent sinkhole formation. Infiltration basins or swales would be more appropriate in such settings.

- Sites where the basin would need to be located within 3 m of a sound wall or another structure. Because infiltration from the basin has the potential to affect immediately adjacent structures, such situations should be avoided; however, it may be possible to locate basins near structures with certain designs. A site-specific engineering evaluation can be conducted to determine the feasibility of locating a basin near a structure.

- In the northern part of District 4 or other areas of high rainfall frequency, the basin vegetation may need to survive relatively long inundation periods that may cause wetland type vegetation to invade the basin. In such locations, wetlands or an extended detention basin that includes a constructed wetland or wet pond may be a more appropriate storm water phytoremediation strategy (if approved by Caltrans for treatment of storm water runoff).

4.0 Glossary and Abbreviations

4.1 Abbreviations

The most costly maintenance element would be basin sediment removal and revegetation—see EX-1-L for an example of the cost for this basin. Relative to sediment removal and revegetation cost, the cost for annual maintenance activities (inspection, correction of minor problems, forebay sediment removal, and mowing) would be small; for similar basins, annual maintenance costs have been estimated to be a few thousand dollars per year (San Francisco Bay RWQCB, 2001)

ASCE – American Society of Civil Engineers

BMP – Best Management Practice

Caltrans – California Department of Transportation

CWA – Clean Water Act

fps – Feet per second

ha – Hectares

HDM – California Department of Transportation *Highway Design Manual*

m – Meters

mm – Millimeters

m/s – Meters per second

m^2 – Square meters

m^3/s – Cubic meters per second

MEP – Maximum extent practicable

MLRA – Major Land Resource Area

NPDES – National Pollutant Discharge Elimination System

NRCS – Natural Resource Conservation Service (formerly Soil Conservation Service)

PS&E – Plans, Specifications & Estimates

RWQCB – California Regional Water Quality Control Board

R/W – Highway right-of-way

SCS – Soil Conservation Service

sq. ft. – Square feet

SWMP – Storm Water Management Plan

SWPPP – Storm Water Pollution Prevention Plan

SWQTF – California Stormwater Quality Task Force

SWRCB – California State Water Resources Control Board

TMDL – Total Maximum Daily Load

TSS – Total Suspended Solids

TPH – Total Petroleum Hydrocarbons

U.S. EPA – United State Environmental Protection Agency

WDR – Waste Discharge Requirements

WQF – Water Quality Flow

WQV – Water Quality Volume

4.2 Glossary

Beneficial Uses – Uses of water that must be protected against water quality degradation. These uses, according to the California Porter-Cologne Water Quality Control Act, include domestic, municipal, agricultural and industrial supply; power generation; recreation; esthetic enjoyment; navigation; and preservation and enhancement of fish, wildlife, and other aquatic resources or preserves.

Best Management Practice – Physical, structural, and/or managerial practices that, when used singly or in combination, reduce the downstream quality and quantity impacts of storm water.

Clean Water Act – The federal law that regulates the discharge of pollutants to surface water. In California, the State Water Resources Control Board and Regional Water Quality Control Boards implement the Clean Water Act together with a similar state law, the Porter-Cologne Act.

Hydrograph – A graph of runoff rate, inflow rate or discharge rate, past a specific point over time.

Hydrologic Soil Groups – A soil characteristic classification system defined by the U.S. Soil Conservation Service in which a soil may be categorized into one of four soil groups (A, B, C, or D) based upon infiltration rate and other properties.

Impervious Surface – A hard surface area that either prevents or retards the entry of water into the soil.

Major Land Resource Area – A geographic area, usually several thousand acres in extent, that is characterized by a particular pattern of soils, climate, water resources, land uses, and potential natural vegetation.

Manning's Equation – A hydraulic equation used to predict the flow velocity or capacity of an open channel or culvert.

National Pollutant Discharge Elimination System – The national program for issuing, modifying, revoking and reissuing, terminating, monitoring and enforcing permits under the Clean Water Act. Permits issued under this program (like that issued to Caltrans for storm water runoff from its highway facilities) are called NPDES Permits.

Plans, Specifications and Estimates – The bid documents, including general design, specifications and estimated costs, commonly referred to as PS&E.

Project Engineer – The person responsible for the preparation of Project Study Reports, Project Reports, and PS&E documents.

Rational Method – A means of computing storm drainage flow rates (Q) by use of the formula $Q = 0.00275\ CIA$, where C is a coefficient describing the runoff potential of the drainage area, I is the rainfall intensity (mm/hr) and A is the area (ha).

Resident Engineer – The person who oversees a highway construction project.

Total Suspended Solids – The entire amount of organic and inorganic particles dispersed in water.

Underdrain – Plastic pipes with holes drilled through the top, installed underground to collect and remove excess runoff.

5.0 Resource List

Caltrans Storm Water Resources

Caltrans water quality regulatory documents include the Caltrans statewide storm water permit and *Storm Water Management Plan* (SWMP). Both of these documents are available on the Internet.

http://www.dot.ca.gov/hq/env/stormwater/special/index.htm

Caltrans Storm Water Management Program Information

http://www.dot.ca.gov/hq/env/stormwater/index.htm

Caltrans has produced three *Storm Water Quality Handbooks*. The *Project Planning and Design Guide*, describes how Caltrans integrates highway runoff management into project design and will eventually contain Caltrans design standards for water quality flow and water quality volume..

http://www.dot.ca.gov/hq/oppd/stormwtr/

The *Caltrans Water Quality Planning Tool* allows users to quickly obtain information on water quality standards and water quality problems (water bodies listed as impaired under Clean Water Act Section 303[d]) in waters that receive runoff from Caltrans facilities. Using this tool, an engineer or scientist can quickly identify which pollutants are of special concern in the geographic area of a highway project.

www.stormwater.water-programs.com

The Caltrans report *California Roadsides: A New Perspective* addresses Caltrans' vegetation management challenges, including implementing its integrated vegetation management program. The report analyzes a variety of methods suitable for preventing erosion in the clear strip. The executive summary is available on the Internet; the entire report can be obtained from Caltrans' Publication Distribution Unit.

Summary:

http://www.dot.ca.gov/hq/maint/roadside/

Ordering information:

http://caltrans-opac.ca.gov/publicat.htm

California Department of Transportation *Highway Design Manual* (HDM) is the basic document that guides all California Highway design, including drainage designs. An unofficial version is available on the Internet; the official version is the hard copy available from Caltrans' Publication Distribution Unit.

Unofficial Internet Version:

http://www.dot.ca.gov/hq/oppd/hdm/hdmtoc.htm

Ordering information:

http://caltrans-opac.ca.gov/publicat.htm

Design Resources

Washington State Department of Transportation developed the *Highway Runoff Manual* to provide procedures for integrating storm water runoff management best management practices into highway design. The manual, which was revised and re-released as a draft, reflects more than five years of experience using the previous version of the manual for highway construction in certain portions of Washington State. While the manual addresses conditions in Washington State, the detailed design specifications in the manual address the special issues relating to highway runoff management (*e.g.*, safety, maintenance).

http://www.wsdot.wa.gov/FASC/EngineeringPublications/Manuals/Highway.pdf

The *Stormwater Manual for Western Washington*, prepared by Washington Department of Ecology, contains detailed design instructions, examples, and specifications for installation of various storm water runoff treatment best management practices. Although this manual is not highway specific, it is more detailed than the Highway Runoff Manual. The portions of the manual of greatest relevance to design of phytoremediation facilities for highway runoff are Volume III - Hydrologic Analysis and Flow Control Design and Volume V - Runoff Treatment BMPs. The Manual and related information are available on the Internet.
http://www.ecy.wa.gov/programs/wq/stormwater/manual.html

The *Stormwater Manager's Resource Center* contains design guidelines, references to design procedures, and construction and maintenance specifications for all standard best management practices for treating storm water runoff. The design information reflects the Center for Watershed Protection's more than 10 years of experience with runoff management systems. While most of the information is general, guidelines for plant selection, use of permanent pools in ponds (possible in wet climates), and facility sizing are specific to the eastern seaboard, and need to be modified to address California conditions.
http://www.stormwatercenter.net/

The California Storm Water Quality Task Force (SWQTF) created the *California Stormwater Best Management Practices Handbooks* in the early 1990s. The Municipal and Industrial/Commercial Handbooks provide California-specific design guidelines for runoff water quality management facilities; the construction handbook addresses erosion and sediment control during and after construction. These manuals, while somewhat dated, are still the most comprehensive design guidelines for California. The SWQTF plans to update the manuals in 2002.

The manuals may be purchased from BPS Reprographic Services, 1700 Jefferson St., Oakland, CA, 94612, (510) 287-5485, Fax (510) 444-1262. An order form is available on the Internet at http://www.swrcb.ca.gov/stormwtr/bmp.pdf.

The American Society of Civil Engineers and the Water Environment Federation jointly developed the *Urban Runoff Quality Management* manual (ASCE Manuals and Reports on Engineering Practice No. 87; WEF Manual of Practice No. 23). The 1998 manual provides methods for sizing and designing runoff water quality management facilities.

The manual is available for purchase from ASCE or WEF.

The U. S. Department of Transportation *Urban Drainage Design Manual, HEC-22* (FHWA-SA-96-078, November 1996) is the recommended reference for determining the appropriate Manning's *n* values for vegetated channels. Section 5.1.5 of that manual describes an iterative method for establishing the depth of flow and the Manning's *n* value.

http://www.fhwa.dot.gov/bridge/hec22.pdf

Other Water Quality Resources

The Federal Highway Administration (FHWA) water quality and storm water management web page has links to FHWA publications on managing highway runoff, and to ongoing research regarding the impacts of highway runoff (being conducted jointly by FHWA and USGS). Among the resources listed on this site is *Evaluation and Management of Highway Runoff Water Quality*, FHWA, June 1996. While this manual is highway specific, it is somewhat dated and does not reflect recent experience implementing some of the described runoff management methods. Newer manuals (*e.g.*, those from Washington state) reflect recent experience and are thus preferred sources.

http://www.fhwa.dot.gov/environment/h2o.htm

California State Storm Water Program information is available in the Internet from the State Water Resources Control Board. Available resources include state and regional contacts, regulatory information, and links to storm water resources useful in California.

http://www.swrcb.ca.gov/stormwtr/

The *National Stormwater Best Management Practices Database*, sponsored by ASCE and U.S. EPA, provides access to BMP performance data in a standardized format. The database, which may be searched and/or downloaded from the Internet, provides a relatively limited set of data, but the data is of relatively high quality. Eventually, when sufficient high quality data becomes available, ASCE and U.S. EPA hope to identify specific factors that affect BMP performance (to date, such factors have been identified through trial and error testing).

http://www.bmpdatabase.org

The *Stormwater Treatment Practice Pollutant Removal Performance Database* contains data from testing of many more facilities than are included in the ASCE database; however the data quality is variable.

Available in hard copy from the Center for Watershed Protection (http://www.cwp.org/), the database is soon to be available on the Internet at the Stormwater Manager's Resource Center (http://www.stormwatercenter.net/).

Rainfall Data

A common source of rainfall data is the HYDRO modeling package within the Federal Highway Administration's *HYDRAIN – Integrated Drainage Design Computer System*. The HYDRAIN software and user's manual is available from FHWA's Internet site.

http://www.fhwa.dot.gov/bridge/hydrain.htm

Hydrologic Soil Groups

NRCS Technical Release 55 (TR–55), *Urban Hydrology for Small Watersheds*, includes a national hydrologic soils group listing (it also provides simplified procedures to calculate storm runoff volume, peak rate of discharge, hydrographs, and storage volumes required for floodwater reservoirs.) The TR-55 manual can often be obtained from local NRCS offices, or it can be ordered from the National Technical Information Service (1-800-553-6847). The software and/or manual can be downloaded from the NRCS web site:

http://www.wcc.nrcs.usda.gov/water/quality/common/tr55/tr55.html

Plants and Planting Considerations

A recent District 4-specific update to the Soil Conservation Service *Seeding Guide for California by Major Land Resource Area*, called *Seeding Guidance Manual* a seed selection guide and planting guidance for all MLRAs in District 4. *Seeding Guidance Manual*

If the MRLA for a project site is not readily available from the Caltrans geographic information system, it can be obtained from the Natural Resources Conservation Service publication *A Vegetative Guide to Selected Native Grasses of California*, Natural Resources Conservation Service Technical Note – Plant Materials – 40, March 1996. The handbook can be obtained from the Natural Resources Conservation Service.

Phyto-remediation Resources

Because phytoremediation is an emerging technology, few phytoremediation-specific resources are available.

A preliminary investigation to identify available information regarding the potential to use phytoremediation to reduce pollutant levels in highway runoff was conducted by the San Francisco Estuary Project for Caltrans. The results of that investigation are available in the report *Investigation of Phytoremediation Potential For Treating Highway Runoff*, available *Seeding Guidance Manual*
The U.S. EPA *Citizen's Guide to Phytoremediation* provides an excellent overview of phytoremediation technologies.
http://clu-in.org/products/citguide/phyto2.htm

The Phytoremediation of Organics Action Team web site includes has extensive resources, including a database of research and demonstration project reports. Although web site is limited to organic pollutants, it is the most complete phytoremediation site on the Internet. It contains links to sites operated by academic research groups that are addressing metals as well as organic pollutants. http://www.rtdf.org/public/phyto/default.htm

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