Hydromodification management plan for
the Fairfield-Suisun
Urban Runoff Management Program

Submitted in partial fulfillment of the
FSURMP stormwater discharge permit
(NPDES permit number CAS612005)

Report prepared for:
Fairfield-Suisun Urban Runoff Management Program
(Cities of Fairfield and Suisun, and the
Fairfield-Suisun Sewer District)

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1. INTRODUCTION

1.1 Regulatory Framework

The Fairfield-Suisun Urban Runoff Management Program (FSURMP) is required to submit a Hydrograph Modification Management Plan (typically abbreviated as 'HMP') to the California Regional Water Quality Control Board, San Francisco Bay Region (RWQCB) as described in section C.3.f of its stormwater discharge permit, NPDES permit number CAS612005 (re-issued by the RWQCB in 2003, and amended in 2007; attached as Appendix A). The HMP describes how the cities of Fairfield and Suisun and the Fairfield-Suisun Sewer District will manage increases in peak flows and increased runoff volume that result from new urban uses and redevelopment, or related changes such as the decrease in time of concentration caused by the connection of the impervious areas to the creek.

The permit states that section C.3.f applies to the "mid to upstream sections of Laurel and Ledgewood Creeks." Finding 38 in the permit provides the rationale for the limited coverage of the permit, stating that the mid to upstream sections of Laurel and Ledgewood Creeks "are the only creek sections within the Permittees' jurisdiction that are not urbanized."

1.2 Definition of the problem

This section summarizes the causes and effects of hydromodification, in the context of the FSURMP permit. It is intended to be a brief description to frame the recommendations made within this HMP, rather than an in-depth technical discussion. For a more detailed review of hydromodification issues, there are several useful resources that are described in Section 2.3 (e.g., Santa Clara Valley Urban Runoff Management and Pollution Prevention Program's hydromodification plan literature review, GeoSyntec, 2002).

What is hydromodification?

The term "hydromodification" refers to changes to the natural streamflow hydrograph due to disturbances in the watershed. While the term can be used to generally describe any significant change to natural streamflow, it is most commonly used in a present-day regulatory context with reference to hydrograph changes caused by urban development. The increase in impervious area[1] and the number of drainageways[2] associated with urbanization reduce infiltration of rainfall and increases runoff, diverting more water at a faster rate to local streams. These processes typically increase both the peak flow and the total volume of water in a stream for a given rainfall amount. The effect is proportionately most prominent for smaller rainfall events, when a higher percentage of the rainfall is diverted to runoff rather than infiltration[3].

Why is it a concern?

Increases in the amount and timing of runoff can cause changes in stream channel morphology, including reach-wide erosion of the streambanks and down-cutting of the channel bed. The severity of channel response depends on the degree of hydromodification (typically expressed as percent imperviousness of the watershed), soil infiltration rates within the watershed, the resistance to erosion of the stream bed and bank material (including in-stream grade control), the amount and type of vegetative cover, and stream slope, among other factors.

Channel response to hydromodification typically induces a larger channel (incised and/or widened) with reduced channel complexity and floodplain connectivity. This response further accentuates and speeds flood peaks downstream, increasing the magnitude and frequency of flooding while concurrently resulting in a loss of habitat quality. Channel enlargement typically increases sediment production, which leads to siltation of downstream channels, contributing to flooding incidence or increased dredging costs to maintain channel capacity for flood control. Stream incision and bank widening can also threaten existing infrastructure, such as roads, improvements, and community facilities, as well as parks and recreation areas.

How can it be controlled?

Hydromodification effects can be controlled or reduced by implementing features or practices to encourage infiltration or reduce the potential for hydromodification effects (typically called

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[1] We use the term 'impervious area' in deference to its widespread use in this field. A more accurate term might be 'compacted area'. Research on the effects of unpaved roads, agriculture, grazing, or confined animal areas shows that compacted or scraped earth generates similar hydromodification effects to paved surfaces.

[2] Urbanization also results in longer and denser drainageways, such as roof gutters, drains, curbs, and storm drains, resulting in water entering the creek system much more rapidly than under natural conditions due to the high connectivity of impervious surfaces and drainage networks, plus diminished infiltration, subsurface flow, and depression storage.

[3] Section 3 in Appendix B highlights the effects of hydromodification in the Laurel Creek watershed in the City of Fairfield.

hydromodification management measures or HMMs). There are, on a broad scale, three different types of HMMs:

- Reduce hydromodification by limiting total impervious area or the connectivity of impervious areas to the stream, and/or implement source controls to encourage on-site infiltration/retention/detention.
- Detain/retain excess water in a basin, before it gets to the stream. This is typically done using a project-scale or regional basin, with an outlet designed to match the pre-existing flow conditions, releasing excess stormwater volume at flows below the erosion threshold of the stream to which the water is being discharged. Smaller-scale detention or retention at the lot- or block-scale can also be effective.
- Implement in-stream alterations to increase the resistance of the stream channel to erosion, or augment the frequency with which water is detained and stored on floodplains or other features in or along the channel. This solution is typically recommended only when the downstream channel has been impacted by existing hydromodification, and would significantly benefit from channel restoration.

1.3 HMP format and guidelines

Many of the analyses and assessments described in this report stem from work conducted by Balance Hydrologics and GeoSyntec for the Santa Clara Valley Urban Runoff and Pollution Prevention Program (SCVURPPP) as part of developing their HMP[4]. The general approach to hydromodification management planning for the cities of Fairfield and Suisun follows what was put forth by the SCVURPPP, but it has been adapted to account for local conditions within the Laurel and Ledgewood watersheds, as well as considering local planning practices.

This HMP is intended to be used as a tool to help the communities of Fairfield and Suisun achieve the hydromodification management goals described in the FSURMP permit. It is composed primarily of three parts. Sections 2 through 4 describe the general physical characteristics and site-specific constraints of the area covered by the HMP, field reconnaissance and flow modeling results, and other data that are important to consider when planning for hydromodification management. Section 5 describes the design process for different types of

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[4] The SCVURPPP Final HMP was submitted to the RWQCB in April 2005. While the document has yet to be officially adopted by the Board, the general approach is a sound and tested approach to hydromodification management, as shown though the various supporting studies completed for the SCVURPPP HMP.

facilities, as well as other factors to consider when planning hydromodification management measures. Detailed analyses of the data used in making recommendations and specific design guidelines for hydromodification facilities are found in the appendices.

1.4 Technical approach

The technical approach that guided the development this HMP is based on similar approaches developed in the Bay Area region to manage the effects of hydromodification in urbanizing watersheds (the SCVURPPP technical study, GeoSyntec, 2002, for example). The technical approach consists of two primary components, a field assessment and continuous flow modeling, which led to the formation of hydromodification management measure (HMM) recommendations that are the best-suited for the Laurel Creek and Ledgewood watersheds. Section 3 and Appendix B provide details of the field assessment work conducted in the watersheds. Section 4 and Appendix C describe the hydraulic and hydrologic modeling effort.

Field assessment included:

- background review of hydrologic, soils, geologic, ground-water and hydrographic reports developed for the two watersheds
- reconnaissance geomorphic surveys of portions of the Laurel and Ledgewood watersheds to assess channel conditions, classify stream reaches, and evaluate potential future response to hydromodification,
- streamflow and sediment transport monitoring in the Laurel Creek watershed to describe baseline conditions and assess effects of existing hydromodification, and
- aerial photograph analysis to support channel classification, to extend classification to stream channels not field-surveyed, and to estimate impervious cover.

Modeling tasks included:

- development of a baseline model of existing urban conditions for the upper Laurel Creek watershed, calibrated to the 2004-2005 streamflow data,
- comparison of modeled existing conditions to potential future conditions, using a 55-year historic rainfall record, and
- modeling of cross-section-scale channel stability to assess how stream channel stability may change in response to anticipated future urbanization.

1.5 HMP procedure for compliance

This section guides project proponents through the HMP process, outlining the steps to take toward compliance with the hydromodification provision in the FSURMP NPDES permit. These steps should be followed in the order in which they appear, unless it is mentioned that a particular step can be skipped.

Step 1. ***Outline the planning area for the project and evaluate if any portion of the project will discharge (directly or indirectly) to a susceptible stream reach, as shown on Figures 2 and 3.*** Further discussion of channel reach classification is provided in sections 3.1.1, 3.2.1 and 3.3 below. The project proponent is responsible for providing documentation of the flow path of stormwater runoff downstream (or "down-pipe") of the site to highlight the ultimate discharge point of that water. If no portion of the project will discharge to a susceptible stream channel, then no hydromodification management measures are required (Skip to Step 5).

Step 2. ***Calculate the impervious area for the portion (or portions) of the project discharging to susceptible channel reaches.*** Documentation must be provided to show where impervious area within the project will drain. For projects with large percentages of compacted earth areas (stables and corrals, for example) the compacted areas should be considered impervious surfaces. If the net change in connected impervious area[5] discharging to a susceptible channel is less than one acre[6], then no hydromodification controls are required, though use of the design practices discussed in section 5.3.1 is encouraged (Skip to Step 5). If the impervious surface is equal to or greater than one acre, continue to Step 3.

Step 3. ***Is the project one single-family home not associated with any other project?*** If yes, the project proponent must incorporate the site design practices

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[5] "Connected impervious area" means the impervious area connected to the storm drain system. If a pre-existing impervious surface is not connected to the storm drain system, but is planned to be connected under the redevelopment project, then that area should be included as new impervious area. However, all new impervious surfaces should be included in the area calculation, regardless of their connection to the storm drain system.

[6] This threshold differs from that stated in the original version of the NPDES permit (10,000 square feet), and was changed in agreement with the RWQCB. Should this threshold be revised in the future, the change will also be applicable to the HMP.

described in section 5.3.1 of the HMP to the maximum extent practicable. If the project proponent shows that these practices will be implemented, no further analysis is needed. If the design practices cannot be incorporated, the project proponent must provide justification for the proposed exclusion (Skip to Step 5). If the project is not one single-family home, continue to Step 4.

Step 4. ***Design and implement hydromodification controls.*** For all other projects, the project proponent must demonstrate that the post-project flow duration matches the pre-project conditions. Acceptable design practices to achieve these standards are described in Chapter 5. Specific design guidance is given for flow duration (infiltration) basins and bioretention facilities using the field-calibrated sizing charts in Appendix D (section 2.2). Adherence to these guidelines is considered acceptable control for hydromodification. If a project proponent chooses to control hydromodification using other suggested methods, then they must match the existing flow duration curve according to the guidelines in Appendix D (section 2.1). Alternatively, a project may propose to control hydromodification effects by restoring impacted stream reaches to accommodate additional flows. This option may only be used if the receiving stream channel has already been impacted by existing hydromodification. The project proponent must show that significant benefit will be gained from proposed restoration. Restoration designs must be approved by the California Department of Fish and Game, the Army Corps of Engineers, and the California Water Board. Therefore, it is necessary to bring these agencies into the planning process as early as possible. Restoration project designs are best handled on a project-by-project basis, to consider local conditions and constraints, and should follow the most up-to-date standards of the permitting agencies (see section 5.3.3). Continue to Step 5.

Step 5. ***Provide documentation to show compliance with the FSURMP HMP.*** Where the HMP applies, project proponents must submit maps highlighting impervious areas (including significant compacted earth areas) and where those areas will drain, as well as the location of the hydromodification management features. For projects planning to use the standard sizing charts, a summary of sizing calculations must be provided (see section 2.2.6

for procedure). For projects using modeling and flow duration matching, a summary of the modeling calculations with corresponding graphs showing curve matching (existing, post-project, and post project with controls curves) must be included. For projects that are exempt from HMP requirements, justification for the exemption must be provided (a map showing that the project drains only to non-susceptible stream channels, for example)[7].

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[7] Projects that are exempt from HMP requirements are still encouraged to incorporate site design elements that to reduce hydromodification. See section 5.3.1 for details.

2. BACKGROUND AND SUPPORTING INFORMATION

2.1 Physical setting

2.1.1 Physiography

The Fairfield-Suisun area is bounded to the south by Suisun Bay, to the west by the Suisun Valley Agricultural District (unincorporated Solano County), to the north by Napa County and the City of Vacaville, and to the east by the Fairfield-Suisun-Vacaville Greenbelt.

Laurel Creek is located in the northern portion of Fairfield, just south of Vacaville (Figure 1). The lower portion of the watershed flows through urbanized portions of the City of Fairfield into Hill Slough and then to the Suisun Marsh, while the upper watershed straddles Interstate 80 and is primarily un-urbanized.

Ledgewood Creek is in the western portion of the City of Fairfield (Figure 1). Much of the main creek channel, however, is predominately outside of the city's urban limit line, and only falls under City jurisdiction in its downstream reaches, which are excluded from the HMP according to C.3.f.ii of the Permit. Several headwater tributaries, however, are within the current city limits, as well as areas of potential urban expansion as defined in the City's general Plan (City of Fairfield, 2002).

2.1.2 Climate

The project site is located in an interior, central California Mediterranean climate zone characterized by cool, wet winters and hot, dry summers. Based on 55 years of rainfall data obtained from a weather station operated by the National Climatic Data Center located in the Laurel Creek watershed southeast of Interstate-80 (Fairfield NNE), the average annual rainfall for the area covered by the HMP is approximately 22 inches per year, but has varied between 7.5 inches to 47.2 inches[8]. The majority of rainfall occurs during the period of October through March.

2.1.3 Geology and soils

Uplands in the Fairfield-Suisun area are comprised of folded and faulted sedimentary rocks that are part of the eastern fringe of the Coast Ranges. The watersheds of Laurel and Ledgewood

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[8] Annual rainfall is calculated by water year, which extends from October 1st to September 30th and corresponds to the water year used by most federal and state agencies.

Creeks are underlain by steeply-dipping beds of the Venado, Funks, Guinda, and Sites Formations, of the Great Valley complex (Graymer, R.W., Jones D.L., and Brabb, E.E., 2002). These formations consist of interbedded, Late-Cretaceous wacke, siltstone, mudstone, and shale. An older unit of massive sandstone with beds of wacke, gritstone, and pebble conglomerate dating to the Early Cretaceous and Late Jurassic is found along the ridgetop that divides the watersheds of Laurel and Ledgewood Creeks. Younger alluvial fan and stream channel deposits overlie the bedrock along major drainage features.

Published soil maps for Solano County (Bates, 1977) show several distinct soil groups within the upper watersheds of Ledgewood and Laurel Creeks. The steep hillsides that form the headwaters of the creeks are characterized by loams and clay loams primarily derived from sandstone and other sedimentary rocks. The lower valleys are comprised of clay loam and silty clay loam, with some loam and sandy loam. Soils found in the lowland areas that flank Laurel, Ledgewood and Soda Springs Creeks are derived from alluvium. Most of the soil groups are classified as Hydrologic Soil Group C or D, which are indicative of poorly-drained soils with rapid runoff, typically with profiles that are very shallow or having at least one horizon with infiltration rates slower than 0.06 to 0.2 inches per hour. Table 1 summarizes the properties of the dominant soils that comprise the project site.

The Dibble-Los Osos soil group is found in both the Ledgewood and Laurel Creek watersheds developed on the steeper hillslopes. These relatively shallow soils are characterized as having moderate to high erodibility due to the steep slopes, with moderate permeability (0.20-2.0 inches/hour) in the upper 13 to 18 inches of soil. Easily weathered sandstone is the usual parent material, though some areas are underlain by siltstone units.

Lower on the floodplain, adjacent to the main channels of Soda Springs, Ledgewood and Laurel Creeks, are the Rincon, Sycamore, Antioch-San Ysidro, and Yolo soil groups, which consist of old alluvium deposits. These soils tend to have similar topsoil permeability values as the upland areas, with the exception of the Rincon series, which has low permeability (0.06-0.20 inches/hour).

2.1.4 Regional aquifers and ground water

The Late Cretaceous sedimentary rocks that underlie the Fairfield-Suisun region are considered generally non-water-bearing for ground-water supply. Younger alluvium flanking the creeks are typified by low to moderate permeability, but contain strata of permeable sand that yields some water to wells. Because of the low permeability of the alluvium and the poor quality of the limited water encountered in this area, the U.S. Geological Survey declined to identify any developable regional aquifer or estimate any volume of usable water in the vicinity of the watersheds of Laurel and Ledgewood Creeks (Thomasson and others, 1960, p. 333). No subsequent regional ground-water investigation has been conducted, to the best of our knowledge. Despite the lack of regional aquifer data, localized information on ground water can be obtained by evaluating data from two wells located in the watersheds of Laurel and Ledgewood Creeks.

The California Department of Water Resources (CDWR) manages ground water data from two monitoring wells located in the upper portions of the Laurel and Ledgewood Creek watersheds. One well is located just upstream from the confluence of Soda Springs Creek and Laurel Creek near the City of Fairfield Paradise Valley golf course (State Well Number 05N01W07E001M). Ground-water level data are available for this well from 1943 to 2003, collected by three different agencies over the sixty-year period of record; the USGS from 1943 to 1953, the CDWR from 1953 to 1960, and the Solano Irrigation District from 1960 to 2003. Data show that ground water levels have been relatively consistent since 1963, fluctuating around a mean of approximately 103 feet above mean sea level, with a range between 98.5 to 106 feet above mean sea level. Ground-water levels are typically highest in the spring and lowest in the fall prior to the beginning of the rainfall season. The average ground-surface elevation at the monitoring well is 115 feet above mean sea level, suggesting that the ground-water table is most often slightly deeper than ten feet below the ground surface.

The second monitoring well is located near Rancho Solano South, west of Interstate-80, in the Ledgewood Creek watershed (State Well Number 05N02W14N003M). Ground-water levels for this well are available from 1948 to 1970, and similar to the monitoring well in the Laurel Creek watershed, it was monitored by different agencies (USGS, CDWR, and Solano Irrigation District) over the years. The data are not stable around a consistent mean value and instead show two distinct rising trends; one from 1948 to 1953 and another from 1960 to 1970. These increases could be related to decreases in ground water pumping due to imported surface water associated with the Solano Project (Solano County Water Agency, 2004), and/or multi-year dry periods in the mid- to late-1940s and 1959-1961. Ground-water levels are generally shallower than at the monitoring well located in the Laurel Creek watershed, with the water table located from five to ten feet below the ground surface. It is important to note that the record only extends to 1970 and land use changes in the watershed that have occurred from 1970 to the present are not represented in the ground-water data.

2.2 Anticipated urban expansion

To best tailor the FSURMP HMP to local conditions, it is important to understand where urbanization is most likely to occur, as well as the constraints and incentives for development in different areas of the watersheds.

Figure 1 highlights the existing city limit line for the City of Fairfield. The current urban limit line, as defined in the 2002 general plan (City of Fairfield, 2002), includes the existing city limits and the Rancho Solano North planning area (also highlighted on Figure 1). One of the main changes from the previous plan is that the urban limit line was actually pulled back in many places, to reflect the latest development patterns, and to preserve the agricultural district within the Suisun Valley. The plan specifically states that "All land located beyond the ultimate urban limit line…shall not be included in the City's sphere of influence and shall not be annexed by the City in the future."

One of the newest areas of urbanization within the City of Fairfield, the Rancho Solano South project, has occurred in the northern portion of the city at the base of the southern Vaca Mountains, including portions of Ledgewood Creek (Figure 1). Because all phases of this project are already permitted and under construction, they will not be subject to the requirements described in this HMP. However, should additional development occur within this area, HMP controls may apply[9].

The Rancho Solano North planning area (RSNPA) is the last remaining area planned for urban expansion in the Fairfield master plan (Figure 1). This planning area consists of approximately 2000 acres of unincorporated land predominantly within the Vaca Mountains to the north of the City of Fairfield. The planning area is bounded by Napa County to the north, the Vacaville-Fairfield-Solano County Greenbelt to the north and east, and the Suisun Valley agricultural district (also designated as an American Viticulture Area) to the west. The current general plan has designated this area as a single planning area; therefore any planned urbanization within the area would require a development plan for the area as a whole, or an amendment to the existing general plan.

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[9] The Rancho Solano South project contains several areas of designated open space that are protected by a conservation easement. While these areas contain channels that would be susceptible to hydromodification, the conservation easement prohibits development within the open space areas.

Though there is no specific plan for this area of Fairfield, the city planning department has made projections of what urbanization in this area might look like, given the current guidelines and constraints to development in the area (personal communication, Erin Beavers, Fairfield Planning Department). This area is mostly rugged, hilly terrain with relatively little opportunity for large-scale development under current city planning ordinances, and due to constraints to the extension of city services, such as water and sewer. The most likely places for mid- to high-density urbanization within the RSNPA are in the Soda Springs watershed, above Interstate 80, and in the lower portion of the upper Ledgewood watershed.

Currently, the most likely scenario for urbanization within the RSNPA area would be:

- Medium- to high-density housing in the portions of the Soda Springs watershed directly upstream of Interstate I-80, with up to 300 units.
- Low- to very low-density housing in the hills of the upper Soda/Laurel watershed, on the order of 10 single-family homes.
- "Homestead"-style homes on large (potentially greater than 5 acre) lots in the Ledgewood watershed, most likely individually permitted.

Because most of the future urbanization is expected to be concentrated in the upper Laurel watershed, specific hydrologic studies were concentrated in that area. While this likely scenario was considered when developing the HMP, it is certainly not the only scenario under which the HMP would be valid. Because of the close proximity, relatively small size, and the similarities between the Laurel and Ledgewood watersheds, the results of the feasibility study within the Soda/Laurel watershed are applicable to the entire area covered by the permit.

2.3 Work Reviewed

Even though the C.3.f provision is a relatively new addition to the RWQCB stormwater permits, a significant amount of work has been done in the San Francisco Bay area over the last few years to prescribe hydromodification management measures that and implementation methods for these measures.

The following is a description of the main hydromodification resource documents that were reviewed in the preparation of this HMP, which primarily consist of recent documents prepared by other stormwater programs within the Bay Area. These documents will serve as helpful secondary resources for project proponents working their way toward provision C.3.f compliance.

Start at the Source (BASMA, 1999)

In 1999, the Bay Area Stormwater Management Association released the "Start at the Source" manual, which described the basis for implementing many "best management practices" (BMPs) in the San Francisco Bay Area. While this document is primarily directed at reducing non-point source pollution generated from urban runoff, many of the planning practices are also valid for limiting hydromodification effects. The "Start at the Source" manual encourages planners to incorporate BMPs into the beginning stages of the planning process, and suggests the use of source controls implemented at the individual unit scale to limit the need for downstream (or down-pipe) controls.

Stormwater Best Management Practice: New Development and Redevelopment (California Stormwater Quality Association, 2003)

The California Stormwater Quality Association updated the Best Management Practice (BMP) handbook from 1993 to reflect changes and innovations in the way stormwater can be managed. This handbook provides informative fact sheets that describe specific BMPs and how they can be implemented in projects, as well as maintenance requirements.

Santa Clara Valley Urban Runoff Management Pollution Prevention Program (SCVURPPP)

The SCVURPPP re-issued stormwater permit was the first in the Bay Area to include the hydromodification management provision. In preparation for the HMP, SCVURPP prepared a literature review that extensively considers some of the key work done throughout the country and gives an overview of the causes and effects of hydromodification (GeoSyntec, 2002). The main objectives of the literature review were to educate those responsible for preparing and implementing the HMP, and to help identify assessment methods for predicting channel instability due to hydromodification.

As part of the HMP development process, the Santa Clara Valley Water District (SCVWD), working with the SCVURPPP, sponsored a technical study to evaluate and model the potential effects of further hydromodification on various streams in the county and model the effectiveness of various solutions for hydromodification control (GeoSyntec, 2004). These solutions included on-site and regional control basins, source controls, and in-stream channel restoration and stabilization. Portions of this draft hydromodification report prepared for the SCVWD were incorporated into the SCVURPPP HMP document as Appendix I (SCVURPPP, 2004).

The SCVURPPP C.3 handbook was finalized in May 2004 and describes the approaches and solutions Santa Clara County will take to manage stormwater and hydromodification.

Alameda County Clean Water Program (ACCWP)

ACCWP used the SCVURPPP literature review as the basis for outlining the science behind hydromodification control, but concentrated their literature review on design and implementation of BMPs for their HMP, as well as regional considerations specific to Alameda County (URS, 2004).

ACCWP's HMP was primarily based on a mapping approach, defining which channels are susceptible to the effects of hydromodification, as well as which areas are most-likely to cause significant hydromodification with an increase in impervious area (Alameda County Public Works Agency, 2004). Areas that are not susceptible or do not drain to susceptible channels are not required to implement hydromodification controls. Other areas may be required to implement controls based on the mapping designations or on site-specific studies conducted during the planning stages of a given project. ACCWP is currently working to develop a model to assist in the sizing and design of flow duration basins for their HMP.

Contra Costa Clean Water Program (CCCWP)

The CCCWP recently completed at update to their Stormwater C.3 Guidebook (CCCWP 2004). The close proximity and similar physical setting of Contra Costa County to the Fairfield Suisun region make this a particularly applicable reference for project planners incorporating aspects of the FSURMP permit.

The CCCWP HMP was submitted to the RWQCB in April 2005. This document addresses hydromodification control by emphasizing distributed flow control facilities (on a lot or block scale), called integrated management practices (IMPs).

Due to its smaller size, FSURMP has more limited resources than the county-wide stormwater management programs, and therefore has fewer funds for an exhaustive testing of methods, and implementation of large, regional-scale hydromodification control projects. No formal literature review is required for the FSURMP HMP, though many Solano County-specific documents were reviewed in the preparation of this HMP. Many of the proposed solutions in this document are similar to those proposed for the ACCWP, SCVWD, and CCCWP HMPs and, where appropriate, documents, materials, and studies completed for those HMPs are referenced in this HMP.

3. FIELD ASSESSMENT

Stream reconnaissance surveys were conducted by Balance Hydrologics for both Laurel and Ledgewood Creeks. Because much of Fairfield's urban expansion is expected to occur within the Laurel Creek watershed (see section 2.2), field studies were concentrated in that watershed, with only preliminary baseline surveys conducted within the Ledgewood Creek watershed.

3.1 Laurel Creek

Portions of the Laurel Creek watershed were surveyed by Balance Hydrologics staff on August 26 and October 27, 2004. The headwaters area of the watershed (beyond the first quarter-mile upstream from Interstate 80) was inaccessible due to limited access on private property, however a general characterization was made using aerial photographs and knowledge of other headwater streams in the area.

The upper portion of the Laurel Creek watershed is located in the Vaca Mountains, and is characterized by steep tributary drainages. At an elevation of about 300 feet, these tributary valleys empty onto a broad, flat alluvial plain, with a corresponding sharp break in stream gradient. Channel depths within this plain are typically six to ten feet, and the channel is stabilized primarily by riparian vegetation (grasses, shrub and tree roots, and dense root mats) through much of its length (Figure 4). Nearly-continuous riparian vegetation in and along the stream is a key factor (if not the primary factor) in maintaining the stability of the system.

The segment of the stream between Interstate 80 and Cement Hill Road is heavily- to moderately-urbanized, with urbanization generally decreasing northward (or upstream). The stream flows through a predominately natural channel, though the floodplain has been somewhat constrained by small levees in the downstream portion near Cement Hill Road. Riparian vegetation is relatively intact, with heavy willow growth in some sections stabilizing one- to two-foot knickpoints (Figures 5 and 6).

Preliminary assessment of this section showed only minimal channel response, if any, to existing hydromodification. However, the upper portion of the watershed is only about ten percent impervious, and the channel may respond to further increase in impervious area, or it may eventually develop a delayed response to recently urbanized areas. The fact that the stream flows through the Paradise Valley Golf Course just below the area most likely to be developed adds an additional element of sensitivity, as any channel response to upstream urbanization could cause significant damage to the city facility (Figure 7).

Downstream from Cement Hill Road, Laurel Creek is confined to a boulder riprap-lined, leveed flood control channel, designed by the Army Corps of Engineers in the 1970s and 1980s (USACOE, 1973 and 1985). This portion of the watershed is also heavily urbanized, with little recent development or opportunity for new development, and for these reasons it is not significantly susceptible to further hydromodification effects.

3.1.1 Definition of reaches

In order to be consistent with the wording within the permit, we have divided Laurel Creek into three broad segments based on channel type (engineered versus natural, for example), condition (eroded/non-eroded), and watershed urbanization. These segments were delineated using the results of the reconnaissance surveys, as well as topographic map and aerial photograph interpretation, and will become the formal definition of the "mid to upstream sections" referenced in the FSURMP permit.

> **Lower Laurel Creek**: The lower portion of Laurel Creek includes the heavily urbanized, primarily engineered channels deemed no longer susceptible to hydromodification effects. This includes the channel downstream of Cement Hill Road, as well as the Union Creek bypass channel. Lower Laurel Creek has been explicitly excluded from the FSURMP permit (Permit finding 38).
>
> **Middle Laurel Creek**: We define the middle portion of Laurel Creek to be stream channels susceptible to hydromodification effects that are moderately- to heavily-urbanized (as of 2006). This includes the stream segment between Cement Hill Road and Interstate 80 (including the Soda Springs tributary).
>
> **Upper Laurel Creek**: Stream channels within the upper portion of the Laurel Creek watershed are primarily unurbanized, and most are steep headwater tributaries. For planning purposes, we have divided those channels into two different groups: channels that fall within designated open space (and are unlikely to be urbanized) and those that fall within land that may be urbanized in the future (designated on Figures 2 and 3).

3.1.2 Stream gaging

Balance Hydrologics installed two stream gages in the Laurel Creek watershed during early November, 2004. The purpose of these gages was to collect flow and sediment data to aid in development of the HMP, as well as to provide at least one season of baseline monitoring for assessing any possible future impacts if these areas are urbanized.

One gage was installed near the downstream end of the middle reach, just below Manuel Campos Road. This gage, designated 'LCMC', records flow downstream of the confluence of Soda Springs and the Laurel mainstem, near the southern edge of the Paradise Valley project (Figure 2). At the gage, the watershed is approximately ten percent impervious. The second stream gage was installed on the Soda Springs tributary at the downstream end of the upper reach (SS80). The watershed above this area is entirely ranchland and open space, with no urban impervious area[10].

The following is a summary of the most pertinent results from the stream gaging/sediment transport study. A complete presentation and analysis of the data is included in Appendix B.

- Upper Soda Springs has no summer baseflow, and a relatively short winter baseflow period. There was no significant flow in upper Soda Springs until the watershed was largely saturated, commencing at approximately 6 inches of cumulative seasonal rainfall.
- Laurel Creek at Manuel Campos responded to four storm events early in the season (including the second highest peak flow of the season), whereas Soda Springs above I-80 responded to only one (which was one of the smallest peaks in that record). This highlights the substantial early-season storage capacity of the open-space soils within the upper Soda Springs watershed.
- After watershed saturation, peak flow per square mile is actually higher for SS80 in many cases, though duration of high flows is much longer at LCMC.
- For a given flow, suspended-sediment transport is of similar magnitude at all sites, with the exception of slightly higher sediment transport rates in upper Soda Springs early in the season (during the "first flush" event).
- Bedload sediment presently moves only at very high flows, above at least 27 cfs at LCMC. This is likely due to the fact that the stream is supply limited (limited coarse sediment is available for transport), and that stream velocities are very low, even at relatively high discharges (average velocity at 27 cfs was only 1.2 feet per second).

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[10] While there is no urban development in this portion of the watershed, past hydromodification in the watershed due to the conversion to grazing land (probably in the late nineteenth or early twentieth century) was probably significant.

3.2 Ledgewood Creek

Portions of the middle reach of Ledgewood Creek were surveyed by Balance Hydrologics' geomorphologists on October 27, 2004 and January 19, 2005. Reconnaissance geomorphic studies of portions of lower Ledgewood Creek were conducted on August 26, 2004 and January 19, 2005. Due to limited access (private property with few to no accessible roads) the upper reaches of Ledgewood Creek were not walked.

These preliminary reconnaissances were conducted to provide a frame-of-reference for the FSURMP HMP, and to assess qualitatively the potential response to urbanization within the watershed. For some reaches, channel condition was assessed near several road crossings (which provided regular access), from which generalized reach descriptions were compiled.

The lower portion of Ledgewood Creek, from just above Interstate 80 down to Suisun Bay, is confined to a predominately engineered channel. The channel is well-vegetated, has a low gradient, and has several artificial grade control structures throughout its length (Figure 8). The watershed to the east of this segment of the channel is heavily urbanized, within the City of Fairfield, while to the west of the channel the watershed is predominately unurbanized land within the Suisun Valley Agricultural District (unincorporated Solano County).

Upstream from the predominately engineered portion of Ledgewood Creek, the mainstem channel lies almost entirely outside of the City of Fairfield urban limit line. The channel is typically incised up to 10 feet and much of the channel length has been altered and/or realigned in response to agricultural practices; however, there are significant sections that have maintained the original stream alignment.

Balance staff surveyed the Ledgewood Creek channel at several locations near Mankas Corner, just downstream of the Rancho Solano North Planning area. This portion of the channel is historically incised about 8 feet below the floodplain; however no recent signs of incision were evident. Riparian vegetation was well-established through much of the reach, contributing to the strength of the bank material, though there were several occurrences of localized erosion of the banks (Figure 9). Even with adequate riparian vegetation, however, the fact that this channel occurs within valley fill alluvium suggests that it is subject to hydromodification effects, if significant development within the watershed were to occur.

The upper watershed within the RSNPA was inaccessible for our reconnaissance survey, but based on the geology of the region and our study of the Laurel Creek watershed, we assume that these channels are susceptible to hydromodification effects, specifically to local erosion and/or incision due to increased stormflow downstream of storm drain outfalls.

3.2.1 Definition of reaches

The Permit refers to the "mid to upstream sections" of Ledgewood Creek, but gives no formal definition of these terms. For the purposes of the HMP we have divided the stream into three broad segments, following the terminology laid out in the Permit:

> **Lower Ledgewood Creek**: This segment extends from Suisun Bay to the upper end of the predominantly-engineered portion of the channel, about 1.1 miles above I-80 (see Figure 3). All portions of this watershed within the city of Fairfield (the eastern side of the creek) are heavily urbanized, and this segment of the channel is unlikely to respond to any further increase in impervious area.
>
> **Middle Ledgewood Creek**: For the Ledgewood watershed, we define the Middle reach as extending from the upper portion of the predominately engineered channel, to upstream of the Napa/Solano County boarder. Much of the length of channel within this segment, especially in the lower portion, has been altered and realigned in the past by agricultural practices. With the exception of the lower 650 feet of channel, the channel is entirely outside of the Fairfield city limits as well as the planned urban limit line. The FSURMP permit would not apply to this area unless annexed by the city.
>
> **Upper Ledgewood Creek**: We define the upper reaches of Ledgewood Creek as the headwater drainages that are tributary to Ledgewood Creek, specifically those that are within the RSNPA (Figure 3). No areas within Napa County were considered in our assessment, and therefore are not classified.

The lower reaches of the Ledgewood Creek channel are specifically excluded from HMP controls in the permit, because this portion of the watershed is primarily built-out, and the predominately engineered and low-gradient channel appears to be resistant to hydromodification effects down to Suisun Marsh.

3.2.2 Impervious Area

A preliminary analysis of potential impervious area change in the upper Ledgewood watershed was conducted to describe the potential impacts to the stream due the anticipated very low density development. A similar analysis for the Laurel watershed was not necessary because of the concentration of field studies and hydraulic modeling in that area.

The current Fairfield General Plan includes just over two square miles within the Ledgewood watershed, with the majority of that area draining to the tributary that enters the Ledgewood Creek just upstream of Clayton Road (Figure 3). Current land cover within this area is limited to dirt/gravel roads and small buildings, with a negligible impervious area. Using a conservative estimate of one percent as the impervious threshold for stream channel response within the watershed[11] we suggest that the upper portion of the watershed could accept an additional 13 acres (+/-) of impervious area before hydromodification impacts begin to occur, assuming that all runoff drains to the lower portion of the upper watershed. With this information we conclude that hydromodification effects to the portion of channel within the RSNPA will be negligible if the watershed is developed as planned (including only a few individual homes), especially if the recommendations outlined in Section 5 are followed.

Hydromodification effects to the *mainstem* of Ledgewood Creek from very low density development within Rancho Solano North are even less likely. Just downstream of the RSNPA, the mainstem of Ledgewood Creek joins the tributary and triples the size of the watershed. Three-quarters of a mile downstream, Gordon Valley Creek joins Ledgewood, adding another 4.6 square miles to the watershed. Because Gordon Valley Creek and the mainstem of Ledgewood Creek flow through a predominantly very-low impervious watershed, a small increase in percent imperviousness at the upper end of the watershed with the development of a small number of Group 2 projects is insignificant relative to the watershed area of the Ledgewood Creek mainstem. Assuming that the City of Fairfield does not annex a large amount of Solano County Agricultural land within the middle Ledgewood watershed, which would only be done for a large (Group 1) project, hydromodification impacts due to Group 2 projects are very unlikely, even without controls. However, given that long-term urbanization plans may change over time hydromodification management will still be required for this watershed, as outlined in Section 5.

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[11] Studies in Western Washington (Booth, 1993) and Santa Clara County (GeoSyntec, 2004), among other areas, have shown that hydromodification effects typically begin to occur at a percent imperviousness of less than ten percent. One percent is used here as a conservative estimate, and allows a buffer for some cumulative hydromodification from other small projects within the watershed.

3.3 HMP channel classification and exempted areas

As discussed previously, the FSURMP permit states that the HMP applies only to the mid to upper sections of Laurel and Ledgewood Creeks. These segments are formally defined in the sections above. Figures 2 and 3 highlight the stream channel designation for the HMP, though we have chosen to characterize the channels by susceptibility to hydromodification rather than simply using the 'mid' and 'upper' classifications. Table 2 expands the description of this classification, and also lists how the designations translate to the 'mid' and 'upper' segments referenced in the permit.

Projects that drain directly or indirectly to susceptible channels (as shown on Figures 2 and 3) are subject to provisions described in this HMP. Projects that drain only to non-susceptible channels (though hardened storm drains or other non-susceptible channels) are not subject to HMP provisions. Because of the complexities of the drainage system within the City of Fairfield, as well as the potential for projects to change existing drainages from one watershed to another, we have chosen to define the area in which the HMP will apply by relating directly to the stream channels. Figures 2 and 3 delineate the approximate area draining to susceptible channels within the Laurel and Ledgewood watersheds. However, HMP applicability is tied to the channels themselves and not the area delineated on the map. For example, if a project inside the delineated drainage area on Figure 2 is shown to drain to lower Laurel Creek exclusively through existing (hardened) storm drain systems, then the HMP would not apply to that project. Similarly, if a project outside the delineated drainage area in fact drains to a susceptible channel, then HMP control measures would be required.

When beginning the HMP planning process, the project proponent is required to delineate the project area and determine where the project will discharge (whether that be a stream or city storm drain). The project proponent will also denote the flow path of the discharge water downstream to Suisun Marsh. If that delineated path, at any point, intersects a susceptible channel as designated on Figures 2 and 3, then the provisions described in Chapter 5 below apply. If only a portion of the project drainage area flows to a susceptible channel, then the HMP applies only for that portion of the project.

4. HYDROLOGIC MODELING

The following sections summarize the results of the hydrologic and channel stability modeling effort. For a complete discussion of the technical background, procedure, modeling analyses and results, see Appendix C.

4.1 Approach

The project team modeled creek flows under pre-urban, existing, and future land use conditions. The watershed models convert rainfall input sequences to estimated stream flow rates at various selected points throughout the project watersheds. The model rainfall input consists of a continuous rainfall record, where actual measured rainfall from a nearby gage over a long time period is input into the model. This method of modeling is referred to as "continuous simulation."

Within continuous simulations, the model incorporates information about the watershed (topography, soils, vegetation, land use, urbanization, etc.) to estimate how much rainfall is held in the watershed ("losses", including infiltration to the soil, trapping by vegetation or shallow depressions, etc.), and how much precipitation results in surface runoff, eventually reaching stream channels.

The project team chose to model the Laurel Creek watershed using the U.S. Army Corps of Engineers' Hydrologic Engineering Center - Hydrologic Modeling System (HEC-HMS) rainfall-runoff model. The U.S. Army Corps of Engineers developed HEC-HMS to supersede the HEC-1 Flood Hydrograph Package. Unlike HEC-1, HEC-HMS allows continuous hydrograph simulation over long periods of time in addition to event-based analysis.

Continuous modeling allows for continuous accounting of soil moisture and infiltration and other losses for an extended time period. Therefore, continuous modeling is preferable when trying to identify the hydromodification effects of development on small, frequent flows and to evaluate their impacts on stream stability.

The fundamental approach used to a) evaluate changes in baseline flow hydrographs from existing conditions to future build-out conditions and b) identify and design effective hydromodification management measures (HMMs) is to build and run a continuous simulation model and analyze all erosive flows rather than selecting only a few discrete events. Results from the continuous simulation are then used to perform a creek stability assessment to identify and test different hydromodification management solutions. This approach was selected because stream erosion, sediment transport, and work are all functions of the cumulative duration of erosive flows. Therefore, controlling flow duration for the full range of flows is the most effective method to protect streams from urbanization impacts.

Existing hydrologic conditions were modeled using detailed soils and land use GIS data provided by the Fairfield-Suisun water district and supplemented with Balance Hydrologics' field observations and aerial photograph interpretations. The land-use data were then modified to model hydrologic conditions for future and past (pre-urban) conditions, since GIS data were not available for these scenarios. For future conditions, the percentage of impervious land for each subwatershed under current conditions was increased based on future build-out percent impervious information from the City of Fairfield General Plan 2020 (City of Fairfield, 2000). All other land uses for each subwatershed were then decreased in proportion to the increase in impervious area.

4.2 Summary of results

The following list summarizes some of the main results from modeling for the Laurel Creek watershed

- On the basis of the total cumulative percent impervious area (TCIA), existing impervious area for the Laurel Creek watershed upstream from the LCMC gage falls within the range of uncertainty (2% to 10%) of published thresholds for stream response to imperviousness.
- Future TCIA however, is predicted to double and likely exceed any real threshold (> 10%) for both Soda Springs and Laurel Creek. On the basis of TCIA, future development could potentially impact both Soda Springs and Laurel Creek.
- Analysis of flow duration and total stream flow volume shows minor increases in the total hours of flow and volume between pre-developed and existing conditions. The number of hours of stream flow increased by 30% and the overall flow volume increased by 20%. Under future conditions, the number of hours of stream flow is twice (100%) that of pre-development and volume increases by 62%.

- Stability assessment results for the existing conditions predict erosion potential values that support the field observations of no significant reach-wide excessive erosion or instabilities under current conditions. However because much of the development within the watershed is recent, the stream channel may not yet have responded to the watershed changes.

- Modeled estimated *risk* of channel instabilities for future build-out conditions if ***no*** hydromodification management measures (HMMs) are implemented ranges from 21% to 38%. A 20% *risk* suggests that one in five stream segments could show signs of excessive channel erosion due to development.

- One positive thing to note is that the predicted magnitude of potential hydromodification impacts are still well below the level of 100% *risk* of wide spread instabilities. This suggests that there is opportunity for more flexibility when implementing hydromodification control strategies.

These results suggest that the risk of wide-spread channel degradation is currently low and over time we could see increasing pockets of degraded channel segments, especially if the current vegetation density is lost. The anticipated future conditions, however, are well within the range that can be controlled with proper hydromodification management measures.

5. GUIDANCE FOR HMP IMPLEMENTATION

This section describes the process for meeting the requirements of the C.3.f provision of the NPDES permit. It is intended to expand on the step-by step process that was laid out in the HMP introduction (section 1.5), and describes, in greater detail, the methods for developing hydromodification control strategies. The text also directs readers to specific design guidelines, which are included as appendices to the HMP.

5.1 HMP Standards

The Permit (C.3.f) states that "…the HMP will be implemented so that post-project runoff shall not exceed estimated pre-project rates and/or durations, where the increased stormwater discharges rates and/or durations will result in increased potential for erosion…" The erosion potential analysis discussed in Appendix C provides an index, Ep, which measures the impact of modified flows on stream stability; and has been developed as a means to define an in-stream management standard.

Using this approach as a point of reference, the following management standard was defined:

- Stormwater discharges from Group 1 development projects shall not cause an increase in the erosion potential (Ep) of the receiving channel over the existing condition.

With the above hydromodification management standard in mind, the following list presents performance criteria for meeting that standard:

- Projects shall provide stormwater controls as needed to maintain the receiving channel's existing erosion potential, as described in this section and in Appendix D. Stormwater controls may include a combination of site design, on-site, regional, and as a last resort, in-stream management measures.
- On-site or regional controls that are designed to match the pre-project flow duration condition are considered to meet the in-stream management objective and comply with the HMP.

- Stormwater runoff controls shall be designed such that post-project flow duration curves match pre-project flow duration curves to the degree specified by the 'goodness-of-fit'[12] criteria.

- Flow duration control design criteria can be developed by: 1) conducting a flow duration analysis of pre- and post- project conditions, as described in Appendix D, section 2.1; or 2) using the design charts provided in Appendix D, section 2.2. The selection and design of control measures is discussed below in section 5.2.

- Site design, on-site and regional controls shall be used to provide treatment and flow controls to the maximum extent practicable. Treatment and flow controls may be considered impractical when the combined costs for both treatment and flow controls exceed 2% of the projects construction costs (excluding land costs).

- Where feasible, off-site or in-stream controls may be used to meet the management objective, if approved by the responsible managing agency. In-stream controls (e.g., channel modifications, restorations, etc.) are still subject to the required environmental review and permitting process, and should be considered only when the receiving channel has already been impacted by existing hydromodification and would significantly benefit from restoration efforts (see section 5.3.3 below).

5.2 Selection Process

The FSURMP hydromodification solution philosophy involves the following, and should be considered in the order listed:

1. Avoid, to the extent possible, the need to mitigate for hydromodification and water quality impacts. Preserve the natural hydrologic conditions and protect sensitive hydrologic features, sediment sources, and sensitive habitats.

2. Minimize the effects of development by maximizing the use of site design techniques (low-impact development) and by incorporating on-site hydromodification controls to limit the increase in runoff volume and pollutant transport.

3. As a last resort, manage the stream corridor itself by implementing in-stream controls, such as biotechnical bank and bed stabilization controls and restoration. Provide allowances for the modified stream flow characteristics and enhance the beneficial uses of streams.

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[12] The post-project flow duration curve shall not exceed the pre-project flow duration curve by more than 10%, over no more than 10% of the length of the curve for flows greater than Qcp and less than the 10-year peak flow. See Figure D-10 for an example of the application of the "goodness-of-fit" test. These parameters are consistent with the "goodness of fit" standard being used by other programs' HMPs.

The following three step process is suggested for selecting hydromodification control measures:

Step 1: ***Select Appropriate Site Design Measures***: Maximize the use of site design measures to avoid and minimize the effects of hydromodification. Site design techniques are briefly described in section 5.3.1, and additional information is provided in the BASMAA "Start at the Source" Manual (1999). The companion document, "Using Site Design Techniques to Meet Development Standards for Stormwater Quality" (BASMAA, 2003) illustrates how various site planning concepts can be used to help minimize the quantity of runoff.

Step 2: ***Select Stormwater Treatment Measures that Reduce Runoff Volume***: After selecting appropriate site design measures, identify treatment control measures that also provide hydromodification benefits, such as bioretention, infiltration swales or trenches, and other treatment measures that promote infiltration or slow the rate of runoff. All projects require stormwater quality treatment measures, which are described in the FSURMP document "Stormwater Requirements for Development Projects—Packet for Project Applicants" (June 28, 2005). Hydromodification management requires runoff volume reduction. In some cases, water quality treatment controls can be modified to address hydromodification.

Step 3: ***Select Hydromodification Control Measures***: The third step in the selection process is to design hydromodification controls to meet the flow duration criteria in the hydromodification management standard. These controls must be capable of achieving the flow duration criteria before discharge to receiving waters. At this stage, there are a limited number of BMPs that achieve this objective. Water quality treatment measures can be combined with hydromodification control measures to reduce the total area and infrastructure required for stormwater management.

5.3 Hydromodification Control Strategies

Effective management of hydromodification consists of a series of progressive control measures combined into a single integrated solution. This integrated solution ultimately must achieve the hydromodification management standard of no change in the receiving channel's erosion potential.

Potential solutions consist of project-specific strategies such as site design and on-site BMPs and hydromodification control strategies, regional solutions that combine stormwater runoff from multiple projects, and in-stream modifications that may take the form of flood control and restoration projects.

Any control measure that reduces or eliminates the increase in runoff volume created by adding impervious surfaces helps to reduce the in-stream effects of hydromodification. Larger, regional flow control facilities can be cost effective for multiple projects depending on the local authority's desire to manage and maintain such facilities.

The question that must be addressed is how much control is necessary to be effective. Flow duration control is an effective control strategy that does not require a project proponent to conduct detailed watershed scale analyses. In-stream modifications that help the stream accept the new flow regime can also be a solution, but are considered only for stream systems already degraded to the extent that makes restoration desirable. The 'erosion potential' methodology provides a means to measure effectiveness should a developer or agency wish to conduct an analysis on their own, or use in-stream modifications to meet the management objective.

Hydromodification control strategies have been divided into three different types: site design practices, hydromodification control facilities, and in-stream solutions. These are further described in the sections below. Tables 3 and 4 summarize several of these concepts, and can serve as a useful planning tool in the beginning stages of HMP planning.

5.3.1 Site design practices

The main premise of *site design* techniques is to maintain the natural functions of the hydrologic and geomorphic processes to minimize the magnitude of change caused by hydromodification and to integrate stormwater controls into the landscape. The following points summarize this concept:

- Preserve areas of natural moderate to high infiltration to maintain, to the extent practical, infiltration quantities, stable baseflows and groundwater recharge. Maximize opportunities for infiltration. Amend the soils where less infiltrative soils are present to enhance sub-surface storage of stormwater runoff.

- Reduce and disconnect impervious surfaces such as building areas, roofs, parking lots and streets. Use open-jointed or permeable paving materials. Allow surface runoff from impervious surfaces to drain to vegetated pervious areas with infiltration and volume reduction before discharging from the project site.

Site design may be incorporated into the standard features of a development with small to moderate changes in the project design. Site design techniques can reduce the runoff volume and can reduce the infrastructure necessary to control and convey stormwater. Several applicable site design techniques are briefly described in below. Additional information is provided in the BASMAA "Start at the Source" Manual (1999), and the companion document, "Using Site Design Techniques to Meet Development Standards for Stormwater Quality" (BASMAA, 2003), which illustrates how various site planning concepts can be used to help minimize the quantity of runoff. Two other documents, *Pennsylvania Handbook of Best Management Practices for Developing Areas* (1998) and *Stream Response to Stormwater Management Best Management Practices in Maryland* (2000) also provide useful discussion of site design techniques[13].

The following site design practices should be considered in the when planning hydromodification controls:

- **Reduce impervious area in planning process.** For low-density residential developments there are many opportunities to reduce the impervious area created as a part of the development. Incorporating these hydromodification management measures into projects will allow for protection of the streams without having to model for flow duration and/or flow volume control.
    - Use flared design, crushed aggregate or wheel-only pads for driveways (see section 6.4 in Richman and Associates and others, 1999).
    - Use permeable pavement or gravel/crushed aggregate for access roads (see section 8.1 in Richman and Associates and others, 1999).
    - Use minimum required width for access roads.
- **Reduce impervious area connectedness to streams.** Impervious area not only increases the volume of runoff to the stream channel, it typically increases the time of concentration, producing more erosive flows. Limiting impervious area connectedness to the stream will reduce changes in peak runoff volume to the stream. (For specific examples see section 4 in CDM, 2003.)
    - Drain roof runoff to planters, infiltration trenches, lawn spreaders or cisterns, rather than to the creek (see section 6.5 Richman and Associates and others, 1999).

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[13] These documents were produced for other regions of the country, however many of the concepts are similar to those described in the BASMAA documents, and therefore can serve as valuable secondary sources.

  - Divert street and driveway runoff to lawns, swales, or other vegetated areas, and avoid using storm drains to channel runoff to streams. This method will be especially appropriate in the flat areas of the Laurel and Ledgewood watersheds.

- **Concentrate additional impervious area on low-infiltration soils.** The soil infiltration rates within the Solano North planning area range from 0.02 to 2.0 inches/hour. Siting impervious area on low-infiltration soils reduces the net runoff increase for that area.

5.3.2 Hydromodification control facilities

Project-specific hydromodification controls include on-site volume and flow control structures such as retention, detention, and infiltration facilities. Such controls must be designed to meet the flow duration criteria. The following points briefly summarize this concept:

- The objective is to maintain, to the extent possible, the hydrologic balance between rainfall, natural storage, infiltration and overland flow from a project site; ultimately to maintain the receiving stream's capacity to transport sediment or erode its banks, as measured by the Erosion Potential[14].
- Stormwater control facilities must be designed to:

  a) ***Retain*** the increase in runoff volume created by adding impervious surfaces and infiltrate this volume into the ground (or divert to storage for stormwater reuse), and/or ***detain*** and ***discharge*** the increased volume at a flow rate less than a fraction of the critical flow for bed mobility for the receiving stream.

  b) ***Match*** the flow duration curve from the pre-project site for discharges in excess of Qcp up to the 10-year peak flow.

- Flood control and water quality treatment facilities can be combined with flow duration control to reduce the land requirements and costs for stormwater management. Controls designed to meet flow duration criteria reduce pollutant loads to receiving waters and can achieve water quality objectives through infiltration.

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[14] Erosion potential (Ep) is described in section 3.2 of Appendix C.

In areas of the watershed where land is available, larger-scale, regional facilities can be built that provide volume and flow control. Regional controls intercept runoff from several projects before discharging to the receiving stream. They are designed to reduce runoff volume and match discharge durations, and/or divert runoff to a less-sensitive location or storage (such as for stormwater reuse). The benefits of regional controls are that 1) they can be economical for serving several development projects; 2) they allow for efficient maintenance in one location; and 3) they can serve dual uses as multi-purpose facilities. Potential facilities could include the following:

- Retention and infiltration basins
- Interceptor and bypass systems
- Stormwater reuse systems that store stormwater for irrigation.

Appendix D provides specific guidance for designing hydromodification control facilities. Two methods of demonstrating compliance are included. The first method (Appendix D section 2.1), involves developing a continuous-flow model of pre- and post-project conditions, and sizing appropriate hydromodification controls to match the pre-existing flow duration curve. Using this method, the project proponent can employ a range of solutions, using a combination of source controls, stormwater treatment measures, and hydromodification control facilities to meet the flow duration standards. This method allows for customization of the hydromodification facility sizing, potentially reducing the size of the facility based on other controls being used within the project.

The second method (Appendix D section 2.2) employs the use of standard design charts to size hydromodification control facilities using two options—flow duration basins and bioretention facilities. These charts allow for the sizing of hydromodification controls without employing the use of hydrologic modeling, however design configurations are somewhat limited. The sizing charts were created using the Laurel watershed calibrated model, described in Appendix C. Because of the similar geologic and hydrologic setting within the Ledgewood Creek watershed, the sizing charts are applicable for that watershed as well. However, use of the design charts outside of these two watersheds is not advised without adjusting to local conditions.

5.3.3 In-stream solutions

In-stream solutions involve modifying the receiving stream channel slope and geometry so that it can convey the new urban flow regime while reducing the potential for erosion and aggradation problems, and damage to habitat. These measures are intended to improve channel stability and prevent erosion by reducing the erosive forces imposed on the channel boundary. Modifications must be designed according to fluvial geomorphic principles and must meet the hydromodification management objective.

In-stream modification is applicable only to stabilize a stream channel that is already impacted by erosive flows. For streams that are somewhat impacted or where delayed impacts are anticipated (after an area is developed, any impacts may take years to become evident), in-stream controls can improve the stream condition or minimize impacts that would otherwise continue. For stable healthy streams, project specific or regional controls are preferable since they do not disturb the stream system.

The following points summarize this concept:

- Reduce the applied shear forces by reducing the longitudinal slope, modifying cross sectional geometry and roughening the surface.
- Reduce longitudinal slope by using environmentally sensitive grade control measures and natural materials.
- Maintain flow energy dissipation along the stream channel by installing or leaving in place features that add roughness (e.g., bed and bank vegetation, root wads, large woody debris).
- Implement biotechnical engineering solutions to increase the resistance of the stream channel to the increased flow energy.
- Maintain or increase hydrologic connectivity between streams and floodplains. Use floodplains for flood storage, riparian habitat, recreation, and water quality.

Note that all such projects require a Stream Alteration Agreement from the State Department of Fish & Game, a 404 permit from the US Army Corps of Engineers and a 401 certification from the Water Board[15]. Early discussion on the acceptability of an in-stream modification is necessary to avoid project delays or redesign.

5.4 Site-specific HMM considerations

In planning which BMPs to use for a given project, several factors must be considered:

- **Stream drainage area.** Generally, the smaller the drainage area of a given stream channel, the more susceptible it is to the effects of hydromodification from a given project because it causes a greater change in the percent imperviousness of the watershed. All other factors being equal, it is generally best to place project drainage outfalls (with proper hydromodification controls) as far downstream as possible.

- **Stream channel condition.** Stream channels that have already responded to some degree of hydromodification are typically more susceptible to further hydromodification. Spillage of flows onto the floodplain can act as a natural limit to the magnitude of shear forces acting on the bed and banks, so control of flows in excess of bankfull is not typically required (MacRae, 1993). If this connection to the floodplain is lost due to incision, the constriction of higher flows will increase shear stress, and thus increase erosion. Similarly, a loss in riparian vegetation can reduce bank and bed strength, allowing erosion at lower flows.

- **Depth to ground water.** Implementation of infiltration BMPs may be limited in areas of high ground-water. The presence of shallow ground water can significantly reduce infiltration rates, even in areas with high infiltration soils. Also, if BMPs are being designed for water quality treatment, depth to ground water may influence treatment quality. Provision C.3.i of the FSURMP permit describes several limitations on using infiltration BMPs.

- **Sensitive habitat areas.** Some riparian areas may have additional requirements that need to be met to protect habitat of sensitive species. Stormwater control BMPs designs may need to be altered to incorporate certain riparian habitat considerations.

- **Capacity and cost of hydromodification facilities.** The capacity of the hydromodification control facility (or equivalent storage volume associated with alternative controls such as bioretention) is dependent on the nature of the infiltrative capacity of the soils. Basin size in terms of capacity and area are

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[15] The California Water Board is currently working on a Stream Protection Policy that will help guide restoration projects. Regular contact with the Board during the planning process will allow for incorporation of the latest updates to this policy.

concerns for the owner or developer who may need to dedicate additional land for a hydromodification facility. This additional cost may be reduced or even eliminated if low impact development type alternatives are used instead of end-of-pipe strategies, such as flow duration control.

- **Infiltration constraints**. A key design issue is whether soil and ground-water conditions are conducive for infiltration and if so, whether infiltration can be accomplished without adversely affecting ground-water quality. The C.3 provisions call for caution with regard to ground-water quality impacts. In some cases where the tributary area is considered a significant source of pollutants (e.g., heavy industrial site), pre-treatment would be required. Infiltrative soils also may settle or clog over time, requiring renovation and removal of fine sediment. None of the general soil types within the areas of Fairfield likely to be developed preclude using infiltration measures to manage hydromodification. However, in many situations stormwater infiltration rate also depends on the infiltration rate of the underlying rock or sediment. Even in high-infiltration soils, infiltration BMPs may cause perched ground-water mounding (with corresponding decrease in infiltration) if that soil overlies a relatively impervious layer. In these situations, underdrains may be required.

- **Potential impacts from infiltration on slope and/or foundation stability**. Infiltration near the foundation of buildings can cause uneven settlement, and infiltration near steep slopes can cause or contribute to slope failures. Infiltration near buildings may be feasible by utilizing designs that isolate the infiltrating area from the foundation and by maintaining a 2% slope away from the building. Many infiltration BMPs are inappropriate for use on sloped properties. On slopes greater than about 5%, swales, downspout spreaders, and planters may not be feasible due to geotechnical constraints or risk of hillside rilling. Special consideration for these projects may be needed to reduce direct discharge to a stream or tributary.

- **Mosquito concerns**. Drain times of 3 days or less are recommended to prevent mosquito production. However, recent communication with the Vector Control and the RWQCB indicates that infrequent events that cause drain times of up to 5 days would be acceptable. For these events, the 3-day drain time is generally exceeded in the winter when temperatures are cold and mosquito production is reduced.

- **Vegetation choices for BMPs that incorporate vegetation**. Vegetation type can enhance the performance of a basin by increasing evapotranspiration. Deep-rooted vegetation can enhance infiltration. Where vegetation is desirable, a water balance analysis is necessary to ensure that there is adequate water to support the vegetation during dry periods.

- **Safety considerations**. Basin depths and side slopes can be a concern for public safety. Fencing may be required for basin with large depths and steep side slopes. Moderate side slopes and safety benches also can be employed to avoid the use of fencing. If the basin is to be part of a multi-purpose facility, consideration must be given to public safety as well as ease of use.

- **Outlet operation and clogging**. To discharge at flow rates necessary to match flow duration curves, or to discharge at Qcp, small orifice diameters may be required. These small openings will be subject to clogging if not properly protected. Basin designs must include features to help prevent clogging, such as screens, filter fabric and gravel barriers. The sand filter outlet shown in Figure D-3 (Appendix D) is one such design. This is particularly true for small developments where flow rates are small and less true for larger basins (such as regional basins). Outlet weir designs may also be considered.

5.5 Special Provisions

5.5.1 Fairfield Creekside Protection Plan

The City of Fairfield developed a Creekside Protection Plan to "provide for the maintenance, restoration, protection and enhancement of streams and riparian zones" (Fairfield City Codes, Chapter 25, Article VIII). This plan documents specific goals and provisions for development in various watersheds within the city, including both Ledgewood Creek upstream of I-80, and Laurel Creek upstream of Paradise Valley Drive. For both streams, the protection plan requires a riparian zone buffer at least 50-feet wide on each side of the creek. We recommend that this guideline be extended to the Soda Springs tributary of Laurel Creek to a point approximately 0.5 miles upstream of I-80, where the stream exits the hills onto the alluvial fan. Similarly we recommend including the Ledgewood tributary that drains the Rancho Solano North Planning Area, up to the break in stream gradient corresponding to the transition to the alluvial fill (up to about 2.25 miles upstream of the confluence), be included in this provision as well.

Allowing for adequate stream corridor buffers minimizes hydromodification impacts to the stream in two ways. The first is that bank-top vegetation provides resistance to bank erosion, and deep rooted vegetation is a primary factor in providing grade control for upper Laurel and especially Ledgewood Creek. Secondly, providing a buffer zone between impervious area and the stream channel breaks up drainage continuity, slowing runoff directly into the stream channel and reducing effects on peak runoff. For example, runoff from a road built next to the top of a stream bank would drain directly into the creek, whereas a road set-back from the stream could drain to a vegetated buffer to slow impervious runoff before entering the stream channel.

5.5.2 City of Fairfield General Plan

The City of Fairfield has outlined planning policies for the Rancho Solano North Planning area in its general plan (City of Fairfield, 2002). This requires that an area-wide plan for the entire Rancho Solano North area be developed. The methods outlined in this HMP can be used in the early stages of preparation of the master plan for Rancho Solano North, incorporating planning measures that reduce changes to stream hydrographs by concentrating imperviousness in areas that are least likely to cause hydromodification effects within the stream.

5.5.3 Other considerations

The hydromodification management plan was written to provide a method of addressing the C.3.f provision of the FSURMP NPDES permit. None of the methods described in the HMP are intended to conflict with existing ordinances and/or other regulatory practices. The following is a list of other considerations that are not part of the HMP but must be considered in the planning process. This list is provided as an example of other considerations and is ***not*** a complete list of all other requirements in the planning process.

- **Flood control:** Hydromodification management measures (HMMs) are not explicitly intended to address concerns of flooding during high magnitude, low frequency events. Compliance with local flood control regulations is still required, and resulting controls should be designed to meet both flood control and hydromodification control requirements (i.e., one set of regulations does not supersede another).

- **Water quality:** While HMMs often also serve a secondary function of improving water quality of urban runoff, they are not specifically designed to meet water quality treatment goals. Compliance with certain water quality treatment goals may require adjustment of HMM function or additional facilities specifically designed for water quality treatment.

- **Slope stability:** Many HMMs take advantage of infiltration to reduce stormwater runoff volume; however, some areas may have geotechnical constraints that prevent the use of infiltration as a management strategy. Methods other than infiltration would be required in these areas, such as minimizing impervious area, retaining and reusing water, and/or diverting water to a facility in a location that does not have infiltration constraints.

5.6 Monitoring

The above recommendations have been written based on available data, data collected specifically for this study, and review/implementation of practices being proposed for other areas in the San Francisco Region. It is anticipated that implementation of these recommendations will reduce the impacts of hydromodification to insignificant levels.

Following the review of the Draft HMP, the RWQCB recommended that the maximum allowable low-flow release from hydromodification basins has been reduced to twenty percent of the two-year peak flow (down from the originally-proposed forty percent of the two year peak flow). This reduction provides an additional level of conservatism in hydromodification management and therefore provides additional buffering of the potential for downstream effects. Therefore, in agreement with the RWQCB, no monitoring of downstream reaches is required in this HMP.

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TABLES

Table 1. Properties of surficial soils near Laurel Creek, Solano County

Map Symbol	Soil Series	Hydrologic Soil Group	Erodibility	Depth Zone	USCS	Atterberg Limits		Permeability	Available Water Capacity		Reaction	Parent Materials
						Liquid	Plastic		Per Inch	Profile		
				(in)				*(in/hr)*	*(in./in. of soil)*	*(total, in)*	*(pH)*	
AcE	Altamont clay,	D	moderate	0-28	CH	50-60	30-40	0.06-0.2	0.14-0.16	4.2	6.1-8.4	Siltstone
	9 to 30 percent slopes			28-38	CL	30-40	15-25	0.06-0.2	0.19-0.21	2.0	7.4-8.4	
				38						6.2		
AoA	Antioch-San Ysidro complex,	D	slight	0-19	ML or CL	20-30	0-10	0.63-2.0	0.15-0.17	3.0	5.6-6.5	Alluvium from sedimentary sources
	0 to 2 percent slopes			19-60	CL	40-50	20-30	<0.06	0.04-0.06	2.1	5.6-9.0	
										5.1		
AsA	Antioch-San Ysidro complex,	D	slight	0-19	ML or CL	20-30	0-10	0.63-2.0	0.15-0.17	3.0	5.6-6.5	Alluvium from sedimentary sources
	thick surface, 0 to 2 percent slopes			19-60	CL	40-50	20-30	<0.06	0.04-0.06	2.1	5.6-9.0	
										5.1		
AsC	Antioch-San Ysidro complex,	D	slight	0-19	ML or CL	20-30	0-10	0.63-2.0	0.15-0.17	3.0	5.6-6.5	Alluvium from sedimentary sources
	thick surface, 2 to 9 percent slopes			19-60	CL	40-50	20-30	<0.06	0.04-0.06	2.1	5.6-9.0	
										5.1		
Ca	Capay silty clay loam	D	slight	0-60	CL	30-45	15-25	0.06-0.20	0.16-0.18	10.2	6.1-8.4	Clay and silt settled out of suspensior
CeA	Clear Lake clay	D	none	0-60	CH	50-70	35-55	0.06-0.20	0.14-0.16	9.0	6.1-8.4	Clay and silt settled out of suspensior
	0 to 2 percent slopes											
CeB	Clear Lake clay	D	none	0-60	CH	50-70	35-55	0.06-0.20	0.14-0.16	9.0	6.1-8.4	Clay and silt settled out of suspensior
	2 to 5 percent slopes											
DbE	Dibble-Los Osos	C	moderate	0-18	ML or CL	20-30	0-10	0.63-2.00	0.16-0.18	3.1	5.6-6.5	Easily weathered sandstone
	loams, 9 to 30			18-36	CH	50-60	30-40	0.06-0.20	0.15-0.17	2.9	6.1-7.3	
	percent slopes			36						6.0		
DbF2	Dibble-Los Osos	C	high	0-18	ML or CL	20-30	0-10	0.63-2.00	0.16-0.18	3.1	5.6-6.5	Easily weathered sandstone
	loams, 30 to 50			18-36	CH	50-60	30-40	0.06-0.20	0.15-0.17	2.9	6.1-7.3	
	percent slopes, eroded			36						6.0		
DIE	Dibble-Los Osos	C	moderate	0-13	CL	30-40	10-20	0.20-0.63	0.18-0.20	2.5	5.6-6.5	Easily weathered sandstone
	clay loams, 9 to			13-30	CH	50-60	30-40	0.06-0.20	0.15-0.17	2.7	6.1-7.3	
	30 percent slopes			30						5.2		
DIF2	Dibble-Los Osos	C	high	0-13	CL	30-40	10-20	0.20-0.63	0.18-0.20	2.5	5.6-6.5	Easily weathered sandstone
	clay loams, 30 to 50			13-30	CH	50-60	30-40	0.06-0.20	0.15-0.17	2.7	6.1-7.3	
	percent slopes, eroded			30						5.2		
MmG2	Millsholm loam	D	high to very high	0-17	SM or ML	15-25	0-15	0.63-2.00	0.16-0.18	2.9	6.1-7.3	Easily weathered sandstone
	30 to 75 percent			17								
	slopes, eroded											
RoA	Rincon clay loam,	C	slight	0-60	CL	25-40	10-30	0.06-0.20	0.15-0.17	9.6	6.1-7.8	Older alluvium
	0 to 2 percent slopes											
RoC	Rincon clay loam,	C	slight	0-60	CL	25-40	10-30	0.06-0.20	0.15-0.17	9.6	6.1-7.8	Older alluvium
	2 to 9 percent slopes											
RnC	Rincon loam,	C	slight	0-60	CL	25-40	10-30	0.06-0.20	0.15-0.17	9.6	6.1-7.8	Older alluvium
	2 to 9 percent slopes											
SeB	San Ysidro sandy loam,	D	slight to moderate	0-14	SM or ML	10-20	0-15	2.00-6.30	0.13-0.15	2.0	5.6-6.5	Older alluvium
	0 to 2 percent slopes			14-68	CL or ML	30-45	15-30	<0.06	0.03-0.05	2.2	6.1-8.4	
Ys	Yolo silty clay loam	B	slight	0-36	CL	35-50	25-35	0.2-0.63	0.19-0.21	7.2	6.1-8.4	Mixed alluvium derived

Notes:
Information taken from the most-recent USDA soil survey for the area.
This soil survey generally does not distinguish areas smaller than about 20 to 40 acres, so that wetlands, alluvium, or swale fills smaller than 10 to 20 will not be mapped.
USCS = Unified Soils Classification System, commonly used in geotechnical or soil-foundation investigations, and in routine engineering geologic logging
Available water capacity is the held water available for use by most plants, usually defined as the difference between the amount of soil water at field capacity (one day of drainage after a rain or recharge event) and the amount at the wilting point.

Table 2. Expanded legend for HMP channel classification maps (Figures 2 and 3).

Channel Designation (from Figure 2 and 3 legend)	**Segment Description**	**Permit Classification**	**HMP applies?**
Urban channels not susceptible to significant hydromodification effects	These are typically large, reinforced earthen flood control channels, cement-lined channels, low gradient channels, or underground stormwater culverts. All channels of this type are heavily urbanized. No HMMs are required for projects flowing directly to this type of channel.	Lower Laurel/ Lower Ledgewood	Hydromodification management is not required for projects that drain directly to these channels
Urban channels susceptible to hydromodification effects	These natural- to semi-natural channels that flow through urban areas. Urbanization is typically light to moderate, although some sections may be effectively “built out”. Projects that divert stormwater to these channels (either directly or indirectly) may be subject to hydromodification control requirements.	Middle Laurel/ Middle Ledgewood	Hydromodification management measures apply for projects draining to these channels.
Non-urban channels susceptible to hydromodification effects	These are natural to semi-natural channel reaches not affected by significant urbanization. They occur mainly in two zones, the Suisun Valley agricultural area outside the jurisdiction of the City of Fairfield, and the Rancho Solano North Planning area.	Upper Laurel/ Mid-to upper Ledgewood	Hydromodification management measures apply for projects draining to these channels.
Stream channels in designated open space that are susceptible to hydromodification effects	These are predominately steep headwater tributaries with distinct channel form, delineated on aerial photographs. They are in areas classified as designated open space within the City of Fairfield. Due to the steep terrain and zoning classification, these watersheds are very unlikely to be developed.	Upper Laurel/ Upper Ledgewood	Urbanization of these watersheds is unlikely, however hydromodification management measures would apply if areas are developed

Table 3. Potential on-site design features and elements to control hydromodification.

Potential On-Site Design Features	
Site Design Feature	**To Be Implemented**
a. Conservation of natural areas. Use natural drainage systems.	1. Protect sensitive hydrologic features, sediment sources, and sensitive habitats.
b. Maximize canopy interception and water conservation.	2. Provide setbacks and buffers between development and sensitive ecological areas.
c. Maximize the permeable area. Minimize the use of impervious surfaces	3. Conserve natural areas and use natural drainage corridors and swales where possible.
d. Construct on-site ponding areas or retention facilities to increase opportunities for infiltration.	4. Cluster development; in less infiltratable soils if possible.
e. Where soils conditions are suitable, use perforated pipe or gravel filtration pits for low flow infiltration.	5. Reserve areas of high infiltration to maintain natural recharge volumes.
	6. Construct BMPs in areas to maximize opportunities for infiltration.
	7. Minimize the amount of impervious surfaces.

Potential On-Site Design Elements	
Design Elements	**To Be Implemented**
a. Construct walkways, trails, patios, driveways, and low traffic areas with open-jointed paving materials or permeable surface	1. Integrate water quality and flow control facility into the landscape.
b. Reduce widths of street where off-street parking is available. Construct streets, sidewalks and parking lot aisles to the minimum widths necessary.	2. Direct runoff from impervious surfaces to vegetated areas, such as swales and rain gardens.
c. Where landscaping is proposed drain rooftops, impervious sidewalks, walkways, trails, and patios into adjacent landscaping.	3. Use vegetated swales in lieu of underground piping or lined ditches.
d. Increase the use of vegetated drainage swales in lieu of underground piping or imperviously lined swales.	4. Drain driveways, rooftops, sidewalks, walkways, trails, and patios into adjacent landscaping.
e. Use one or more of the following: Rural swale system, urban curb/swale system, dual drainage system	5. Construct walkways, trails, patios, driveways, and low traffic areas with open-jointed paving materials or permeable surface
f. Use one or more of the following features: design driveways with shared access, wheel strips (pave under tires); uncovered temporary, overflow and guest parking may be paved with a permeable surface	6. Construct streets, sidewalks and parking lot aisles to the minimum widths consistent with building codes.
	7. Use an urban curb and swale system design approach, where possible.

Table 4. Design considerations for hydromodification management measures. Table summarized from SCVURPPP C.3 handbook.

Control Measure	Reference		Design Objective	Application	Constraints	Cost
	SAS[1]	CA BMP[2]				
Flared driveways	66, 131		reduce impervious area	suitable for all slopes		reduced materials cost
Wheel-only driveway pads	65, 130		reduce impervious area	suitable for all slopes	Avoid curing driveways	reduced materials cost
Permeable pavement (unit pavers)	65-66, 129, 132		infiltration	temporary parking areas	use only for slopes <5%; avoid expansive soils	$9-15/ sq. foot to install; easy to repair
Gravel driveways	64, 128		infiltration; retention; slow runoff	light-use driveways	use only for slopes <5%	weed control and replenishment of aggregate
Dry well	67, 134	SD-11	infiltration, retention	>10 feet from building	not suitable for low-infiltration soils or slopes > 40%	relatively inexpensive
Cisterns/Rain barrels	67-68, 135	SD-11	retention, slow runoff	good for all soil types	must be designed to be vector-proof	reduce costs of irrigation; regular maintenance
Pop-up drainage emitters (lawn spreaders)	68, 137	SD-11	infiltration, slow runoff	roof runoff	must be 10' away from building	$12-$20 plus pipe
Infiltration trenches		TC-10	infiltration, slow runoff	low slope areas	avoid slopes >15%; need underdrains for low-infiltration soils	$5 per cu.ft. new; maintenance is 20% of construction cost
Vegetated swales	71; 139-141	TC-30	runoff reduction	along roadways	avoid slopes >6%	$0.50 per sq. ft.
Impervious area sloped to landscaping	64, 127		slow runoff	for small segments of impervious area	must avoid flow concentration on slopes >5%	same as conventional

[1] Start at the Source, BASMAA, 1999

[2] California BMP Handbook, CASQA, 2003

FIGURES

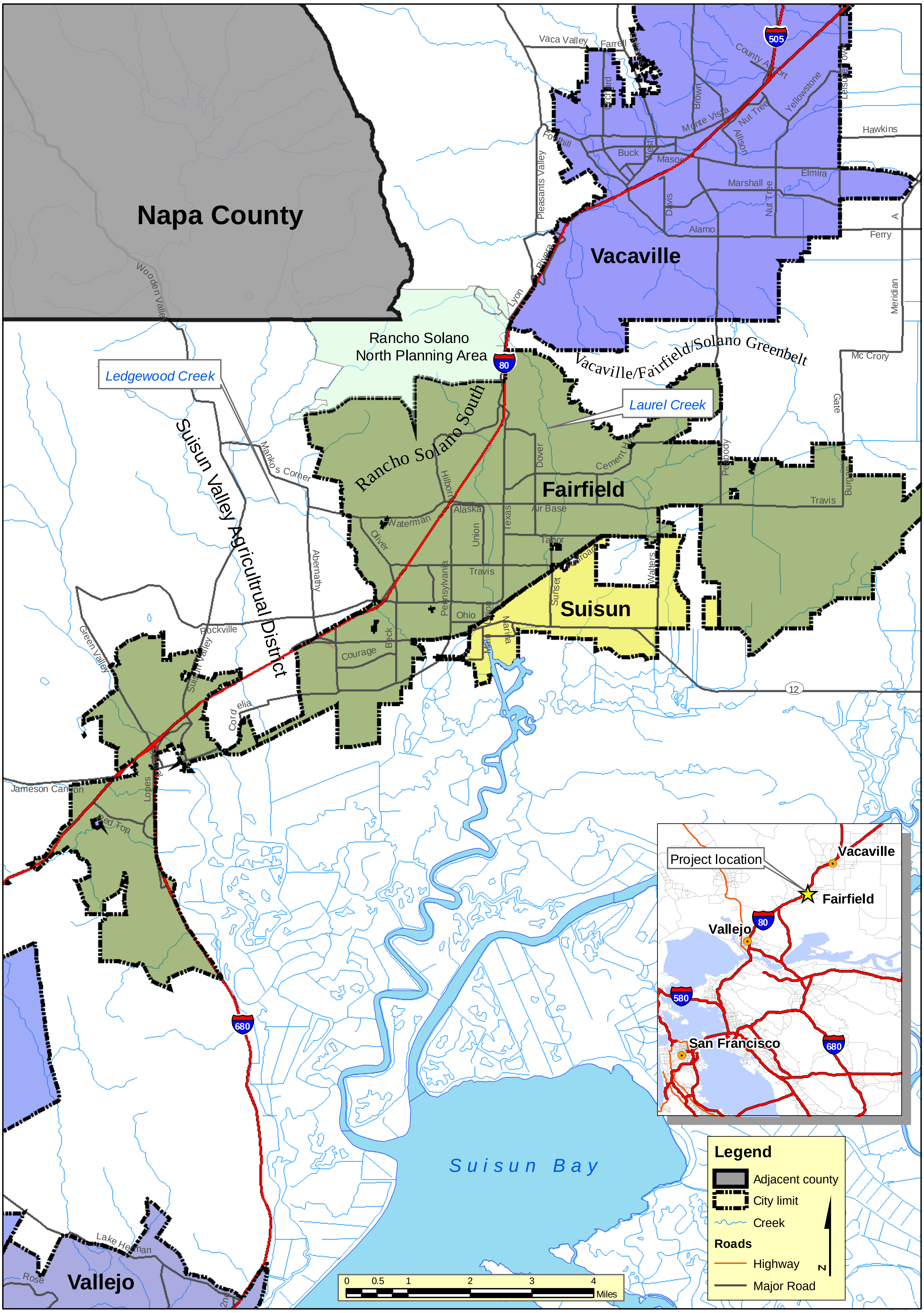

Figure 1. Map showing the Cities of Fairfield and Suisun and surrounding area. The Rancho Solano North Planning Area is the last remaining area of planned urban development under the current general plan.

Balance Hydrologics, Inc.

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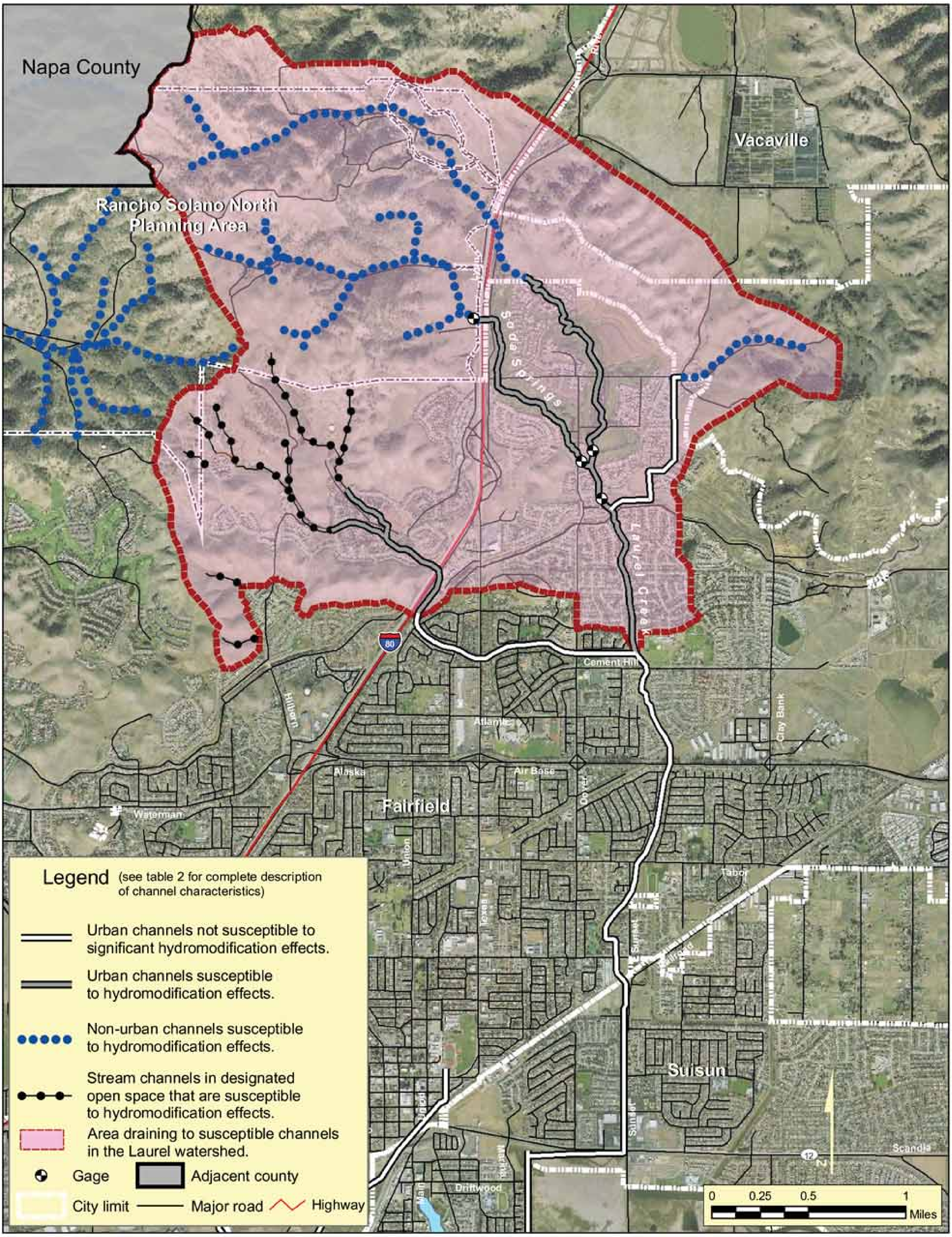
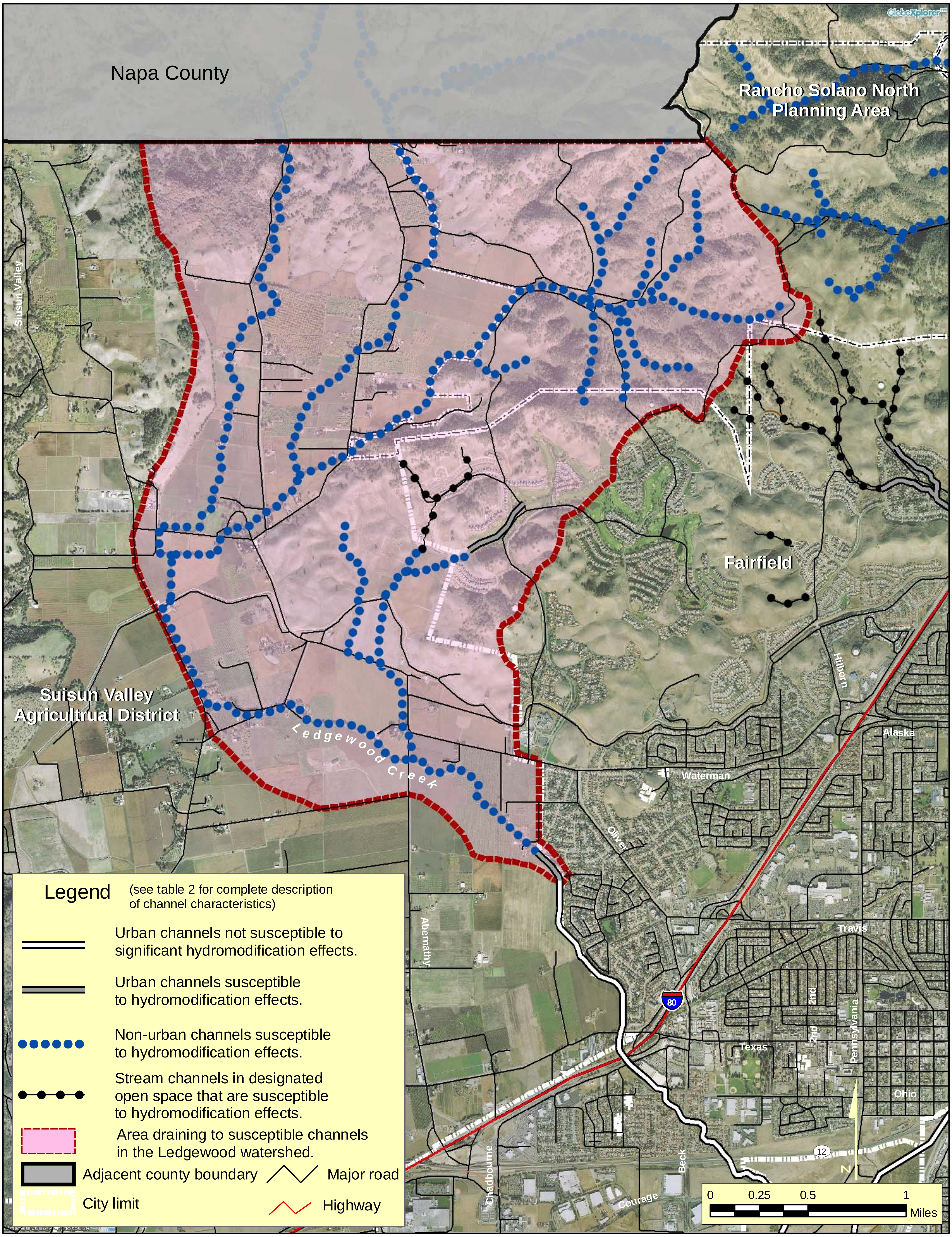


Source: Basemap data provided by Fairfield-Suisun Sewer District. Note that the roads layer does not include the most recently urbanized areas (north of Cement Hill Road, for example).

Balance Hydrologics, Inc.

Figure 2. Map showing HMP channel Classification for the Laurel Creek watershed. The mid- to upper reaches include all channels within the watershed that are susceptible to hydromodification effects (dotted and gray-shaded channels on this map). Hydromodification controls are not required for projects that drain directly to non-susceptible urban channels.



Basemap data provided by Fairfield-Suisun Sewer District. Note that the roads layer does not include the most recently urbanized areas, as shown in the aerial photo.

Balance Hydrologics, Inc.

Figure 3. Map showing HMP channel Classification for the Ledgewood Creek watershed. The mid- to upper reaches include all channels within the watershed that are susceptible to hydromodification effects (dotted and gray-shaded channels on this map), however areas outside the City of Fairfield are not included in this permit unless annexed by the city. The non-developed areas within the current city limits are designated open space in relatively steep terrain, and are unlikely to be converted to urban areas however the HMP still applies in these areas.

W:\Projects\204126 Fairfield HMP\204003\204126_Figure3_edits.mxd

Figure 4. **Photograph of upper Soda Springs, above Interstate 80.** Note the heavy vegetation stabilizing stream riffles, and the limited amount of erosion in the stream channel.

Figure 5. **Photograph of representative channel conditions in the lower portion of middle Laurel Creek.** Note the heavy vegetation and the knickpoint stabilized by thick root mats. Photo taken upstream of the engineered portion of the channel. The watershed above this point is moderately to heavily urbanized.

Balance Hydrologics, Inc.

Figure 6. **Photograph of Laurel Creek below Manuel Campos Road.** Note the dense vegetation along the stream banks and the lack of significant erosion. The watershed above the gage is moderately urbanized, approximately ten percent impervious.

Balance Hydrologics, Inc.

Figure 7. **Photograph of Soda Springs downstream of Interstate 80, within the Paradise Valley Golf Course.** The stream is well-vegetated with no signs of erosion, with only limited imperviousness upstream. Any response to future hydromodification, however, could severely affect the golf course grounds.

Balance Hydrologics, Inc.

Figure 8. **Photograph of lower Ledgewood Creek, above Interstate 80.** The channel is well vegetated, has a low slope, and several artificial grade control structures, reducing the potential for response to hydromodification.

Figure 9. **Photograph of upper Ledgewood Creek, above the Gordon Valley Creek Confluence.** Some localized, minor erosion is occurring in the stream, suggesting that the stream may be sensitive to further hydromodification.

APPENDICES

APPENDIX A

2007 amendment to the FSURMP NPDES Stormwater Permit

LB— KC✓ →File # UR-180.10.50

California Regional Water Quality Control Board

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Date: APR 25 2007
File No. 2129.2063 (JBO)

Certified Mail No. 7005 1820 0005 8828 4509

Mr. Larry Bahr
Fairfield-Suisun Urban Runoff Management Program Manager
1010 Chadbourne Road
Fairfield, CA 94534

SUBJECT: AMENDMENT TO MUNICIPAL STORMWATER PERMIT – MARCH 2007

Dear Mr. Bahr:

Enclosed is the signed original amendment to the Fairfield-Suisun Urban Runoff Management Program NPDES Permit, Order No. R2-2007-0026. We appreciate the Program's extensive efforts in completing the Hydromodification Management Plan and its cooperation in developing the enclosed Order. We hope to continue this cooperation as the hydromodification management requirements are implemented and as the Municipal Regional Permit is constructed.

If you have any questions, please contact Jolanta Uchman of my staff at 510.622.2432 or juchman@waterboards.ca.gov .

Sincerely,

Bruce H. Wolfe

Bruce H. Wolfe
Executive Officer

Enclosure: Adopted NPDES Permit Amendment, Order R2-2007-0026

RECEIVED
APR 26 2007
FAIRFIELD - SUISUN
SEWER DISTRICT

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD
SAN FRANCISCO BAY REGION

ORDER NO. R2-2007-0026
PERMIT NO. CAS612005

AMENDMENT REVISING ORDER NO. R2-2003-0034 FOR:

FOR THE FAIRFIELD-SUISUN SEWER DISTRICT AND THE CITIES OF FAIRFIELD AND SUISUN CITY WHICH HAVE JOINED TOGETHER TO FORM THE FAIRFIELD-SUISUN URBAN RUNOFF MANAGEMENT PROGRAM.

The California Regional Water Quality Control Board, San Francisco Bay Region, hereinafter referred to as the Board, finds that:

Findings

1. Incorporation of related documents: The Fact Sheet for this Order includes cited references and additional explanatory information in support of the requirements of this amendment. This information, including any supplements thereto, and any future response to comments on the Order, is incorporated herein by this reference.

Existing Orders

2. The Cities of Fairfield and Suisun and the Fairfield-Suisun Sewer District (hereinafter collectively referred to as the Permittees and individually as the Permittee) have joined together to form the Fairfield-Suisun Urban Runoff Management Program (hereinafter referred to as the Program).
3. On April 16, 2003, the Board re-issued waste discharge requirements (NPDES Permit No. CAS612005, Order No. R2-2003-0034, hereinafter Permit) under the National Pollutant Discharge Elimination System (NPDES) to the Program to discharge stormwater runoff from storm drains and watercourses within the Permittees' jurisdictions by complying with the Permit and implementing the Permit's associated Stormwater Management Plan.

Hydromodification Management Plan (HMP) Report

4. On December 15, 2005, the Program submitted its Draft Hydromodification Management Plan (HMP) as required under this Permit. An updated HMP[1] was submitted on April 13, 2006. The intent of the HMP is to reduce the hydromodification impacts from stormwater discharges from certain development projects within the Permittees' jurisdictions. This Order amends the Permit to approve key provisions of the HMP, which are incorporated into this Order.
5. The Program has developed design procedures, criteria, and sizing factors for infiltration basins and bioretention units. The Program's current design procedures, criteria, and sizing factors are

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[1] *Hydromodification Management Plan for the Fairfield-Suisun Urban Runoff Management Program*, prepared by Balance Hydrologics, Inc. and GeoSyntec Consultants, April 2006. Available at www.fssd.com .

available for public review.[2] They have undergone technical review by Board staff, which determined the procedures, criteria, and sizing factors are acceptable in all ways except one: they are based on an allowable low flow rate that exceeds the criteria established in this Order. The Program may chose to change its design criteria and sizing factors to the allowable criterion of 20% of the two year peak flow, and seek Executive Officer approval of the modified sizing factors. This criterion, which is greater than the criterion allowed for other Bay Area Stormwater Programs, is based on data collected from Laurel and Ledgewood Creeks and technical analyses of these site-specific data. Following approval by the Executive Officer and notification of the public through such mechanism as an email list-serve, project proponents may meet the HM Standard by using the FSURMP design procedures, criteria, and sizing factors for infiltration basins and/or bioretention units.

6. In the San Francisco Bay Area, the Western Washington Hydrology Model[3] is being adapted to local conditions, and the adapted model is called the Bay Area Hydrology Model (BAHM)[4]. Although the Program has not contributed towards adaptation of the BAHM to date, Permittees may use the BAHM if its inputs reflect actual conditions at the project site and surrounding area. As Permittees gain experience in designing and operating HM controls, the BAHM may be adjusted to improve its function in controlling excess runoff and managing hydromodification impacts. Notification of all such changes shall be given to the Board and the public through such mechanism as an email list-serve.

7. The Board recognizes that the collective knowledge of management of erosive flows and durations from new and redevelopment is evolving, and that the topics listed below are appropriate topics for further study. Such study may be initiated by Board staff, or the Executive Officer may request that all Bay Region municipal stormwater permittees jointly conduct investigations as appropriate. Any future proposed changes to the Permittees' HM provisions may reflect improved understanding of these issues:

   - potential incremental costs, and benefits to waterways, from controlling a range of flows up to the 35 or 50-year peak flow, versus controlling up to the 10-year peak flow, as required by this Order;
   - the allowable low-flow (also called Qcp[5] and currently specified as 20% of the pre-project 2-year runoff from the site) from hydromodification control units;
   - the effectiveness of "self-retaining areas" for management of post-project flows and durations; and/or

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[2] Current sizing factors and design criteria are shown in Appendix D of the FSURMP HMP: *Hydromodification Management Plan for the Fairfield-Suisun Urban Runoff Management Program*, prepared by Balance Hydrologics, Inc. and GeoSyntec Consultants, April 2006.

[3] The Western Washington Hydrology Model models runoff from development project sites, and is used for sizing flow duration control structures and determining overall compliance of such structures and other hydromodification control structures (HM controls) in controlling runoff from the project sites to manage hydromodification impacts. See http://www.ecy.wa.gov/programs/wq/stormwater/wwhm_training/wwhm/wwhm_v2/instructions_v2.html .

[4] See *The Bay Area Hydrology Model – A Tool for Analyzing Hydromodification Effects of Development Projects and Sizing Solutions,* Bicknell, J., D. Beyerlein, A. Feng, September 26, 2006. Available at http://www.scvurppp-w2k.com/permit_c3_docs/Bicknell-Beyerlein-Feng_CASQA_Paper_9-26-06.pdf

[5] Qcp is the allowable low flow discharge from a flow control structure on a project site. It is a means of apportioning the critical flow in a stream to individual projects that discharge to that stream, such that cumulative discharges do not exceed the critical flow in the stream.

- the appropriate basis for determining cost-based impracticability of treating stormwater runoff and controlling excess runoff flows and durations.

8. On July 12, 2006, the Board issued Order No. R2-2006-0050, amending the Contra Costa Clean Water Program's (CCCWP) NPDES Permit No. CAS0029912 to include requirements to control excess stormwater runoff flows and durations from new and redevelopment. The Order allowed the use of sizing charts to design flow duration control devices, and required CCCWP to conduct a specific monitoring program to verify the performance of these devices. Following the satisfactory conclusion of this monitoring program, or conclusion of other study(s) that demonstrate devices built according to the CCCWP specifications satisfactorily protect streams from excess erosive flows, the Board intends to allow the use of the CCCWP sizing charts, when tailored to local conditions, by other stormwater Programs and Permittees. Similarly, any other control strategies or criteria approved by the Board would be made available across the Region. This would be accomplished through Permit amendment or in another appropriate manner following appropriate public notification.

9. This Order allows for alternative compliance when on-site and regional HM controls and in-stream measures are not practicable. Alternative compliance includes contributing to or providing mitigation at other new or existing development projects that are not otherwise required to have HM controls. The Order provides flexibility in the type, location, and timing of the mitigation measure in Provision C.3.f.ix.d. The Board recognizes that handling mitigation funds may be difficult for some municipalities due to administrative and legal constraints. The Board intends to allow flexibility for project proponents and/or Permittees to develop new or retrofit stormwater treatment or HM control projects within a broad area and reasonable timeframe. Toward the end of the Permit term, the Board will review alternative projects and determine whether the impracticability criteria and options should be broadened or made narrower.

10. The Board strongly encourages land use planning agencies and developers to carefully consider, early in the development planning process, the potential impacts on water quality and beneficial uses of new development projects. The Board strongly discourages modifying watercourses to adapt to increased flows and durations of runoff, except in limited circumstances where avoidance or other natural alternatives are not feasible and where the watercourse is in a degraded condition. In these limited circumstances, project proponents should first demonstrate that hydromodification has been minimized to the extent practicable by minimizing increases in flows and durations of runoff from the site. Second, the project proponents should demonstrate that mitigation measures have been employed to the maximum extent practicable to mitigate hydromodification impacts. Following the hierarchy of avoidance, minimization, and mitigation of hydromodification impacts, project proponents should document that there will be no adverse effects to water quality or beneficial uses.

11. Certain control measures implemented or required by Permittees for urban runoff management may create a habitat for vectors (e.g., mosquitoes) if not properly designed or maintained. Close collaboration and cooperative effort among Permittees, local vector control agencies, Board staff, and the State Department of Health Services is necessary to minimize potential nuisances and public health impacts resulting from vector breeding.

12. The Board recognized in its "Policy on the Use of Constructed Wetlands for Urban Runoff Pollution Control" (Resolution No. 94-102) that urban runoff treatment wetlands that are

constructed and operated pursuant to that Resolution and are constructed outside of a creek or other receiving water, are stormwater treatment systems and, as such, are not waters of the State and United States subject to regulation pursuant to Sections 401 or 404 of the federal Clean Water Act. Board staff is working with the California Department of Fish and Game (CDFG) and U.S. Fish and Wildlife Service (USFWS) to identify how maintenance for stormwater controls required under orders such as this Order can be appropriately streamlined, given CDFG and USFWS requirements, and particularly those that address special status species. The Permittees are expected to work diligently and in good faith with the appropriate agencies to obtain any approvals necessary to complete maintenance activities for treatment controls. If the Permittees have done so, when necessary and where maintenance approvals are not granted by the agencies, the Permittees shall be considered by the Board to be in compliance with Provision C.3.e of the Permit.

Applicable Federal, State, and Regional Regulations

13. Pursuant to 40 CFR Sections 124.5(c)(2) and 122.62, only those conditions to be modified by this amendment shall be reopened with this amendment. All other aspects of the existing Permit shall remain in effect and are not subject to modification by this amendment.

14. Provisions C.11 and C.12 of the Permit anticipate that the Permit may need to be modified from time to time to respond to new information, changed conditions, and to incorporate more effective approaches to pollutant control. Amending the Permit to require additional, more effective and stringent requirements is consistent with State and federal law for permit modifications.

15. Under Section 13389 of the California Water Code, this action to modify an NPDES permit is exempt from the provisions of Chapter 3 of CEQA.

Notification to Permittees and Interested Parties

16. The Permittees and interested agencies and persons have been notified of the Board's intent to modify waste discharge requirements for the existing discharge and have been provided opportunities for public meetings and to submit their written views and recommendations.

IT IS HEREBY ORDERED that the Permittees, in order to meet the provisions contained in Division 7 of the California Water Code and regulations adopted hereunder and the provisions of the Clean Water Act as amended and regulations and guidelines adopted hereunder, shall comply with the following revisions:

Provision C.3.f. of Order No. 2003-0034 is hereby modified and amended as follows:

C.3.f. Limitation on Increase of Peak Stormwater Runoff Discharge Rates

i. No later than 90 days after adoption of this Order, the Permittees shall comply with the requirements set forth in this permit amendment.

ii. Hydromodification Management (HM) Standard

Stormwater discharges from applicable new development and redevelopment[6] projects shall not cause an increase in the erosion potential of the receiving stream over the pre-project (existing) condition. Increase in runoff flow and volume shall be managed so that post-project runoff shall not exceed estimated pre-project rates and durations, where such increased flow and/or volume is likely to cause increased potential for erosion of creek beds and banks, silt pollutant generation, or other adverse impacts to beneficial uses due to increased erosive force. Such management shall be through implementation of the hydromodification requirements of this Provision and in Attachment A below.

iii. HM Control Areas

Applicable projects (see Provision C.3.f.iv. below) shall be required to meet the HM Standard when such projects discharge into the upstream reaches of Laurel or Ledgewood Creeks, as delineated in Attachment A. Plans to restore a creek reach may re-introduce the applicability of HM requirements; in these instances, Permittees may add, but shall not delete, areas of applicability accordingly.

iv. Applicable Projects

A new development or redevelopment project in which the combined amounts of impervious surface created and replaced totals one acre or more shall be required to meet the HM Standard unless it falls into one of the exempt categories stated in Provision C.3.c. Permittees shall require project proponents of exempt categories a. – d. (below) to incorporate site design/landscape characteristics which maximize infiltration (where appropriate), provide retention or detention, slow runoff, and minimize impervious land coverage (i.e., use hydrologic source controls[7]) to the maximum extent practicable. For each of these categories, the definition, description, and/or limitations stated in Provision C.3.c., including any changes in future amendments/reissuances, shall apply.

a. Projects consisting of one single-family home that are not part of the larger common plan of development;
b. Sidewalks, bicycle lanes, trails, bridge accessories, guardrails, and landscape features associated with streets, roads, highways, or freeways under the Permittees' jurisdictions;
c. Transit village type of development;
d. A project within a "Redevelopment Project Area" that redevelops an existing brownfield site, or the portion of a project that creates housing units affordable to persons of low or moderate income.

v. Requirements for Applicable Redevelopment Projects

Redevelopment projects in HM Control Areas in which the combined amounts of impervious surface created and replaced totals one acre or more, and which are not exempt under Provision C.3.f.iv. above, shall be required to meet the following requirements:

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[6] Redevelopment is defined in Finding 37 of Order No. R2-2003-0034.

[7] Hydrologic source controls are design techniques that minimize and/or slow the rate of stormwater runoff from the site.

a. No Increase in Impervious Surface

A redevelopment project may be exempted from the HM standard if a comparison of the project design to the pre-project condition shows the project will not increase impervious area and also will not increase the efficiency of drainage collection and conveyance compared with the pre-project condition. The pre- and post-project comparison shall include all of the following:

1. Assessment of site opportunities and constraints to reduce imperviousness and retain or detain site drainage;
2. Description of proposed design features and surface treatments used to minimize imperviousness;
3. Inventory and accounting of existing and proposed impervious areas; and
4. A qualitative comparison of pre-project to post-project efficiency of drainage collection and conveyance that demonstrates that hydrologic source controls will be incorporated into the project to the maximum extent practicable.[8]

b. Increase in Impervious Surface

Where a redevelopment project results in an increase of impervious surface, the HM Standard shall apply to the entire redevelopment project.

vi. Types of HM Controls

Projects shall meet the HM Standard by use of on-site control measures, regional control measures, in-stream measures, or a combination thereof.

vii. On-site and Regional Control Design Criteria

a. *On-site HM controls* are flow duration control structures and hydrologic source control measures[9] that collectively result in the HM Standard being met at the point(s) where stormwater runoff discharges from the project site.

b. *Regional HM controls* are flow duration control structures that collect stormwater runoff discharge from multiple projects (each of which should incorporate hydrologic source control measures as well) and are designed such that the HM Standard is met for all the projects at the point where the regional HM control discharges.

c. *Range of flows to control*: Flow duration controls shall be designed such that post-project stormwater discharge rates and durations match pre-project discharge rates and durations from 20% of the pre-project 2-year peak flow[10] up to the pre-project 10-year peak flow.

d. *Goodness of fit criteria*: The post-project flow duration curve shall not deviate above the pre-project flow duration curve by more than 10% over more than 10% of the length of the curve corresponding to the range of flows to control.

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[8] In addition to reviewing the site plan to determine that opportunities for incorporating hydrologic source control measures are maximized, an appropriate way to make this demonstration is by demonstrating that the time of concentration is not decreased.

[9] Hydrologic source control measures are design techniques that minimize and/or slow the rate of stormwater runoff from the site.

[10] Where referred to in this Order, the 2-year peak flow is determined using a flood frequency analysis based on USGS Bulletin 17 B to obtain the flow peak statistically expected to occur at 2 year intervals. In this analysis, the entire record of hourly rainfall data (e.g., 35-50 years of data) is run through a continuous simulation model (footnote 11), the annual peak flows are identified, rank ordered, and the 2 year flow is generated.

e. *Allowable low flow rate*: Flow control structures may be designed to discharge stormwater at a very low rate that does not threaten to erode the receiving water body. This flow rate (also called "Qcp") shall be no greater than 20% of the pre-project 2-year peak flow.

f. *Standard HM modeling*: On-site and regional control measures designed using the Bay Area Hydrology Model (BAHM) and site-specific input data shall be considered to meet the HM Standard. Such use must be consistent with directions and options set forth in the most current BAHM User's Manual[11]. Permittees shall demonstrate to the satisfaction of the Executive Officer that any modifications of the BAHM made (per Finding 6) are consistent with the requirements of this Provision.

g. *Alternate HM modeling and design*: The project proponent may use a continuous simulation hydrologic computer model[12] to simulate pre-project and post-project runoff and to design HM controls. To use this method, the project proponent shall compare the pre-project and post-project model output for a rainfall record of at least 30 years, and shall show that all applicable performance criteria in C.3.f.vii. (a-e above) are met.

h. *Sizing Charts*: The Program developed design procedures, criteria, and sizing factors for infiltration basins and bioretention units, based on a low flow rate that exceeds the *allowable low flow rate*. After the Program has modified its sizing factors[13] to the allowable criteria, received approval of the modified sizing factors from the Executive Officer,[14] and informed the public through such mechanism as an email list-serve, project proponents may meet the HM Standard by using the Program's design procedures, criteria, and sizing factors for infiltration basins and/or bioretention units.

viii. In-Stream Measures Design Criteria

In-stream measures shall be an option only where a stream is already impacted by erosive flows and shows evidence of excessive sediment, erosion, deposition, or is a hardened channel.

In-stream measures involve modifying the receiving stream channel slope and geometry so that the stream can convey the new flow regime without increasing the potential for erosion and aggradation. In-stream measures are intended to improve channel stability and prevent erosion by reducing the erosive forces imposed on the channel boundary.

In-stream measures, or a combination of in-stream and on-site controls, shall be designed to achieve the HM Standard from the point where the project(s) discharge(s) to the stream to the mouth of the stream. Designing in-stream controls requires a hydrologic and geomorphic evaluation (including longitudinal profile) of the stream system downstream and upstream of the project. This entails computing creek flows at several locations

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[11] *The Bay Area Hydrology Model – A Tool for Analyzing Hydromodification Effects of Development Projects and Sizing Solutions,* Bicknell, J., D. Beyerlein, A. Feng, September 26, 2006.

[12] Such models include USEPA's Hydrograph Simulation Program—Fortran (HSPF), US Army Corps of Engineers hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS), and USEPA's Surface Water M- Model (SWMM).

[13] Current sizing factors and design criteria are shown in Appendix D of the FSURMP HMP.

[14] The modified sizing factors will not introduce a new concept, but rather make an existing compliance mechanism more stringent; therefore, Executive Officer approval is appropriate. See also Finding 5.

within a stream system and the work done on the stream channels before and after the project is built. A continuous hydrologic model is required as well as geometric and geomorphic data at each location. As with all in-stream activities, other regulatory permits/certifications are required and must be obtained by the project proponent.[15]

ix. Impracticability Provision

Where conditions (e.g., extreme space limitations) prevent a project from meeting the HM Standard for a reasonable cost, and where the project's runoff cannot be directed to a regional HM control within a reasonable timeframe, and where an in-stream measure is not practicable, the project shall use (1) site design for hydrologic source control, and (2) stormwater treatment measures that collectively minimize, slow, and detain[16] runoff to the maximum extent practicable. In addition, the project proponent shall provide for or contribute financially to an alternative HM project as set forth below:

a. *Reasonable cost*: To show that the HM Standard cannot be met at a reasonable cost, the project proponent must demonstrate that the total cost to comply with both the HM standard and the C.3.d. treatment requirement exceeds 2% of the project construction cost, excluding land costs. Costs of HM and treatment control measures shall not include land costs, soil disposal fees, hauling, contaminated soil testing, mitigation, disposal, or other normal site enhancement costs such as landscaping or grading that are required for other development purposes.

b. *Regional HM controls*: A regional HM control shall be considered available if there is a planned location for the regional HM control and if an appropriate funding mechanism for a regional HM control is in place by the time of project construction.

c. *In-stream measures practicability*: In-stream measures shall be considered practicable when an in-stream measure for the project's watershed is planned and an appropriate funding mechanism for an in-stream measure is in place by the time of project construction.

d. *Financial contribution to an alternative HM project*: The difference between 2% of the project construction costs and the cost of the treatment measures at the site (both costs as described in Provision C.3.f.ix.a.) shall be contributed to an alternative HM project, such as a stormwater treatment retrofit, HM retrofit, regional control measure, or in-stream measure. Preference shall be given to projects discharging, in this order, to the same tributary, main stem, watershed, then in the same municipality or county.

x. Record Keeping

Permittees shall collect and retain the following information for all projects subject to HM requirements:

a. Site plans identifying impervious areas, surface flow directions for the entire site, and location(s) of HM measures;

b. For projects using standard sizing charts, a summary of sizing calculations used;

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[15] In-stream control projects require a Stream Alteration Agreement from the State Department of Fish & Game, a Clean Water Act Section 404 permit from the US Army Corps of Engineers, and a Section 401 certification from the Water Board. Early discussion on the acceptability of an in-stream modification is necessary to avoid project delays or redesign.

[16] Stormwater treatment measures that detain runoff are generally those that filter runoff through soil or other media, and include bioretention units, bioswales, basins, planter boxes, tree wells, media, filters, and green roofs.

c. For projects using the BAHM, a listing of model inputs;
d. For projects using custom modeling, a summary of the modeling calculations with corresponding graph showing curve matching (existing, post-project, and post-project with HM controls curves);
e. For projects using the Impracticability Provision, a listing of all applicable costs and a brief description of the alternative HM project (name, location, date of start up, entity responsible for maintenance);
f. A listing, summary, and date of modifications made to the BAHM, including technical rationale.

I, Bruce H. Wolfe, Executive Officer, do hereby certify that the foregoing is a full, true, and correct copy of an order adopted by the California Regional Water Quality Control Board, San Francisco Bay Region, on March 14, 2007.

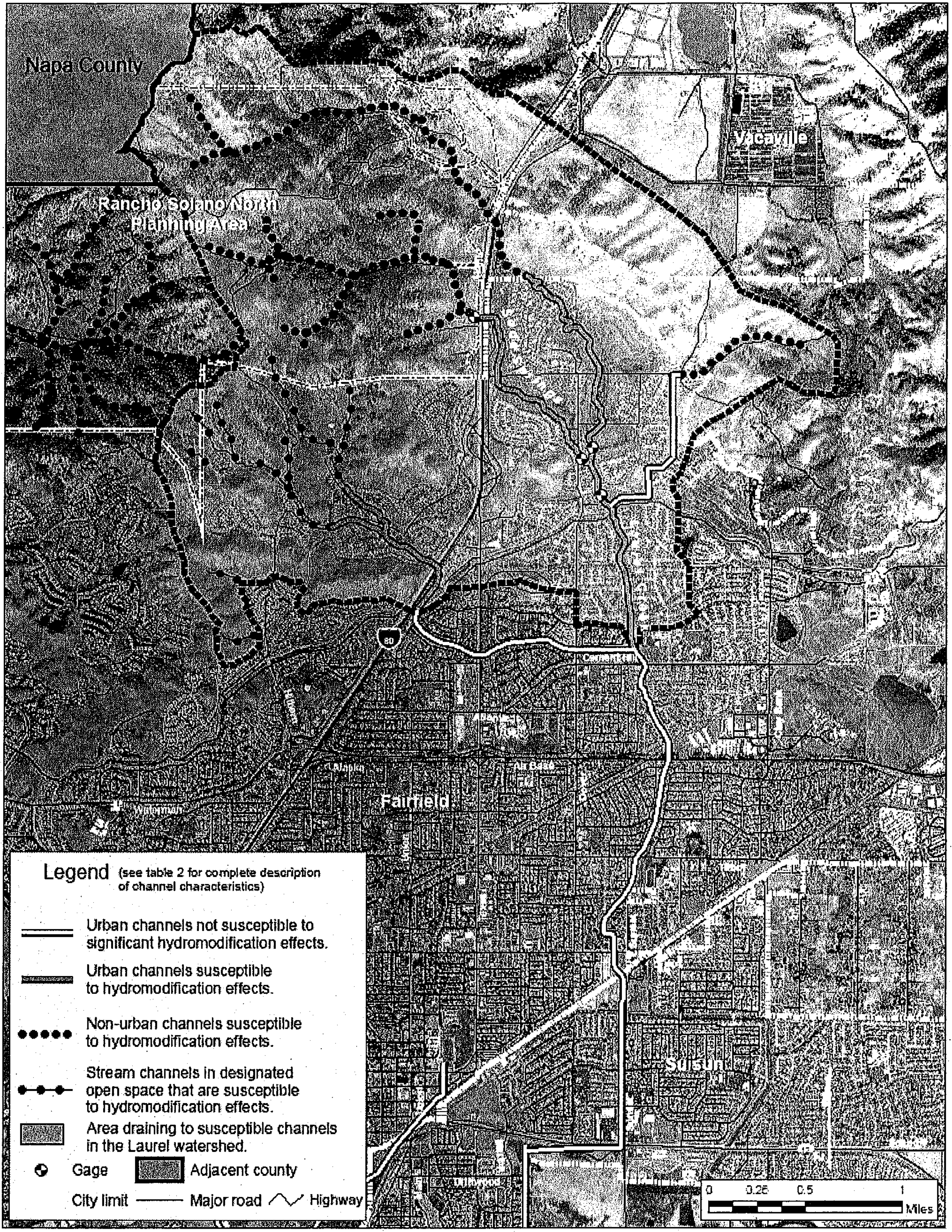
Bruce H. Wolfe

Bruce H. Wolfe
Executive Officer

Attachment A: Hydrograph Modification Management Standard – HM Control Areas

Attachment A:

Hydrograph Modification Management Standard – HM Control Areas



Source: Basemap data provided by Fairfield-Suisun Sewer District. Note that the roads layer does not include the most recently urbanized areas (north of Cement Hill Road, for example).

Balance Hydrologics, Inc.

Figure 2. Map showing HMP channel Classification for the Laurel Creek watershed. The mid- to upper reaches include all channels within the watershed that are susceptible to hydromodification effects (dotted and gray-shaded channels on this map). Hydromodification controls are not required for projects that drain directly to non-susceptible urban channels.

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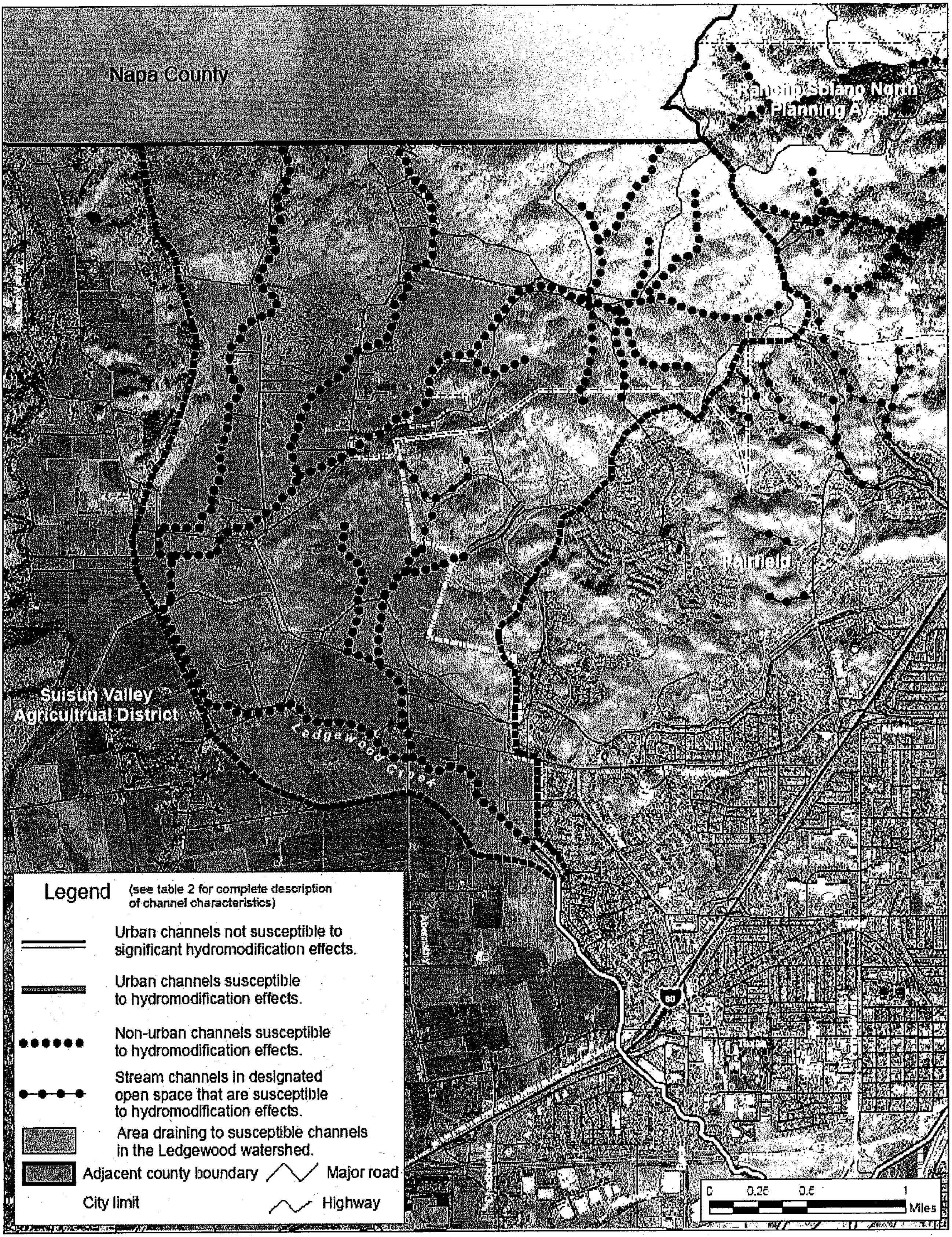

Basemap data provided by Fairfield-Suisun Sewer District. Note that the roads layer does not include the most recently urbanized areas, as shown in the aerial photo.

Balance Hydrologics, Inc.

Figure 3. Map showing HMP channel Classification for the Ledgewood Creek watershed. The mid- to upper reaches include all channels within the watershed that are susceptible to hydromodification effects (dotted and gray-shaded channels on this map), however areas outside the City of Fairfield are not included in this permit unless annexed by the city. The non-developed areas within the current city limits are designated open space in relatively steep terrain, and are unlikely to be converted to urban areas however the HMP still applies in these areas.

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APPENDIX B

Gaging Results
(Balance Hydrologics)

Appendix B. Streamflow and sediment transport monitoring in the Laurel Creek watershed

1. INTRODUCTION

As part of the hydrograph modification management plan (HMP) developed for the Fairfield Suisun Urban Runoff Management Program (FSURMP), Balance Hydrologics conducted a one-season flow and sediment transport study in the upper portion of the Laurel Creek watershed in northeastern Fairfield (Figure B-1). Balance installed stream gages at two different locations in the watershed, and also set up two additional sites to make spot sediment and flow measurements throughout the season. The data collected in this study are intended to assist in developing the HMP and to serve as a baseline in future studies, and also to be used to calibrate the continuous-flow model used for designing and sizing hydromodification management measures. This one-year reconnaissance-level study was particularly necessary due to the near-absence of flow and replicable sediment-transport data in this portion of Solano County.

2. METHODS

The methods and instruments used in this report are highly similar to those applied by state and federal agencies working throughout the Delta and Central California, and enable comparison with measurements made on other streams and in the local receiving waters of Suisun Bay.

2.1 Flow Monitoring

Each primary gaging site was equipped with a continuous recording datalogger, two pressure transducers, and one specific conductance/temperature probe[1]. The datalogger records water depth, specific conductance, and temperature at 15-minute intervals. At periodic intervals, the data was downloaded and compiled into a 15-minute record of stage.

A rating curve expresses the unique relationship between stream stage and discharge, measured at a gaging station. We used the rating curve method for computing a record of streamflow at each station (c.f., Rantz and others, 1982, and predecessor citations in that report). Balance staff conducted periodic station visits to measure streamflow and record staff plate readings. Based on these measurements, we created a stage-to-discharge relationship ('stage-discharge rating curve' or 'rating curve') for each station. The 15-minute stage record was then converted to a streamflow (or discharge) record using the rating curve. A rating-curve shift was applied adjusting for low-flow water-level changes from leaf accumulations or algal growth or to account for bed scour or sedimentation events which typically occur at higher flows. Table B-1 contains a record of stream-flow measurements and observations for all four stations.

2.2 Sediment Monitoring

We distinguish two types of sediment in transport, bedload and suspended sediment. Bedload includes sediment that rolls and saltates along the bed, commonly within the lowermost three inches of the water column. Movement can be either continuous or intermittent, but is generally much slower than the mean velocity of the stream. Bedload consists primarily of

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[1] Specific conductance (SC), a widely-used index of salinity, is the temperature-adjusted measurement of electrical conductance, expressed in micromhos per centimeter at 25 degrees Celsius. It is a worldwide standard used to identify relative changes in salinity between locations, over time or with flow, and can be applied to inferring changes in immediately sources of the water.

coarse sand and gravel, while suspended sediment is generally finer material that is supported by the turbulence of the water, and is transported at a rate approaching the mean velocity of flow. In Laurel Creek, suspended sediment consists primarily of clay and silt, with only a small percentage of fine sand. Total sediment discharge is the sum of bedload-sediment and suspended-sediment discharge.

Standard methods and equipment adopted by the Federal Interagency Sedimentation Program (FISP) were used to make measurements of sediment transport. Whole-sample filtration of nearly all suspended-sediment samples was employed. Table B-2 contains a record of observations and measurements of sediment discharge.

2.3 Additional observations

During the periodic site visits, additional observations were made at each station to provide supporting data to the HMP and flow/sediment study. These observations included channel condition of the bed and banks (erosion, sedimentation, in-channel debris, etc.), high-water marks, and vegetation changes, among others. These observations were used to help interpret the continuous flow record, and cumulatively to assess potential impacts from upstream urbanization. These observations are recorded in Table B-1.

3. STATION DESCRIPTIONS

Four sediment monitoring stations were established in the Laurel Creek watershed, two of which were stations equipped with continuous-recording dataloggers to measure and record stage. These stations were distributed within the watershed so they incorporated a broad range of conditions.

3.1 Soda Springs above Interstate 80

The upstream-most gage was located on the Soda Springs tributary, just upstream of Interstate 80 and is designated herein as 'SS80'. This location corresponds to the break between the "upper" and "middle" reach, as defined in the HMP (see section 3.1.1). The watershed above the station is primarily open rangeland with no impervious area[2].

The station was established on the left bank[3] of the stream just upstream of the I-80 culvert. Two staff plates were installed at the site, one mounted at the side of the culvert entrance (to calibrate high flows), and one in the gage pool next to the pressure transducers (to calibrate low flows). The gage pool was stabilized immediately downstream by a large tree root, and a few feet further downstream by the entrance to the culvert.

3.2 Laurel Creek below Manuel Campos Road

The lower gage was located just downstream of Manuel Campos Road, upstream of the Putah South Canal ('LCMC'). This site is approximately 5,000 feet upstream of the lower end of the "middle reach". The watershed above the gage consists of moderate-density urban housing, a golf course, and open-space, with an estimated impervious area of approximately ten percent.

The gage was installed on left bank of the stream, about 200 feet downstream of Manuel Campos Road. The downstream end of the pool was stabilized by a thick mat of aquatic vegetation roots.

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[2] While there is no completely impervious surface within the upper portion of Soda Springs, there are some non-paved farm roads, and the land has been used for grazing in the past. Both of these factors have most likely significantly changed the runoff characteristics from the natural condition. However, the channel appears to be predominately stable and has probably already adjusted to these altered conditions.

[3] Geomorphologists use the term 'left bank' to refer to the left side of the stream as you face *downstream*.

3.3 Supplementary stations

The two supplementary stations were located near the Paradise Valley Golf Club, on Soda Springs and Laurel Creek just upstream of their confluence ('SSGC' and 'LCGC'). These stations were used to compare the relative amount of sediment being transported in each stream. Both sites drain areas of moderate- to low-density urbanization. No instrumentation was installed at the two supplementary sites, as they were used only for periodic sediment measurements.

The SSGC station is located approximately 100 feet downstream of the entrance bridge to the Golf Course parking lot. This station is far enough downstream to include the drainage from several recent residential developments within the watershed.

The LCGC station is located beneath the golf cart bridge that leads from the Golf Club to the driving range. This station provides easy access for flow and sediment monitoring, however it is downstream of the inlet to driving range detention basin and upstream of the basin outlet. At very high flow events, sampling would need to occur upstream or downstream of the basin. In 2005, the stream never topped the detention basin inlet structure and therefore no adjustments to the station location were made.

4. RESULTS

4.1 Discharge records

4.1.1 Soda Springs above I-80

Figure B-2 shows the 15-minute streamflow hydrograph for station SS80. The peak flow of the season (70 cfs) occurred on March 22, 2005. The stream only flowed during one early season storm event, on the second day of a two-day storm in early December. Significant baseflow was not recorded at the SS80 gage until late December, 2004, after the seasonal rainfall total reached approximately 6 inches within the watershed. The peak flow at the upper gage can be quite prominent, but the stream typically drops to baseflow level (or zero flow early in the season) rather quickly.

4.1.2 Laurel Creek below Manuel Campos Road

Figure B-3 shows the 15-minute streamflow hydrograph for LCMC. The stream supported high baseflow (on the order of one cubic foot per second) throughout the season, even early in the water year after the dry season. Similar magnitude of baseflow was observed during a reconnaissance survey in mid-August and is attributed primarily to golf course irrigation water and residential lawn watering upstream of the gage.

The peak flow of the season at the LCMC gage (270 cfs) was recorded on March 22, 2005. Several other prominent peaks occurred in response to early season storms. These high early-season peaks seem to be a response to high rainfall intensity events rather than a high volume rainfall storm. Because the time of concentration of the lower watershed is relatively low (due to the amount of impervious surface in the watershed) these small, but high-intensity early-season storms can create significant peak runoff even though there is no contribution from the upper watershed.

4.1.3 Gage Comparison

Comparison of the two gaging records highlights the significant effects that urbanization can have on a watershed. Figure B-4 compares the unit discharge (flow per square mile) of the two gages. Several key differences between the two gaging records can be seen when making this comparison. Most notably is the complete lack of streamflow response to most of the early season storms at the SS80 gage, when the LCMC gage experienced several of the highest flows of the season.

The second difference is that in the late season, peak flow per square mile at the SS80 gage is actually higher than the peak at LCMC, despite the difference in urban area within the watershed. The LCMC gage, however, is higher for a longer period of time. For example during the February 18 storm, the SS80 peak per square mile was twice that of LCMC, however LCMC flowed above five cfs per square mile for three additional hours.

The final difference is in the response to storms after wet or dry periods. When the watershed is saturated, peak flow per square mile at SS80 is similar to that at LCMC. However, after long periods peaks are much more muted at SS80. Figure B-5 is an alternative look at how wet and dry periods affect the relative peaks at the two gages. The graph shows that peak flow at upper Soda Springs (SS80) tends to be between 20 and 50 percent of the flow in Laurel Creek below the confluence (LCMC) if that peak follows within about six days of another storm. Storm peaks at upper Soda Springs after prolonged dry spells (greater than about ten days) are less than 20 percent of flows below the Laurel confluence. This difference is a direct reflection of the water absorption capacity of the soils in upper Soda Springs relative to the impervious surface within upstream of LCMC.

4.2 Sediment records

4.2.1 Suspended Sediment

Suspended-sediment rating curves developed for the four sites show that sediment transport at a given flow varies little between sites, outside the sampling variation for each site (Figure B-6). With only one season’s worth of data, it is difficult to make more than preliminary findings; however with the available data some preliminary hypotheses can be made.

- Soda Springs above Interstate 80 (SS80) appears to carry a higher concentration of sediment for a given flow than the other three stations; however this may be a sampling bias as SS80 was the only gage that was sampled during a first flush event[4].

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[4] The first flush event is the first storm the season that creates significant runoff. Typically first flush events carry higher sediment loads, because sediment accumulates in and near the channel during the dry season. The first round

- Suspended-sediment measurements taken at the SSGC site seem to suggest a flatter sediment rating curve than the other sites, however this difference is likely an effect of the small number of sample points, the variation in sediment load coming from the storm drain just upstream, transient one-year effects, or a combination of all three. Nearly all such sediment rating curves in the region are steeper than the data at this gage would suggest.

4.2.2 Bedload sediment

No movement of bedload sediment was recorded during sediment sampling runs at any of the sediment monitoring sites. This is likely due to the combination of two different factors. First, there is little coarse sediment available to be transported along the bed. The stream bed and banks are composed of relatively fine material without significant larger particles. Second, average stream velocity, even at the highest flows measured, was very low and did not exert enough shear stress to maintain transport of larger particles.

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of sediment sampling, during the December 8 storm, caught the first flush in at the SS80 gage, but all three other sites had been "flushed" by previous storms.

5. FUTURE MONITORING

The City of Fairfield (or another interested party) may wish to continue the gaging program established in 2005 in subsequent years. Continuation of this program would serve three purposes:

- Monitoring at the four stations would expand on the data collected in water year 2005 to solidify results,
- Monitoring at LCMC (with supplementary data from LCGC and SSGC) would provide consistent record of streamflow and sediment downstream of the newly constructed urban areas within the Paradise Valley project, to monitor any potential stream channel response to recent hydromodification.
- Continued monitoring would provide the only sediment-transport and directly-measured sediment yield data for the typical channels of central Solano County – one of the most rapidly growing areas in California.

Stream gage staff plates and monumentation have been left in place (though dataloggers were removed) to facilitate the reoccupation of the gaging sites at LCMC and SS80. The SS80 station was re-occupied in February 2008 as part of the Laurel/Ledgewood watershed management plan assessment work, funded through the CALFED watershed program. Flow and sediment gaging at that station (along with new stations on lower Laurel Creek and middle Ledgewood Creek) is anticipated to continue until at least the end of water year 2010.

6. LIMITATIONS

This report was prepared in general accordance with the accepted standard of practice existing in Northern California at the time the investigations were performed. Analyses and conclusions in this report are based on a portion of one season of record. As is customary with new gages, results should be considered preliminary and subject to revision if, and as, we learn that conditions at this site so require.

Balance Hydrologics has prepared this report for the City of Fairfield and the Fairfield-Suisun Urban Runoff Management Program for use on this particular project. Use of these data by others and for other purposes without the review of Balance Hydrologics, Inc. may lead to significant error and/or environmental damage. Readers are asked to contact us if they have additional relevant information, see possible errors, or have questions concerning this work.

7. REFERENCES

Rantz, S.E., and others, 1982, Measurement and computation of streamflow, volumes 1 and 2: U.S. Geological Survey Water-Supply Paper 2175, 63p.

TABLES

Table B-1. Stream observer log for the Laurel Creek watershed, Fairfield, California, water year 2005

Site Conditions				*Streamflow*				*Water Quality Observations*				*High-Water Marks*		*Remarks*
Date/Time *(mm/dd/yr)*	Observer(s)	Stage *(feet)*	Hydrograph *(R/F/S/B)*	Measured Discharge *(cfs)*	Estimated Discharge *(cfs)*	Instrument Used *(AA/PY)*	Estimated Accuracy *(e/g/f/p)*	Water Temperature *(°C)*	Specific Conductance at field temp. *(µmhos/cm)*	Specific Conductance at 25C *(at 25 °C)*	Additional sampling? *(Qbed, etc.)*	Estimated stage at staff plate *(feet)*	Inferred dates? *(mm/dd/yr)*	
Soda Springs above Interstate 80														
10/27/2004 11:30	sb	--	--	0	--	--	--	--	--	--	--	--	--	installed staff plates; bed still covered with leaves, no flow from early storms
11/10/2004 12:19	sb,he	-	-	0	-	-	-	-	-	-	-	-	-	installed datalogger; no flow in stream, no recent HWMs
12/8/2004 12:36	sp,he	0.88	F	0.66	-	F	f/p	10.6	1180	1620	Qss	-	-	very turbid, adjacent gully flowing, HWM ~4-6 inches above current level; no
12/10/2004 12:35	sp,he	0.87	F	--	--	--	--	--	--	--	--	--	--	
12/10/2004 12:53	sp,he	0.86	F	--	--	--	--	--	--	--	--	--	--	
12/10/2004 16:06	sp,he	0.84	F	--	--	--	--	--	--	--	--	--	--	
12/27/2004 10:10	sp, sb	--	--	0	--	--	--	--	--	--	--	--	--	no flow; no evidence of flow since 12/8
12/30/2005 9:00	gp,he	1.05	F	3.34	--	P	g	--	--	312	Qss	2.5	12/27/2004	tall staff plate reads 6.89; no bedload movement; water is turbid; a small amount of flow coming from ditch on LB
1/19/2005 11:00	sb	0.80	B	0.18	--	P	g	8.6	1022	1490	--	1.4	1/10/2005	baseflow observed for first time this season, stream bed has been stripped of grass and debris in places, exposing gravel/cobbles; stream bed grade controlled predominately by roots; some erosion has occurred in side channel since 12/27
2/11/2005 14:30	sb, sp	0.79	B	--	0.12	V	p	--	--	--	--	0.9	1/26/2005	not much change since 1/19 visit; water clear
2/15/2005 10:00	sb, gp	0.80	B	--	0.3	V	p	11.4	1266	1847	--	1.8	early Jan	puddles in side-channel but no flow; water mostly clear
3/25/2005 11:00	sb, jp	0.84	F	0.73	--	P	g/f	11.9	926	1232	--	7.7 (on upper gage)	--	multiple roots were in channel u/s of measurement, causing turbulence; water clear
3/27/2005 17:20	he, gg	0.84	R	0.51	--	P	f	14.9	1033	1271	Qss	2.84	3/22/2005	stage = 6.76 at culvert; LB gully not flowing
Soda Springs at Golf Club														
12/8/2004 14:35	sp,he	-	F	6.17	--	P	g	12.0	262	348	Qss	-	-	lots of vegetation along both sides; silty stream bottom; cut center channel; no bedload moving
12/27/2004 11:00	sb, sp	--	F	1.91	--	P	g	--	--	--	Qssx2	0.3', 2' above current	12/27, 12/8	stage fell 0.05' during flow measurement, took two Qss to bracket flow measurement
12/30/2004 11:27	gp,he	-	F	5.33	--	P	g	--	--	362	Qss	-	-	leaves were raked and piled on left bank
Laurel Creek at Golf Club														
12/8/2004 15:04	sp,he	--	U	5.94	-	P	g	11.4	211	284	Qss	8-12" above current wl	--	bottom is mucky with some sand and roots; no bedload movement
12/27/2004 11:50	sb, sp	--	S	1.42	--	P	g	--	--	--	Qss	--	--	cobbles on bed, no bedload moving
12/30/2004 12:00	gp,he	--	F	6.89	-	P	g	--	--	394	Qss	0.8' above current wl	12/30 early	water is milky brown with some floating foam

Site Conditions				Streamflow				Water Quality Observations				High-Water Marks		Remarks
Date/Time	Observer(s)	Stage	Hydrograph	Measured Discharge	Estimated Discharge	Instrument Used	Estimated Accuracy	Water Temperature	Specific Conductance at field temp.	Specific Conductance at 25C	Additional sampling?	Estimated stage at staff plate	Inferred dates?	
(mm/dd/yr)		*(feet)*	*(R/F/S/B)*	*(cfs)*	*(cfs)*	*(AA/PY)*	*(e/g/f/p)*	*(°C)*	*(µmhos/cm)*	*(at 25 °C)*	*(Qbed, etc.)*	*(feet)*	*(mm/dd/yr)*	
Laurel Creek below Manuel Campos Parkway														
10/27/2004 15:00	sb	4.70	B	--	--	--	--	--	--	--	--	6.0	10/26/2004	installed staff plate on LB; did not estimate flow
11/10/2004 9:42	sb,he	4.64	S	--	1	F	--	--	--	--	--	5.62,5.56, 5.2,9.3	early season, last night, last year	float test
12/8/2004 10:00	sp,he	6.41	F	--	50	V	--	--	--	--	--	--	--	staff plate nearly submerged
12/8/2004 11:15	sp,he	6.23	F	15.10	--	AA	f/g	10.9	192	262	Qss	6.9	12/8/2004	no bedload moving
12/27/2004 9:40	sb, sp	5.70					f	--	--	--	Qss	5.9	12/27/2004	flow dropping rapidly; bed is silty/organic, no bedload moving; stopped raining mid-way through flow measurement
12/27/2004 13:45	sb, sp	5.20		3.30	--	P	g	--	--	--	Qss	--	--	attempted bedload measurement, only got organic debris; flow in channel is choppier due to shallower depth
12/27/2004 15:30	sb, sp	6.67	F	27.50	--	P	g	--	--	--	Qss	--	--	sticks and cans floating down stream during measurement; highest measured flow of the season
12/30/2004 10:16	gp,he	6.37	F	19.10	--	P	g	--	--	343	Qss	7.9	12/30/2004	water is milky brown; no woody debris
1/19/2005 12:20	sb	4.86	B	1.30	--	P	f	10.9	765	1049	--	5.0, 6.66	1/15 baseflow drop, 1/10	possibly some bedload movement during last storm (some pockets of fresh sand); recent flows no higher than 12/27
2/11/2005 15:26	sb, sp	4.68	B	--	0.8	V	p	12.9	830	1078	--	--	--	
2/15/2005 11:50	sb, gp	5.29	F	5.41	--	P	f/p	12.1	277	267	Qss	none recent	--	new grass is not bent above current waterline, possibly sampled near peak; no flow in RB high-flow channel
3/25/2005 12:47	sb, jp	5.04	B	--	--	--	--	13.4	767	985	--	9.75	3/22 early AM	downstream grade control (roots) scoured in most recent storm, root-supported channel widened by 2 feet; evidence of some bedload movement during last storm (fresh deposits of pea gravel)
3/27/2005 18:15	he, gg	5.64	F	11.32	--	AA	f	14.9	691	856	Qss	9.13	3/22/2005	floating debris started coming down channel mid-way through measurement

Observer Key: (sp) = Stacey Porter, (sb) = Scott Brown, (he) = Hilary Ewing, (gp) = Gustavo Porras, (jp) = Jason Parke, (gg) = Greg Guench
Stage: Water level observed at outside staff plate
Hydrograph: Describes stage as rising (R), falling (F), steady (S), or baseflow (B)
High-water mark (HWM): Measured or estimated at location of the staff plate
Specific conductance: Measured in micromhos/cm in field; then adjusted to 25degC by equation
(1.8813774452 - [0.050433063928 * field temp] + [0.00058561144042 * field temp^2]) * Field specific conductance
Additional Sampling: Qbed = Bedload, Qss = Suspended sediment, Nutr = nutrients; other symbols as appropriate
Instrument key: (F) float test, (S) standard meter, (P) pygmy meter, (V) visual estimate

Table B-2. Sediment-discharge measurements: Laurel Creek watershed, water year 2005

Site Conditions						*Suspended sediment transport*			
Sample Date:Time	**Observer(s)**	**Gage Height**	**Streamflow Discharge**	**Streamflow Value Source**	**Stream Condition**	**Suspended-Sediment Concentration**	**Suspended-Sediment Discharge Rate**	**Turbidity**	**Particles Larger than 63 microns**
		(ft)	*(cfs)*	*M,R,E*	*R,F,B,U*	*(mg/l)*	*(tons/day)*	*(NTU)*	*(mg/l)*
Laurel Creek at Manuel Campos									
12/8/04 10:55	sb, he	6.29	18	R	F	57	2.69	--	<1
12/27/04 9:49	sb, sp	5.66	8	R	F	217	4.39	150.0	55.5
12/27/04 13:58	sb, sp	5.24	4	R	R	36	0.34	44.0	0.0
12/27/04 15:13	sb, sp	6.68	28	M	F	211	15.65	190.0	12.7
12/30/04 10:20	gp, he	6.36	21	R	F	171	9.69	230.0	7.7
2/15/05 12:05	sb, gp	5.24	3	R	F	49	0.45	67.0	3.4
3/27/05 18:05	he, gg	5.66	11	M	F	215	6.38	67.0	112.0
Laurel Creek at Golf Course Parking Lot									
12/8/04 14:57	sp, he	…	7.0	M	F	44	0.83	--	7.6
12/27/04 11:40	sb, sp	…	1.4	M	S	37	0.14	42.0	1.8
12/30/04 12:00	he, gp	…	7.3	M	F	203	4.00	330.0	1.7
Soda Springs at Golf Course Entrance									
12/8/04 14:32	sp, he	…	6.2	M	F	22	0.37	--	8.1
12/27/04 10:50	sb, sp	…	1.9	M	F	72	0.37	100.0	3.0
12/27/04 11:14	sb, sp	…	1.9	M	F	53	0.27	81.0	4.4
12/30/04 11:30	he, gp	…	5.3	M	F	41	0.59	120.0	0.0
Soda Springs above I-80									
12/8/04 12:27	sp, he	0.87	0.62	R	F	140	0.23	--	12.0
12/30/04 8:48	gp, he	1.07	3.7	M	F	145	1.45	240.0	1.8
3/27/05 15:55	he, gg	0.85	0.5	M	B	19	0.03	8.2	8.4

FIGURES

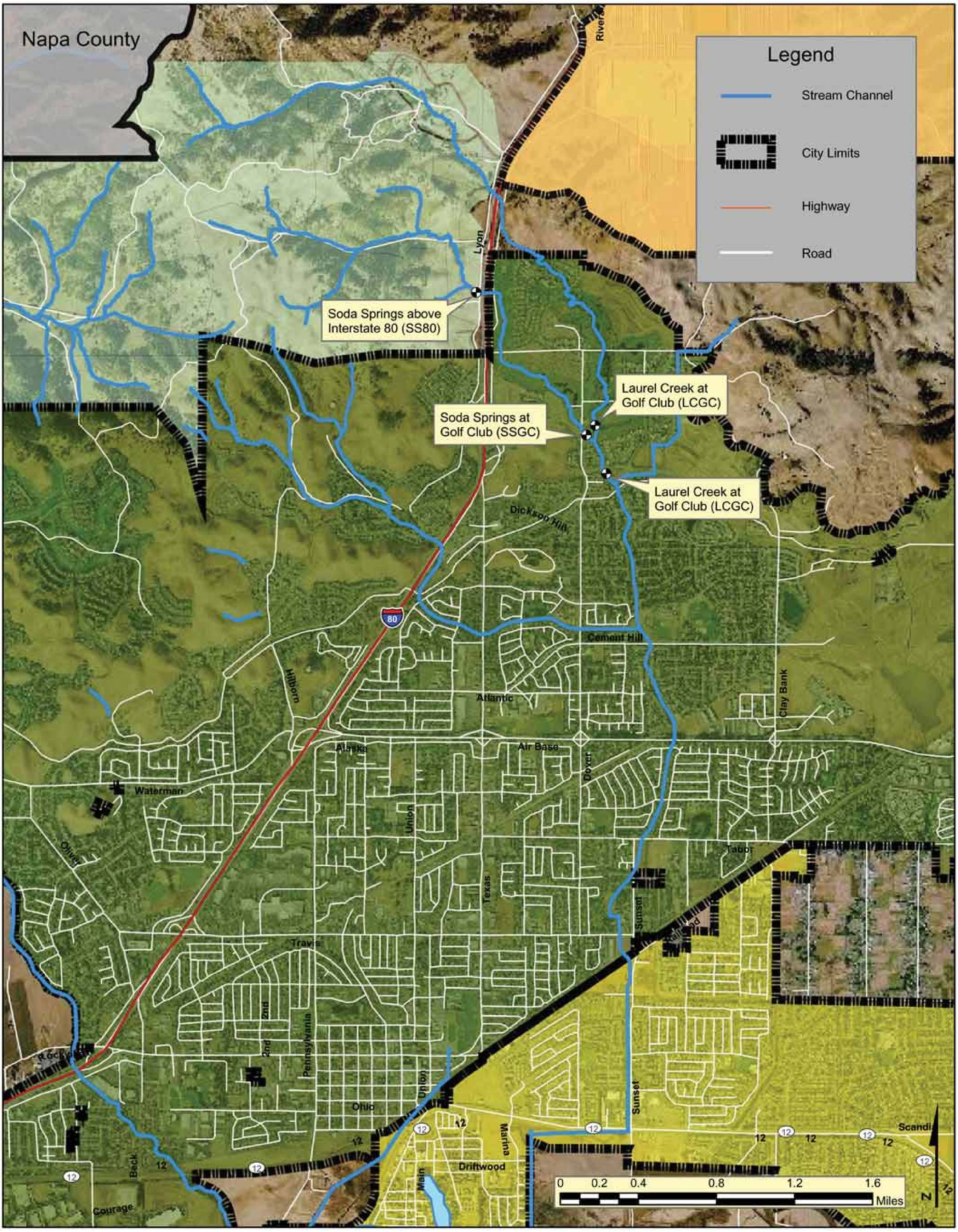

Figure B-1. Map showing location of gaging sites within the Laurel Creek watershed. Note that the road file does not include the most recently constructed roads in northern Fairfield.

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StreamGageMap.mxd

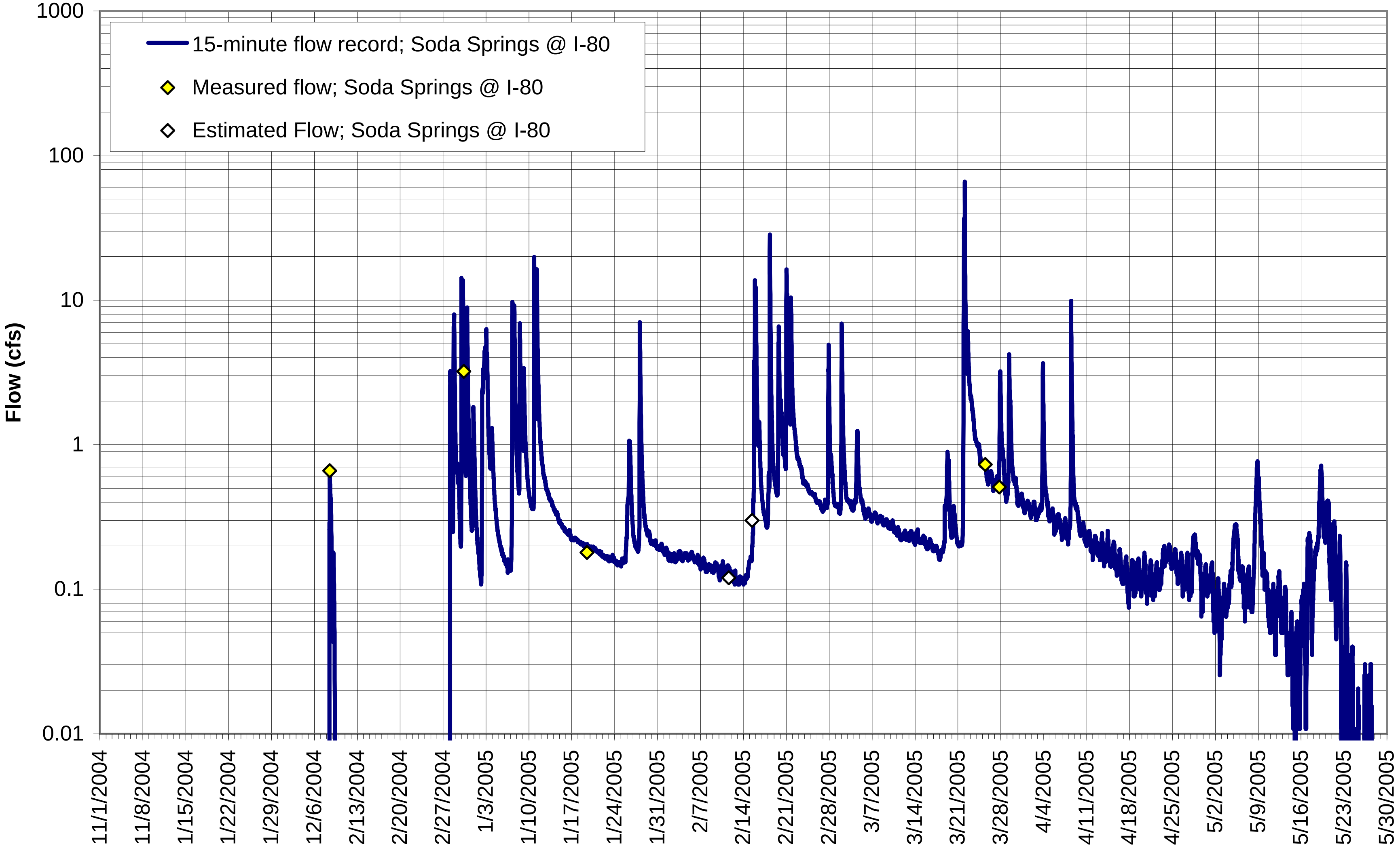

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Figure B-2. **15-minute discharge record for Soda Springs above Interstate 80.** Note that the stream responded to only one storm before late Demeber.

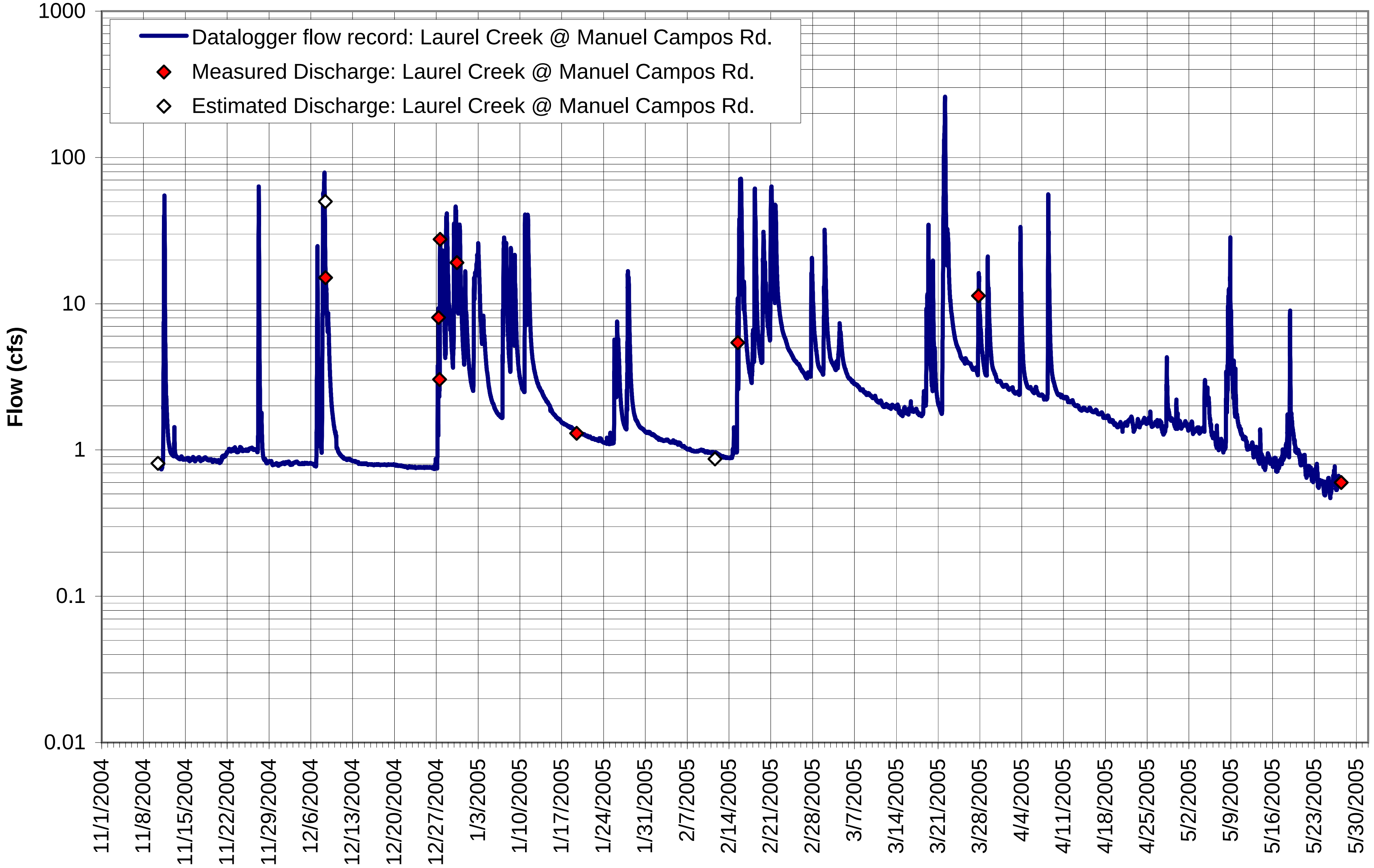

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Figure B-3. **15-minute discharge record for Laurel Creek below Manuel Campos Road.** Note that three of the highest peaks of the season occurred before late Demeber.

LCMC Q record (9-28-05).xls, Flow graph

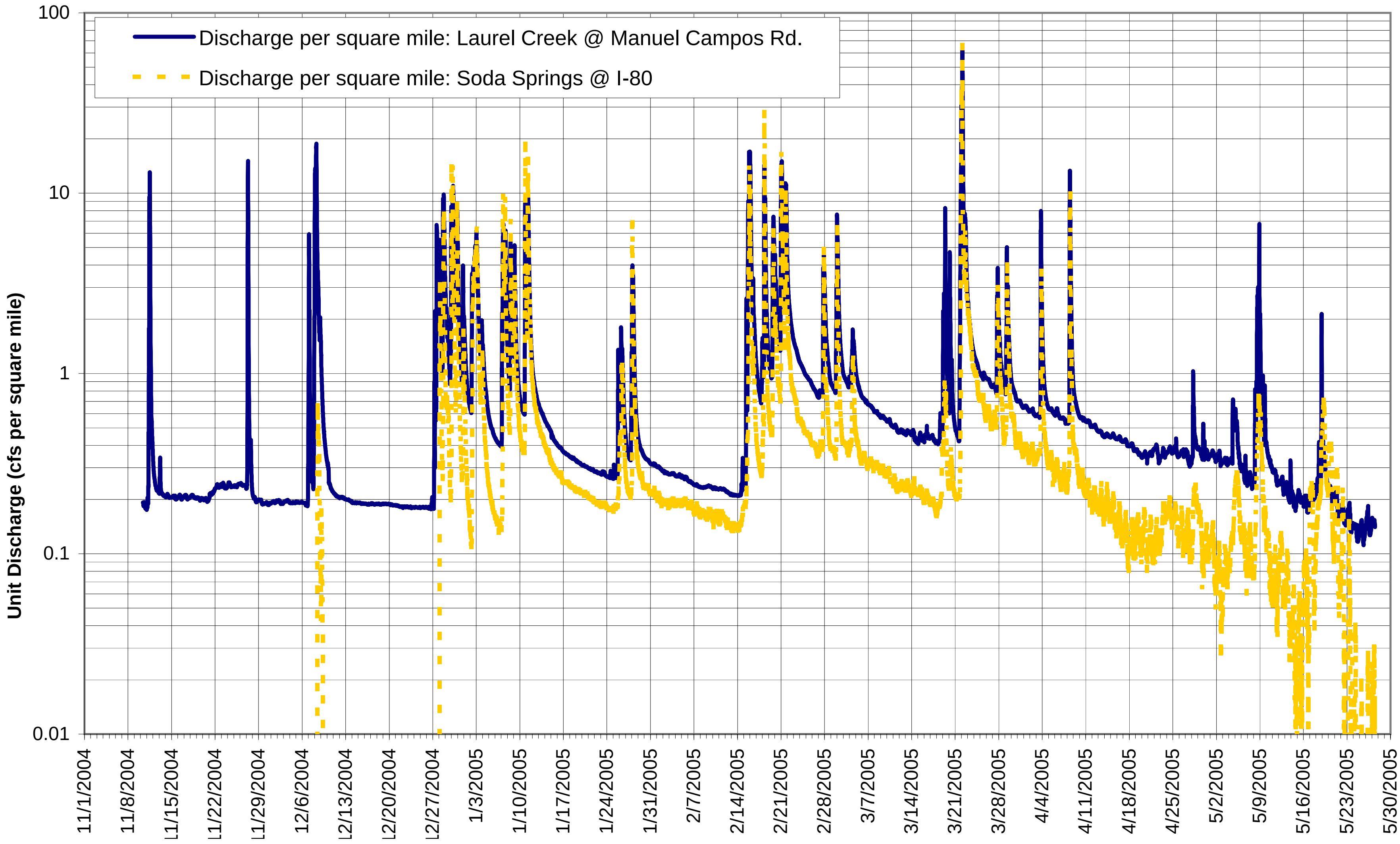

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Figure B-4. **Comparison of 15-minute unit discharge records for Laurel Creek below Manuel Campos and Soda Springs above I-80.** Note that Soda Springs has a much lower unit discharge following dry periods, but can have a higher peak unit discharge after back-to-back storms.

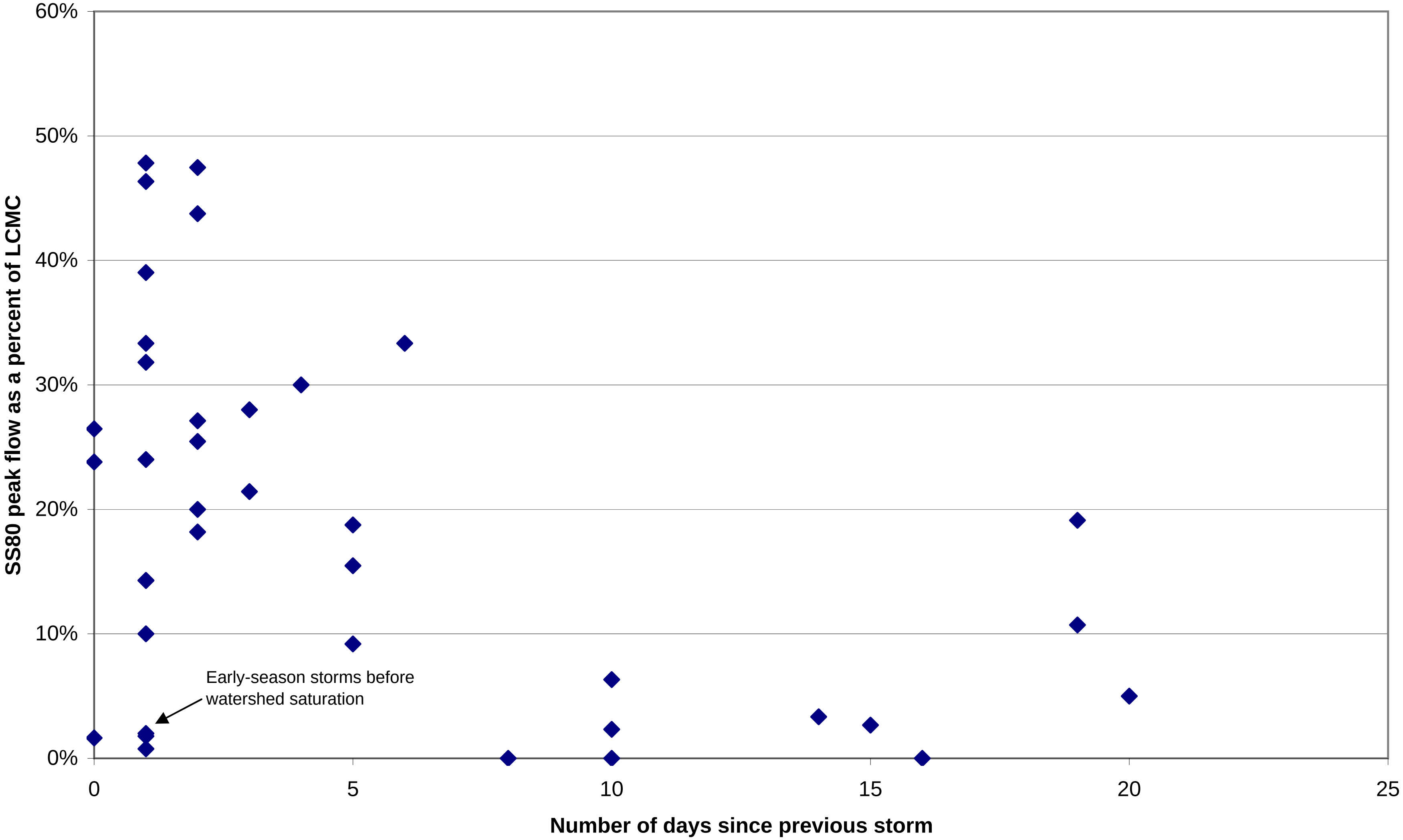

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Figure B-5. Comparison of peak flows at SS80 and LCMC relative to the number of days since the previous storm. When the length of time between storms exceeds approximately one week (after the initial wetting of the watershed) the peak flows at SS80 are much lower than at LCMC, presumably due to increased infiltration as the soils in the upper watershed dry.

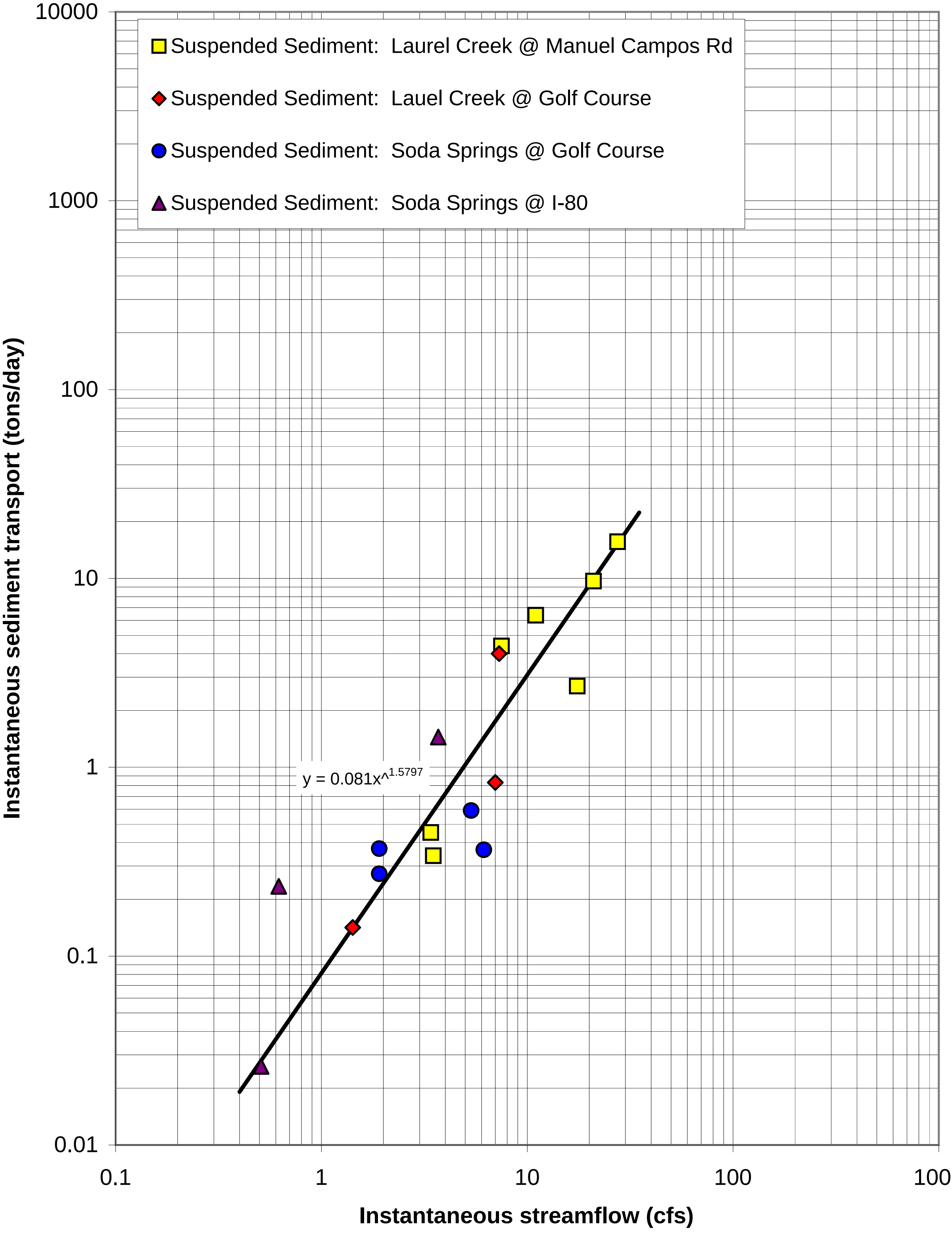

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Figure B-6. **Measurements of suspended sediment transport and estimated rating curve, Laurel Creek watershed, Fairfield, California.** A composit curve composed of samples from all four stations is shown on the graph.

APPENDIX C

Modeling Results
(Geosyntec Consultants)

Fairfield-Suisun Hydromodification Management Plan
Hydrologic Modeling & Impact Assessment

1 Background

1.1 Santa Clara Valley Urban Runoff Stormwater Program

The Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP) developed the first Hydromodification Management Plan (HMP) in the Bay Area. As part of developing the HMP, the SCVURPPP developed and tested a method for predicting channel instability as a function of watershed development. The method developed for SCVURPPP has been used to evaluate potential hydromodification impacts in the Soda Springs and Laurel Creek watershed, and to help develop the Fairfield-Suisun HMP.

The method predicts the likelihood for excessive channel erosion using an index representing the effective work done by flow energy in excess of the amount required to transport the available sediment load or scour stream banks. The predicted “potential for erosion” was compared to observed conditions in test watersheds and found to accurately predict the transition from stable and unstable channel conditions. A “threshold of adjustment” was defined using a probability method to distinguish between the likelihood of having stable or unstable conditions. The probability relationship was used to set management criteria and evaluate effectiveness of proposed management solutions.

The sections that follow briefly summarize topics that are discussed in great detail in the SCVURPPP management plan and supporting technical documents (SCVURPPP, 2005; SCVWD, 2004).

1.2 Hydrologic Processes

1.2.1 Modification to the Hydrologic Cycle

Hydrology plays a critical role in influencing the physical characteristics and ecological health of stream corridors. Stream flow magnitude, frequency, duration, and timing are major driving forces that control the physical and ecological conditions of a riparian corridor. As water flows downstream, it imposes drag forces on the boundary material due to its weight and velocity that scours, erodes and otherwise shapes the channel boundary. When there is a long-term change in runoff discharged to streams, channels adjust until the planform, slope, and cross sectional dimensions have readjusted to the new hydrologic regime. When large areas are rendered impervious, the area of infiltration is reduced, surface storage and interception may be reduced, and overland flow increases due to impervious surfaces (Hollis, 1975). Urbanization changes the natural relative proportions of overland flow, interflow, and groundwater flow to stream channels (Booth et al. 1997). As a result, the natural storage of water in the watershed is reduced and more erosive energy is available to perform work on the streambed and banks. Hollis (1975) concluded that the effect of urbanization is most dramatic for flows with a frequency of 1 to 2-years and smaller, where flows increased as much as 20 times. Booth (1990) reported that the frequency of sediment transporting flows increased by a factor of 10 or more (Booth, 1991; Booth et al. 1997). Bledsoe et al. (2001) found that at 18 percent imperviousness, the frequency of significant scouring events increases by 5 times.

Current management practices generally focus on flood control – i.e., peak flow. SCVURPPP concluded that hydromodification and stream channel stability must address duration and frequency of occurrence for a range of flows, especially sediment-transporting and erosive flows, and vegetation scouring flows. As a result, continuous hydrologic modeling and analysis is required to fully address hydromodification.

1.2.2 Long-Term Cumulative Effects

Current research is showing that design storm approaches are not adequate to address stream channel stability issues. A series of discrete events (2 through 100-year) is often used to predict the effects of development. However, this approach neglects changes in flows less than the 2-year event and the influence of such flows, which can be significant in many stream systems. The continuous hydrologic method incorporates the full probability distribution of rainfall events and uses flow duration as a basis for work and sediment load computations. This approach uniformly captures all the important geomorphically significant flows regardless of their magnitude and local stream conditions.

The key to the hydromodification methodology is the use of continuous simulation and the analysis of all erosive flows as opposed to selecting discrete events. Stream erosion, sediment transport, and work are all functions of the cumulative duration of erosive flows (SCVURPPP, 2005; SCVWD, 2004). Flow duration analysis is essentially an analysis of distributions as opposed to an analysis of single events. The distribution of rainfall is transformed into a distribution of runoff using a standard hydrologic model (e.g., HEC-HMS). The distribution of runoff is then analyzed for cumulative flow duration, total work or total sediment load transported. All sediment transporting and erosive flows are accounted for and used to evaluate the effectiveness of flow control and channel modifications.

1.2.3 Total Cumulative Percent Imperviousness Thresholds

Early hydromodification research focused on empirical evidence of channel failures in relationship to directly connected impervious area (DCIA) or total impervious area. Impervious area that drains directly to a storm drain system and then to the receiving water is considered “directly connected,” whereas impervious area that drains through vegetation or to infiltration facilities is considered “disconnected.”

Booth et al. (1997) reported finding a good correlation between loss of channel stability and increases in DCIA. In Washington State, streams display the onset of degradation when the DCIA increases to 10 percent. Even a lower imperviousness of 5 percent was found to cause significant degradation in sensitive watersheds (Booth 1997). The Center for Watershed Protection (Schuler and Holland, 2000) stated that “a threshold for urban stream stability exists at about 10 percent imperviousness." It further states that a "sharp threshold in habitat quality exists at approximately 10 to 15 percent imperviousness."

The Santa Clara Urban Runoff Pollution Prevention Program (SCVURPPP, 2005; SCVWD, 2004) evaluated the relationship between imperviousness and stream channel degradation in an area that had predominately directly connected impervious areas. SCVURPPP found similar results to those published by Booth and Schuler, where channel erosion was observed at approximately 6 to 9 percent imperviousness for two separate watersheds.

The Southern California Coastal Water Research Project found signs of hydromodification impacts in Southern California streams when watershed percent imperviousness was around 2 to 3 percent for streams with a catchment drainage area of less than 5 mi^2 (SCCWRP, April 2005). More recent studies conducted by GeoSyntec in the Santa Clara watersheds showed that levels as low as 2 to 3 percent total imperviousness could potentially lead to stream channel degradation.

The absolute measure of hydromodification however depends on many factors in addition to percent imperviousness; including watershed area and soil type; impervious area connectedness; longitudinal slope of the river; channel geometry and local boundary materials, such as bed and bank material properties, and vegetation characteristics. Percent TCIA provides an initial assessment on the sensitivity of Soda Springs and Laurel Creek.

Based upon the range of threshold levels a threshold for hydromodification impacts in California Mediterranean climates could be in the range of 2 to 10 percent TCIA in the contributing watershed.

1.3 Hydrologic Modeling Approach

The project team modeled creek flows under pre-urban, existing, and future land use conditions. The watershed models convert rainfall input sequences to estimated stream flow rates at various selected points throughout the project watersheds. The model rainfall input consists of continuous rainfall records, where actual measured rainfall from a nearby gage over a long period of time is input into the model. This method of modeling is referred to as "continuous simulation."

Within continuous simulations, the model incorporates information about the watershed characteristics (topography, soils, vegetation, land use, urbanization, etc.) to estimate how much rainfall is held in the watershed ("losses", including infiltration to the soil, trapping on vegetation or shallow depressions, etc.), and how much precipitation results in surface runoff, eventually reaching stream channels.

The project team chose to model the Laurel Creek watershed using the U.S. Army Corps of Engineers' Hydrologic Engineering Center - Hydrologic Modeling System (HEC-HMS) rainfall-runoff model. The U.S. Army Corps of Engineers developed HEC-HMS to supersede the HEC-1 Flood Hydrograph Package. Unlike HEC-1, HEC-HMS allows continuous hydrograph simulation over long periods of time in addition to event-based analysis.

Continuous modeling allows for continuous accounting of soil moisture and infiltration and other losses for an extended time period. Therefore, continuous modeling is preferable when trying to identify the hydromodification effects of development on small, frequent flows and to evaluate their impacts on stream stability.

1.4 Geomorphic Processes

1.4.1 Channel Stability

Stream channel size and form are established through a balance between the imposed flow energy, sediment type and supply, and the ability of the channel boundary to resist erosion, including the presence and density of riparian vegetation. A stable channel is loosely defined as one that neither aggrades nor degrades, but instead maintains its average cross-section, planform, and profile features over time and within a range of variance. When a stream channel migrates laterally, while maintaining its general shape, channel stability is said to be maintained. Channel instability occurs when excessive erosion leads to degradation or when excessive deposition leads to aggradation. Both aggradation and degradation are often accompanied by bank failures a change in channel dimensions; meander pattern, slope, and the floodplain can be abandoned.

A stable channel can tolerate excessive short-term disturbances without significant change; e.g., El Nino winters. However, a disturbance of sufficient magnitude and duration that exceeds the stream’s ability to self-regulate and causes the channel to begin changing is defined as the threshold of adjustment. The threshold of adjustment is used to identify the limit of long-term and persistent changed that can take place within a watershed before significant channel adjustment occurs. This limit was prescribed in the SCVURPPP hydromodification management plan and used to address potential impacts on Soda Springs and Laurel Creek.

1.4.2 Geomorphically Significant Flows

Researchers have shown that there is a specific range of flows that are important in defining channel form and controlling the rate at which sediment is transported through the stream system. Leopold et al. (1964) suggested that geomorphically significant flows range from a lower limit of competence where bed material begins to move in quantity to an upper limit established where flood flows are no longer contained in the channel. The frequency and duration of geomorphically significant flows are the primary factors that control stream channel stability, or instability, and must be considered in an assessment method. Urbanization significantly alters the frequency of occurrence and duration of geomorphically significant flows. MacRae (1993) et al. showed that urbanization increases the frequency of flows in the mid-bankfull to bankfull flow range. They suggest that the greatest increase in potential scour following urbanization is a result of increases in frequency and duration in this flow range. Bledsoe and Watson (2001) reported that the frequency of significant scouring events increased by factors of 2.5 to 5 for two watersheds with 18 percent impervious cover.

1.4.3 Dominant Physical Processes

The erodibility of stream banks is still one of the most difficult aspects in assessing stream channel destabilization. Channel erosion and adjustment can occur through a combination of several mechanisms, although one mechanism may be more or less prevalent than others depending on the stream system and local characteristics.

Generally, the following processes are observed in unstable stream systems in urbanizing watersheds:

- Channel incision and under-cutting of the bank toe due to shear erosion leading to gradual expansion of the channel bottom.
- Slumping from over-steepened banks or rapid drawdown during the falling limb of a flashy hydrograph.
- Loss of bank vegetation, reducing roughness and apparent bank strength.
- Water forced into the banks from obstructions such as boulders or large woody debris

Shear erosion is the primary mechanism of erosion and is the primary mechanism considered in the index assessment methodology. Channel incision and bank toe erosion initiates channel adjustment, although other mechanisms may be observed as ultimate failure. Channel incision and erosion at the toe increases the height of banks, oversteepens them, priming them for failure by slumping during larger flows. High flow events, rapid recession, and over saturation of soils can contribute to bank collapse.

The ability of a stream bank to resist erosion is dependent on many factors: soil materials, stratigraphy, vegetation density, root strength and apparent cohesion, the amount of clay or cementing of the matrix particles, bank height and slope. Stream channels bounded by clays, compacted silts and loess are often more resistant to erosion and respond more slowly to hydrologic changes than channels bound by loosely consolidated sands and gravels.

1.4.4 Effects of Vegetation

Vegetation influences channel processes and is influenced itself by these same processes. Stream channel destabilization is often attributed to a loss of vegetation, especially if the pre-urban balance was established with vegetation present. Dense vegetation adds roughness and slows flow velocity, reduces shear stresses on stream banks and adds soil cohesion through root structure. A study completed by the Missouri Department of Conservation and the Soil Conservation Service reported that dense woody vegetation along the Missouri River prevented banks from failing during floods of 1993 (Wallace 1994). Root strength of vegetation increases bank stability by holding sediment in place.

Channel geometry may be sensitive to the types of riparian vegetation. For example, characteristics of its rooting structure can have different effects upon resistant to bank erosion, such as lateral spreading roots of alders as opposed to taproots of willows. Different species have varying degrees of tolerance to disturbance such as bays versus oaks, where bays may fall into the channel but may still proliferate, but oaks will likely die. Different species also have different tolerances to having sediment deposited around them or to having their trunks inundated for longer periods of time, such as the difference between willows and alders. Some species can tolerate extended periods of drought or reductions in water table especially those with deep taproots.

1.5 Computational Methodology

The stability assessment is based on the premise that a balance among flow energy, sediment supply, and channel resilience must be maintained in order for the stream network to remain stable (MacRae, 1996). The hypothesis is that, over time, the stream channel slope and geometry co-evolved with vegetation, local physiography and climate to establish its pre-development dynamic equilibrium. By applying this method and establishing management criteria, the intent is to maintain the natural sediment transport and erosion processes, not to eliminate them.

1.5.1 Work Index and Erosion Potential

The direction of current research is to develop simplified methods, or indices that can be used to distinguish between eroding or non-eroding, or stable and unstable channel conditions (Booth, 1990; Bledsoe, 2001; MacRae, 1996 and SCVURPPP, 2004). Indices are attractive because they are simple to use and inexpensive to apply compared to sediment transport modeling. However, as with any simplified scheme, the level of physical representation of true conditions is reduced.

Booth (1990) investigated the effects of urbanization on stream channels in Washington State and suggested that unit stream power (Sp) may be a reasonable measure to distinguish between eroding and non-eroding channels. Stream power is a measure of the "*rate of doing work*" in overcoming resistance, moving sediment down gradient, eroding stream banks and scouring vegetation. Bledsoe and Watson (2001a) showed that simple indices are a viable method to relate stable and unstable channel forms with 80% accuracy. These indices however do not account for changes in channel cross section geometry (e.g., entrenchment and floodplain connectivity) and the actual force applied to the channel boundary, or situations where vegetation density is important. Bledsoe and Watson (2001a) concluded that indices should be referenced to a more detailed description of the limiting factors controlling the boundary's resistance to erosion. MacRae (1993, 1996) recommended that threshold criteria include a measure of erodibility of the most sensitive boundary material and that criterion based on flow alone is not adequate. MacRae developed a "*time integrated*" erosion based index using continuous flow data. The time-integrated erosion index proposed by MacRae (1993) combined with continuous records of discharge provides the most physically based approach to address the impacts from hydromodification (Bledsoe 2001). This is the approach developed for the SCVURPPP and used herein.

The index method focuses primarily on excess shear erosion, both as a mechanism and as a descriptor of the force that stream flow exerts on the bed and banks in excess of its critical value for mobility or erosion. Consequently, it is most effective where shear erosion is the dominant failure mechanism.

The effective work index (W) is computed as the cumulative excess shear stress that exceeds the critical value for streambed mobility or bank erosion; integrated over time, thus:

$$W = \sum_{i=1}^{n} \left(\tau_i - \tau_c\right)^e \cdot V \cdot \Delta t_i \qquad (1)$$

Where τ_c = critical shear stress that initiates bed mobility or erodes the weakest bank layer, τ_i = applied hydraulic shear stress, e = an exponent that captures the exponential rise in stream power with flow (assumed to be 1.5 in this analysis), V = mid-channel velocity (ft/sec), Δt_i = duration of flows (in hours), and n = length of flow record.

The basis of this methodology is to compare pre- and post- land cover scenarios. The work index computed for undeveloped land use conditions is used as the baseline condition that existing and future development conditions are compared too. The magnitude of change between pre- and post- conditions is represented as the Erosion Potential (Ep).

The Erosion Potential, expressed as a ratio, is defined as:

$$Ep = \frac{W_{post}}{W_{pre}} \qquad (2)$$

W_{post} = work index estimated for proposed development, and W_{pre} = work index measured for the pre-development condition.

MacRae (1993, 1996) also recommended that the erosion potential about the channel boundary remain the same under both developed and undeveloped conditions over the range of geomorphically significant flows. A discharge control strategy that maintains the same sediment transport characteristics provides the closest reproduction of pre-development conditions and is the basis of the recommended hydromodification management approach.

1.5.2 Stream Channel Hydraulics

Hydraulic calculations convert the flow rates to depth, velocity, and shear stress based on cross-section geometry and slope. The depth, velocity, and shear stress used in the stability assessment are taken from the central channel not including over banks or floodplains (Figure 1-1). Computations follow the method used in HEC-2 software, where channel roughness is specified for each segment between survey points, which allows roughness to vary by elevation (HEC-RAS simplifies the computation into channel, left and right overbanks). Average channel hydraulic conditions are computed based on the composite roughness coefficient. However, shear stress and velocity are computed based on central channel depth and velocity as opposed to the cross sectional average.

Channel hydraulics is computed using normal flow assumptions. Each cross-section is treated independently from the others; thus backwater effects are not considered. The computations are completed following the Army Corps of Engineers

HEC-2 method, where conveyance (K) is computed and summed between individual survey points. The following equations are used for the hydraulic analysis:

$$Q = 1.49 \cdot K \cdot \sqrt{S} \tag{3}$$

$$K = \sum \frac{AR^{2/3}}{n} \qquad R = \frac{A}{P}$$

where: K = Conveyance, R = Hydraulic radius, P = Wetted perimeter

Figure 1-1 illustrates the hydraulic computation parameters. Conveyance is computed for each element of the flow area defined between two cross section survey points.

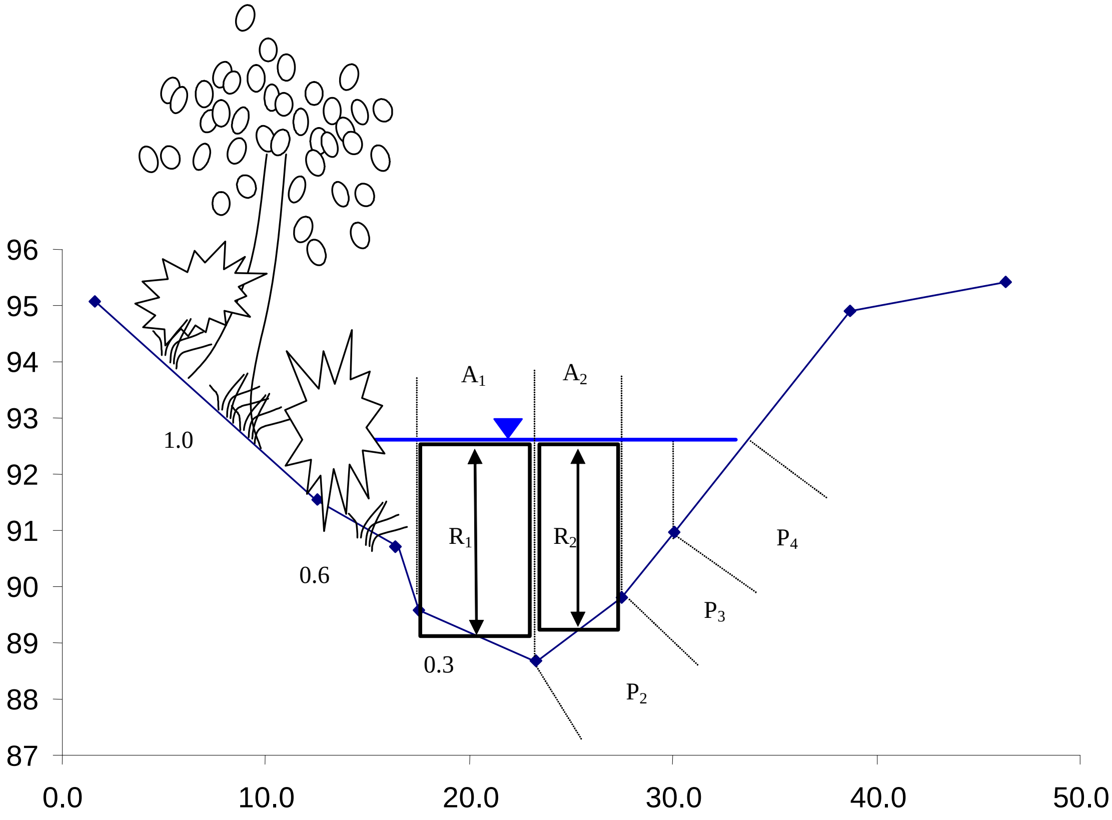


Figure 1-1. Illustration of Hydraulic Computations for a Typical Cross Section

1.5.3 Critical Shear Stress Values

Critical values of shear stress for bank erosion were estimated using shear tables published in ASCE Manual No. 77 (1992). The ASCE Manual No. 77 was considered to estimate critical shear stress for the channel banks. Table 1-1 lists critical shear stress values for a range of bank materials types, with and without vegetation. Bank material properties were qualitatively described by the field crews, which was then assigned a material type associated with the types listed in ASCE Manual.

Table 1-1. Published Critical Shear Stress Values

Bank Material Type	Critical Shear Stress (τ_c lbs/ft^2)
ASCE Manual No. 77	
Compacted Clays	0.5
Stiff Clays	0.32
Alluvial Silts	0.23
Firm Loam	0.23
Silty Loam	0.17
Sandy Loam	0.12
Biotechnical Engineering Data USAE[2]	
Woody vegetation	0.41 to 2.5
Vegetation: short native grass	0.7 to 0.95
Vegetation: long native grass	1.2 to 1.7
Biotechnical Engineering	0.4 to 8
Riprap[1]	1.6

1. The critical value for riprap was based on certain assumptions of 6-inch rock size, flow depth, bed slope, etc. These are typical values and used just for example.
2. Biotechnical engineering data obtained from “Stability Thresholds for Stream Material”, by Craig Fischenich, USAE Research and Development Center, Environmental Laboratory, Vicksburg, MS

1.5.4 The Effects of Vegetation Density

One element where the effects of vegetation are accounted for is with the roughness coefficient. Coefficients are estimated using Cowan’s method as described in Chow (1959). Cowan’s method sums individual roughness elements of the stream boundary, such as, bed material and form, irregularities in the banks, variations in cross-section, obstructions, and vegetation density.

The second element where vegetation can be incorporated is through partitioning of the mid-channel shear stress into bed roughness and form roughness. Bed roughness is the shear stress actually seen by the streambed and toe of banks. A certain amount of the flow energy is used up by turbulence and resistance of vegetation (branches, leaves, etc.) and overcoming channel irregularities. The computed mid-channel average shear stress (τ_c) can be partitioned according to the respective bed roughness and the estimated composite roughness according to Equation 4, to estimate the actual applied shear stress to the streambed.

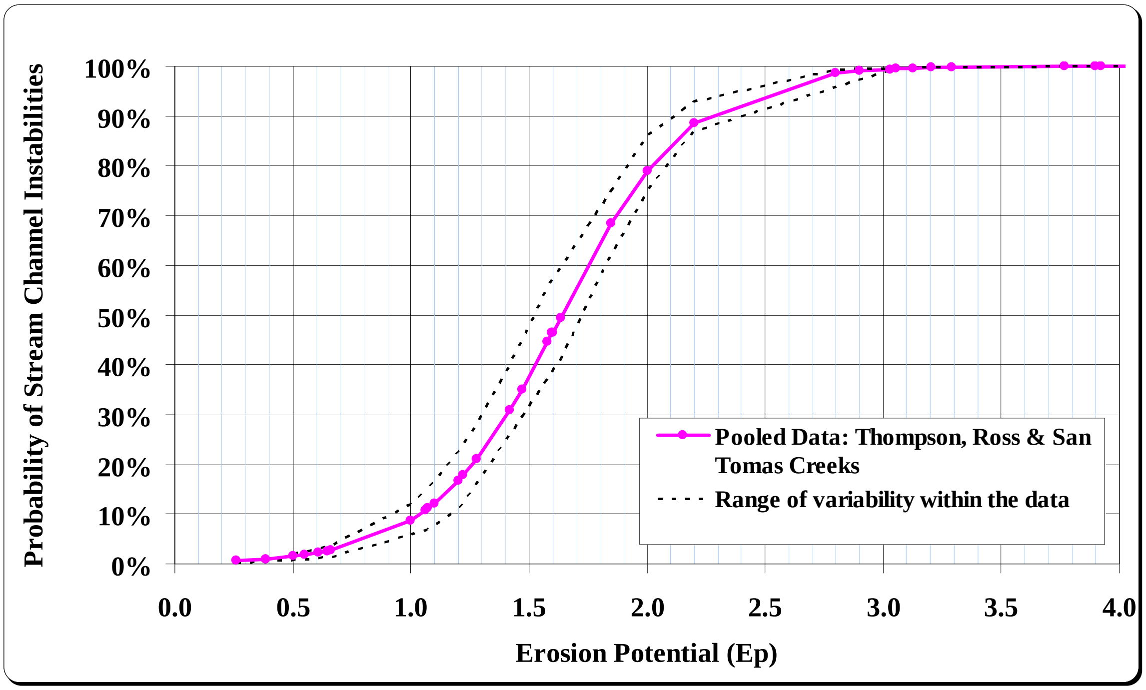
$$\tau_b = \tau_c \cdot \left(\frac{n_b}{n_c}\right)^{\frac{2}{3}} \qquad \tau_b = \rho g h S \qquad (4)$$

1.5.5 Risk-Based Analysis

Bledsoe and Watson (2001b) presented an approach using a probability method, or risk, to predict channel patterns and instability. Their intent was to show that an index could be used to predict the occurrence of stable meandering channels versus braiding and incised channels as a function of simple measurable hydraulic and sediment variables. Their example used descriptive data for 270 streams of both sand and gravel from around the world. The method addresses uncertainty in using indices and provides a means of judging the sensitivity of stream channels. Their approach uses logistical regression to predict the chance of having unstable stream channel conditions given a measure of shear (i.e., the *index*) to qualitative dependent variables, such as stable or unstable.

For the SCVURPPP studies, the ratio of the pre and post *index* was correlated to field observed conditions (stable or unstable) of the stream system to describe the risk of stream channel adjustment given a measured level of change in the erosion potential (Ep). All total, 45 cross sections collected between three test watersheds were used in the analysis. Figure 2-1 presents the results of this correlation.

Figure 2-1. Probability of Stream Channel Instabilities (SCVURPPP, 2005)



An Ep ratio of 2 means that the post-development runoff condition exerts 2 times more total work on the channel boundary then under the pre-development condition. At an Ep=2, the predicted *Risk* of excessive channel erosion and failure is about 80%. One of the objectives of the SCVURPPP studies was to identify a *threshold of adjustment* that could be used to define management strategies and discharge limitations. The probability curve can be used to select an Ep threshold by specifying a level of acceptable *Risk*. For example, to accept a 15% *Risk*, the Ep threshold would be 1.2. The effectiveness of management strategies and BMP's are evaluated by their ability to maintain the Ep below the threshold of 1.2.

2 Application to Soda Springs and Laurel Creek

This chapter describes the project team's hydrologic modeling of the Laurel Creek watershed. Modeling was conducted for the hydromodification assessment and planning process.

2.1 HEC-HMS Model

The following sections describe the methods and data sources used to generate input for the HEC-HMS models.

2.1.1 Drainage Area Delineation

Project watersheds were subdivided into smaller subwatersheds or catchments to provide a detailed assessment. Using GIS data, the project team delineated catchments associated with storm drain outfalls, storm drain flow direction, and topographic data. Catchments were further delineated to reflect land-use patterns. To the extent possible, individual drainage areas were delineated to separate developed (urban) and undeveloped (rural) areas, as many model parameters are derived from a drainage area's weighted average characteristics and are specific to degree of urbanization. Figure 2-2a shows the drainage area delineation of the study watershed. Table 2-1 provides the catchment sizes.

2.1.2 Drainage Area Characteristics

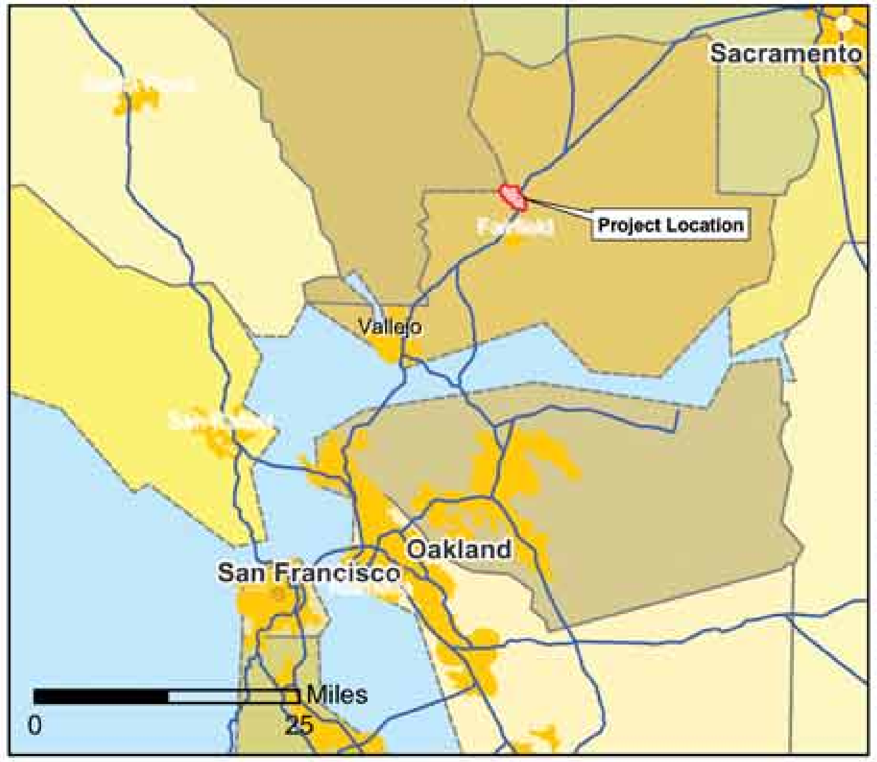
The project team identified land cover characteristics and soil types for the study watersheds based on the project's GIS database. The project team overlaid the drainage area delineations on those data to derive soil and land cover characteristics used in modeling each drainage area (Figure 2-2b).

Existing hydrologic conditions were modeled using detailed soils and land use GIS data from Balance Hydrologics The land use data were then modified to model hydrologic conditions for future and past (pre-urban) conditions, since GIS data were not available for these scenarios. For future conditions, the percentage of impervious land for each subwatershed under current conditions was increased based on future build-out percent impervious information from the City of Fairfield General Plan 2020 (Jones & Stokes, 2000). All other land uses for each subwatershed were then decreased in proportion to the increase in impervious area.

The project team reviewed USGS topographic maps to characterize pre-urban land use conditions. These sources provided a representation of the pre-urban distribution of agricultural and woodland/grassland areas for each subwatershed, which was then converted into model input parameters.

2.1.3 Excess Rainfall

HEC-HMS uses soil infiltration rate estimates and other losses described below to calculate excess precipitation that contributes to stormwater runoff. The continuous simulation routine uses the Soil Moisture Accounting (SMA) method (unique to HEC-HMS).



Legend

- ▭ Hydrologic Delineation
- — Creek System
- ● Model Junctions

N

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Figure 2-2a
Laurel Creek Hydrologic Delineation
Fairfield-Suisun HMP Project

May 2005

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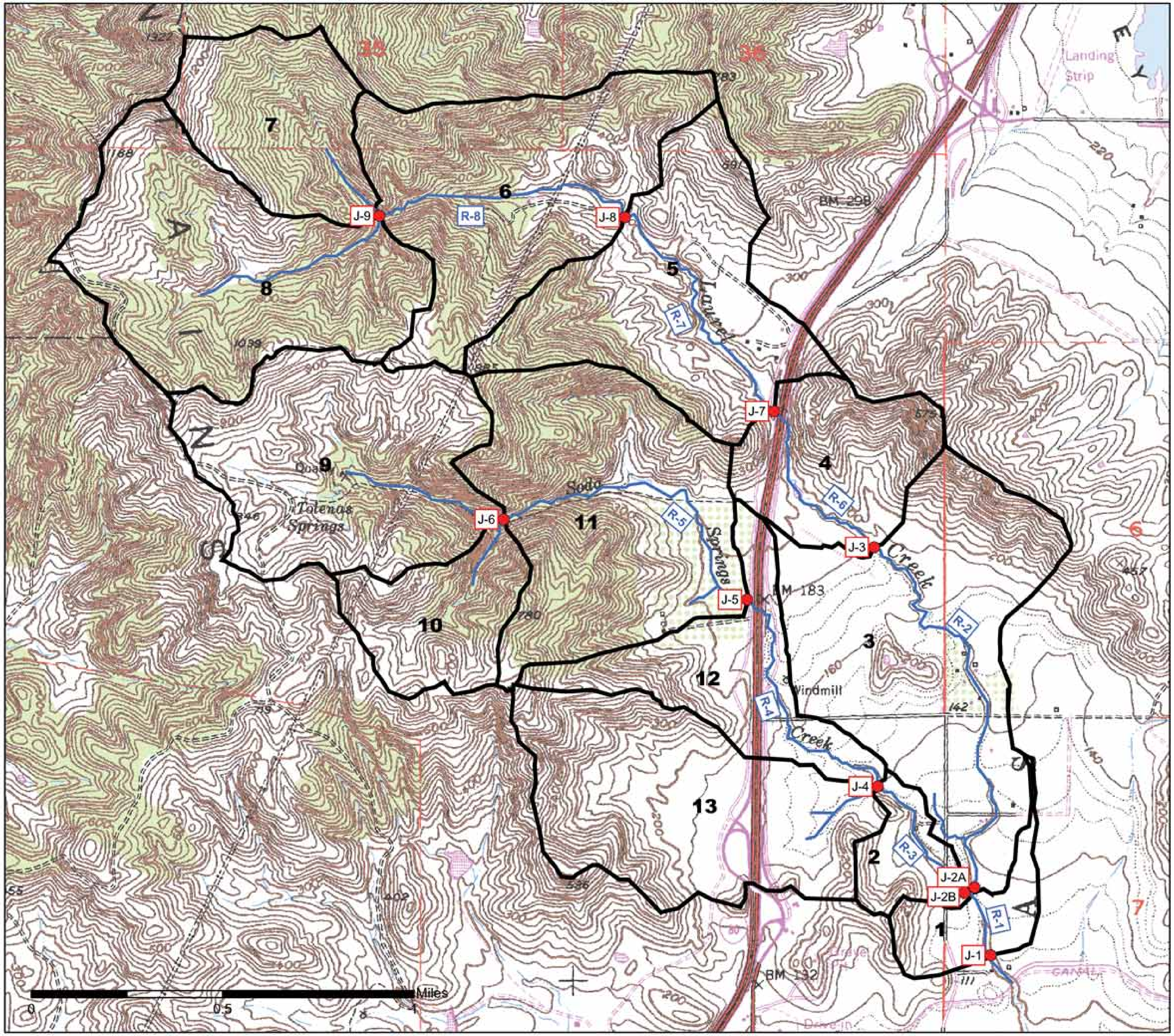

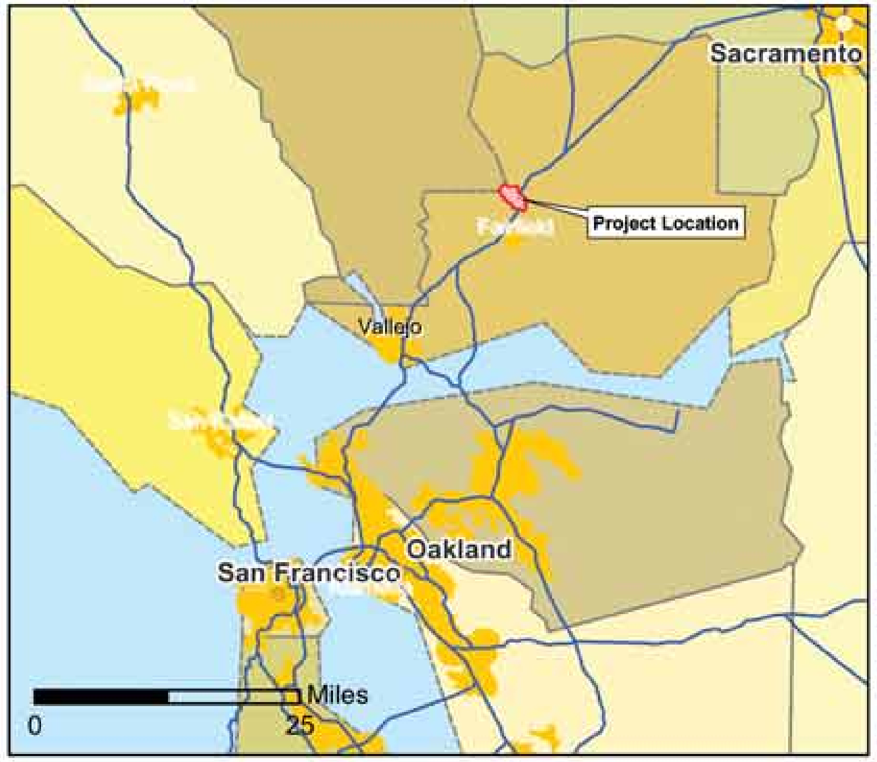

Legend

▭ Hydrologic Delineation

● Stream Gage Locations

— Creek System

LAND_USE

🟧 Highway

🟦 Road

🟩 Golf Course

🟫 Parking Lot

🟫 Existing Residential

🟦 Future Residential

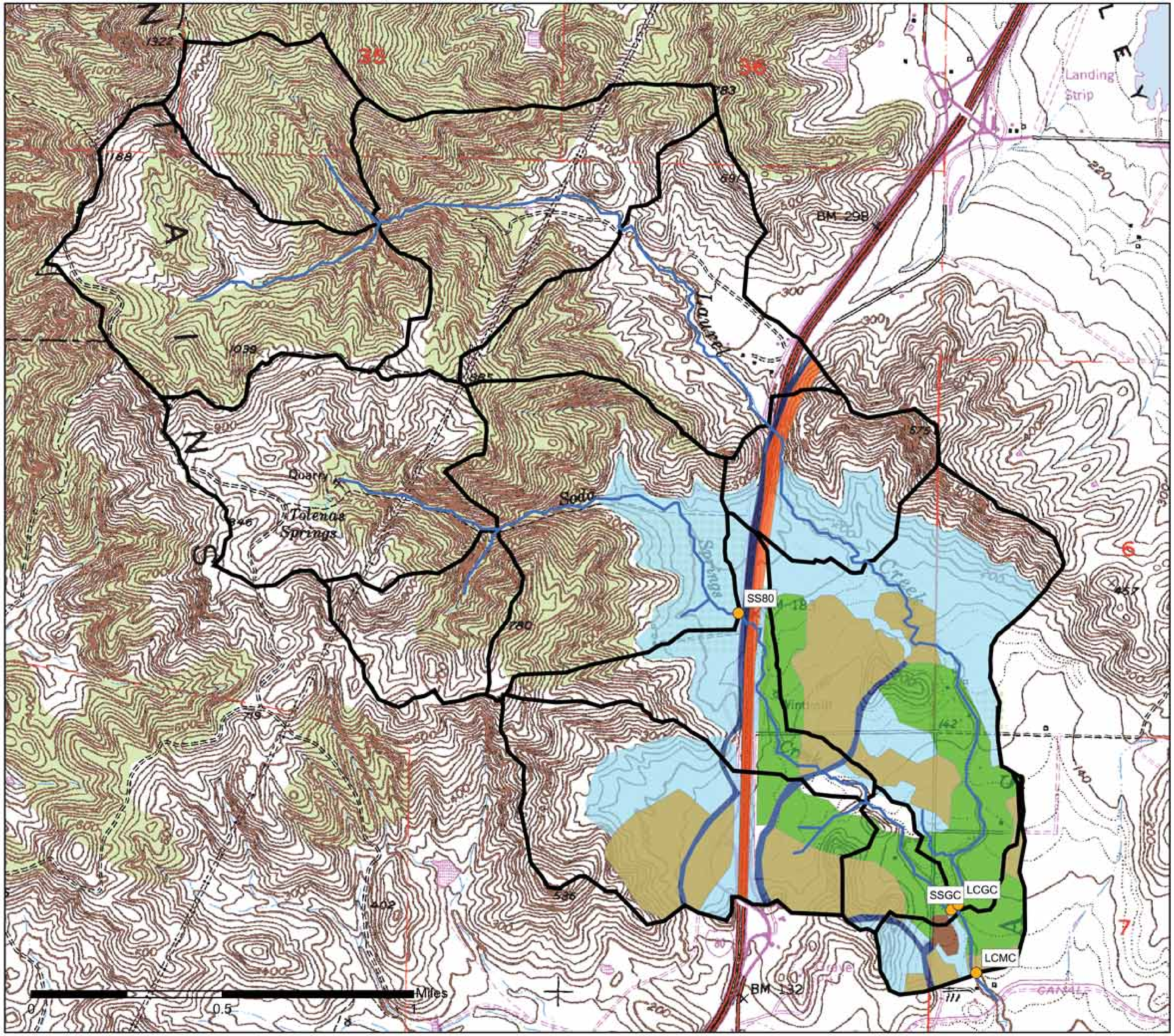

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Figure 2-2b
Laurel Creek Land Use Map
Fairfield-Suisun HMP Project

May 2005

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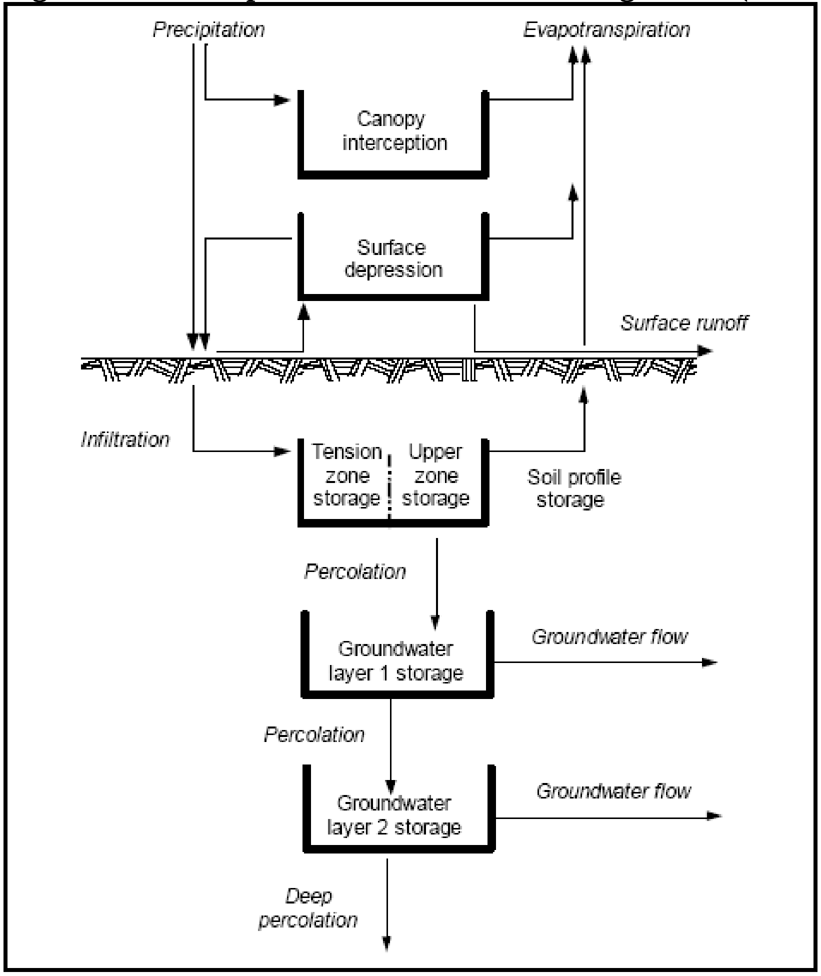
GeoSyntec Consultants

The SMA method provides a more complex method for evaluating rainfall runoff processes in a watershed. In this approach, actual measured rainfall over an extended time period is used as input. Losses are computed on a continuous basis, and include evapotranspiration, surface depression storage, and infiltration. The continuous model is designed to model the dynamic effect of soil infiltration and other losses on storm runoff over the course of a long-term rainfall record. Parameters to compute these losses include climatic data, land use conditions, vegetation cover, and soils data. The simplified conceptual schematic of Figure 2-3 illustrates the SMA model:

For each computational time step in the model, HEC-HMS calculates storage in each of the loss categories shown in the schematic, which allows for a continuous accounting of losses and runoff over a long time series. For infiltration, the model initially assumes that water enters the soil at the maximum infiltration rate and percolates out of the soil column at the percolation rate. Once the soil layer becomes saturated, the infiltration rate is reduced to the percolation rate. SMA parameter estimation is described in section 2.3.

Figure 2-3. Conceptual Schematic of SMA Algorithm (USACE, 2000)



2.1.4 Hydrograph Generation

Initially, the model determines how much incident rainfall is held in the watershed (losses), and how much will appear as runoff. That which appears as runoff is referred to as “excess precipitation.” The model then determines the time distribution of this watershed-wide excess precipitation, as it flows across the land surface or as shallow “interflow,” eventually reaching culverts or small drainage channels, and finally the main stream channel at the various flow computation points of interest. The resulting time distribution of runoff at a given location is referred to as “hydrograph.”

HEC-HMS offers a variety of methods for transforming excess precipitation from any given storm into a runoff hydrograph for each model drainage area. Clark’s synthetic unit hydrograph method was used for the modeling. Clark’s method requires two inputs: time of concentration (T_c) and a storage coefficient (R). T_c values were estimated for each of the subbasins based on the methodology described in the HEC-HMS Technical Reference Manual (USACE, 2000) and the TR-55 Urban Hydrology for Small Watersheds Manual (SCS, 1986). The Clark’s storage coefficient for each subbasin was determined during the model calibration process. The unit hydrograph parameters used in the modeling are listed in Table 2-1.

2.1.5 Reach Routing

HEC-HMS provides a variety of reach routing methods to translate the hydrograph from one drainage area downstream to a point where it can be combined with another drainage-area hydrograph. The project team chose to use the Muskingum Cunge method, which uses basic channel (or culvert) dimensions and characteristics to estimate hydrograph translation and attenuation over the routing reach. For existing and future conditions, surveyed cross-sections and available storm drain data were used to characterize channel dimensions and characteristics for reach routing. For the pre-urbanization scenario, the same channel characteristics established for the existing condition were utilized, based on the assessment that no channel modification has yet occurred in the Laurel Creek watershed. Reach routing parameters are summarized in Table 2-2.

2.1.6 Precipitation

The HEC-HMS continuous simulation was run using National Climatic Data Center (NCDC) continuous, hourly rainfall data from gage station ID 042935, “Fairfield NNE”, for a 56-year period (records for summer of 1948 through summer of 2004 were used within the model). The Fairfield NNE gage, although located outside the study area, has recorded a significantly longer period of precipitation than have other gages in the area. It is recognized that measured rainfall at Fairfield NNE is only an estimate of rainfall distributed across the study watersheds. Actual rainfall rates vary spatially, and intense rainfall rates (resulting from individual convective cells within a rainstorm) often occur over one area, but may miss another area nearby. Thus, while measured rainfall at the Fairfield gage represents a valuable estimate of rainfall for the project watersheds, variations during any individual storm are possible.

2.2 Parameter Estimation Process

To simulate the watershed response to a rainfall event, a variety of parameters must be estimated in the hydrologic model. These estimated parameters affect the size and shape of the storm hydrograph predicted by the model compared to what may result from any individual actual storm. Whenever possible, modelers compare model results to recorded concurrent rainfall and flow data to calibrate the model by adjusting various parameters to reproduce the actual flow resulting from measured rainfall. The project team generally calibrated the models by adjusting SMA parameters and unit hydrograph values.

Initial estimations of SMA parameters were developed in accord with the methodology outlined in the HEC-HMS Technical Reference Manual (USACE, 2000). Model calibration was then utilized to refine the initial SMA parameters within acceptable parameter ranges. A calibration was performed for the Laurel Creek watershed, using rainfall and stream flow measurements collected from within the project area this winter, from November 2004 through March 2005. Historic stream gage data was not available to calibrate the pre-urban Laurel Creek HEC-HMS model to actual pre-development flows in the Laurel Creek system. However, the stream gage on Soda Springs Creek at Interstate 80 collected measured flow data from the upper Laurel Creek watershed which is still considered to be in an undeveloped state. The calibrated SMA parameters for the subbasins draining to Soda Springs at I-80 were then applied to the undeveloped upper region of Laurel Creek above I-80.

Table 2-1. Drainage Area Parameterization

Subbasin	**Area** (acre)	**Tc** (hr)	**Clark's R** (hr)	**Pre-Urban % Impervious**	**Existing % Impervious**	**Future % Impervious**
1	48.7	0.19	0.19	0%	26.2%	42.3%
2	42.4	0.30	0.47	0%	23.0%	25.1%
3	305.3	0.56	3.66	0%	15.4%	35.4%
4	117.7	0.90	1.85	0%	8.5%	29.9%
5	232.4	1.51	2.68	0%	1.2%	1.2%
6	250.6	0.81	1.08	0%	0.0%	0.0%
7	125.7	0.73	1.51	0%	0.0%	0.0%
8	270.2	1.34	1.64	0%	0.0%	0.0%
9	243.8	1.81	1.33	0%	0.0%	0.0%
10	90.3	1.04	2.37	0%	0.0%	0.0%
11	272.6	1.89	8.61	0%	0.0%	11.9%
12	122.3	0.76	6.06	0%	16.1%	32.4%
13	239.8	1.18	2.90	0%	21.8%	33.3%

Table 2-2. Reach Parameters for Muskingum Cunge Routing

Reach ID	Connection	Surveyed XS Used for 8-Point	Length (ft)	Slope (ft/ft)	Channel Manning's n	Overbank Manning's n
R-1	J-1 to J-2	LCMC	1000	0.01	0.085	0.1
R-2	J-2A to J-3	LCGC	5650	0.012	0.065	0.1
R-3	J-2B to J-4	SSGC	2430	0.01	0.06	0.1
R-4	J-4 to J-5	SSGC	4066	0.01	0.07	0.1
R-5	J-5 to J-6	SS80	4646	0.06	0.08	0.1
R-6	J-3 to J-7	LCGC	2746	0.04	0.07	0.1
R-7	J-7 to J-8	LCGC	5280	0.05	0.08	0.1
R-8	J-8 to J-9	SS80	1954	0.11	0.08	0.1

Table 2-3. Calibrated SMA Parameters for Laurel Creek Watershed

Subbasin	Canopy Storage Capacity (in)	Surface Storage Capacity (in)	Soil Infiltration Max Rate (in/hr)	Soil Storage Capacity (in)	Tension Zone Capacity (in)	Percolation Max Rate (in/hr)
1	0.18	0.31	0.75	7.10	3.40	0.22
2	0.24	0.36	0.90	6.00	2.70	0.18
3	0.25	0.31	0.26	6.09	4.10	0.05
4	0.24	0.37	0.72	6.55	5.83	0.27
5	0.24	0.37	0.72	6.55	5.83	0.27
6	0.24	0.37	0.72	6.55	5.83	0.27
7	0.24	0.37	0.72	6.55	5.83	0.27
8	0.24	0.37	0.72	6.55	5.83	0.27
9	0.21	0.42	0.73	6.76	5.83	0.27
10	0.17	0.44	0.68	6.00	6.00	0.29
11	0.29	0.30	0.73	6.55	5.78	0.27
12	0.17	0.25	1.02	6.23	4.59	0.54
13	0.11	0.20	0.40	6.03	5.88	0.22

2.3 Methodology for Hydrologic Calibration

2.3.1 Peak-weighted RMS Error

The degree of correlation between the observed and simulated flows was measure using the peak-weighted root mean square (RMS) error objective function. This function is identical to the calibration objective function included in computer program HEC-1 (USACE, 1998). It compares all ordinates, squaring differences, and it weights the squared differences. The weight assigned to each ordinate is proportional to the magnitude of the ordinate. Ordinates greater than the mean of the observed hydrograph are assigned a weight greater than 1.00, and those smaller, a weight less than 1.00. The peak observed ordinate is assigned the maximum weight. The sum of the weighted, squared differences is divided by the number of computed hydrograph ordinates; thus, yielding the mean squared error. Taking the square root yields the root mean squared error.

Therefore, this function is an implicit measure of comparison of the magnitudes of the peaks, volumes, and times of peak of the two hydrographs. The function is defined as follows:

$$Z = \sqrt{\frac{\sum_{t=1}^{n}(Q_0(t) - Q_S(t))^2 \, \frac{Q_0(t) + Q_A}{2Q_A}}{n}} \qquad (5)$$

$$Q_A = \frac{1}{n}\sum_{t=1}^{n} Q_0$$

Where Z is the objective function, $Q_0(t)$ is the observed flow at time t, $Q_S(t)$ is the computed flow at time t, and Q_A is the average observed flow. The objective function is evaluated for all times t in the objective function time window.

2.4 Calibration Results

This section presents data from the continuous model for pre-urban, existing and future land use conditions. Continuous discharge records from two Laurel Creek stream gages were used to calibrate the HEC-HMS model. Gage SS80 is located on Soda Springs Creek at Interstate-80; Gage LCMC is located on Laurel Creek just below Manual Campos Parkway. Gages SS80 and LCMC correspond to HEC-HMS model nodes J-5 and J-1, respectively (Figure 2-2b). Due to the large quantity of data generated in the Laurel Creek model (56 years of flow estimates at one-hour intervals for multiple locations), this section will limit the results discussion to results from junctions J-5 and J-1. Junction J-5 represents the upper watershed, which is largely undeveloped under existing conditions. Junction J-1 is inclusive of the upper and lower watershed and includes the urbanized areas of the watershed.

The existing condition model for Laurel Creek was calibrated against the observed data for two flow gages within the Laurel Creek watershed. In the upper portion of the watershed, the flow record for Soda Springs Creek Gage SS80 at Interstate-80 was used to calibrate the model at junction J-5. Flow data was available from November 2004 to March 2005 for Gage SS80 for the existing condition calibration of the model at J-5. The hydrograph results for the existing condition calibration at J-5 are shown in Figure 2-4.

The flow record for Laurel Creek Gage LCMC at Manuel Campos Parkway was used to calibrate the lower portion of the Laurel Creek watershed model at junction J-1. Flow data was available for this gage from November 2004 to March 2005 for the existing condition calibration of the model at J-1. The hydrograph results for the existing condition calibration at J-1 are shown in Figure 2-5.

Tables 2-4 and 2-5 list the numerical results for each of the calibration periods discussed above. The total volume for the flow gage record and the simulation are shown. For Gage SS80, the total volume for the flow gage minus all flows less than or equal to 0.5 cfs is also shown. This analysis was added to account for the effects of interflow in this flow gage record. The model results for total volume were compared with this decreased volume, so as to not over predict flow volume in the model, which did not simulate interflow. This additional analysis was not necessary for Gage LCMC because baseflow was included in the lower portion of the model to account for irrigation and other urban sources of baseflow. This baseflow function was not included in the pre-urban model of Laurel Creek.

The percent error from observed volume is presented in Tables 2-4 and 2-5, and due to the variability of hydrologic modeling, a deviation of 20 percent is considered a strong correlation. The average discharge for each condition was included for comparison. The RMS error function value for the model results when compared to both the gage data and the adjusted gage data are presented in the tables. On the basis of past experience by GeoSyntec, these calibration results are very good and better than past excepted models.

Table 2-4: Gage SS80 Calibration - Period from 11/10/2004 – 3/25/2005

	Volume (ac-ft)	Average Q (cfs)	Model Results' Peak-weighted RMS Error	Percent Error in Volume
Gage SS80	2.31	0.52	3.5	22%
Gage SS80 - Flows < 0.5 cfs	1.81	0.41	3.9	0%
Model Results @ J-5	1.81	0.40	-	-

Table 2-5: Gage LCMC Calibration - Period from 11/10/2004 – 3/25/2005

	Volume (ac-ft)	Average Q (cfs)	Model Results' Peak-weighted RMS Error	Percent Error in Volume
Gage LCMC	17.53	3.93	14.9	-1%
Model Results @ J-1	17.65	3.95	-	-

Figure 2-4. Calibration Results for SS80 Gage

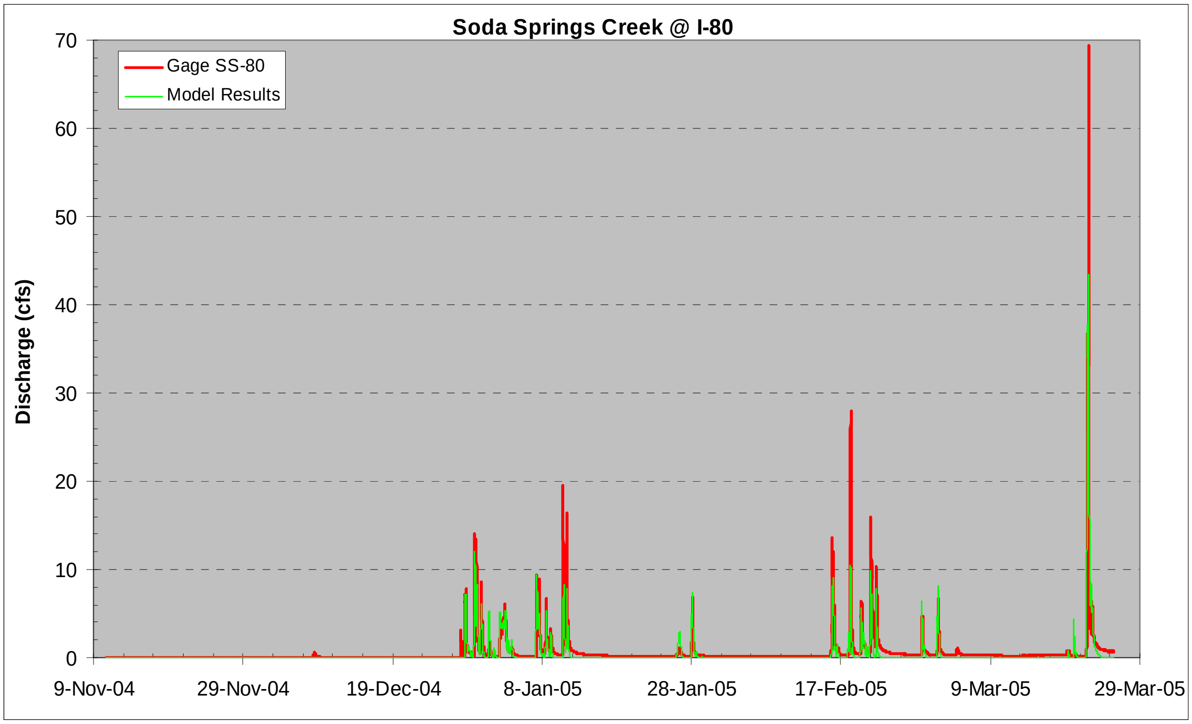
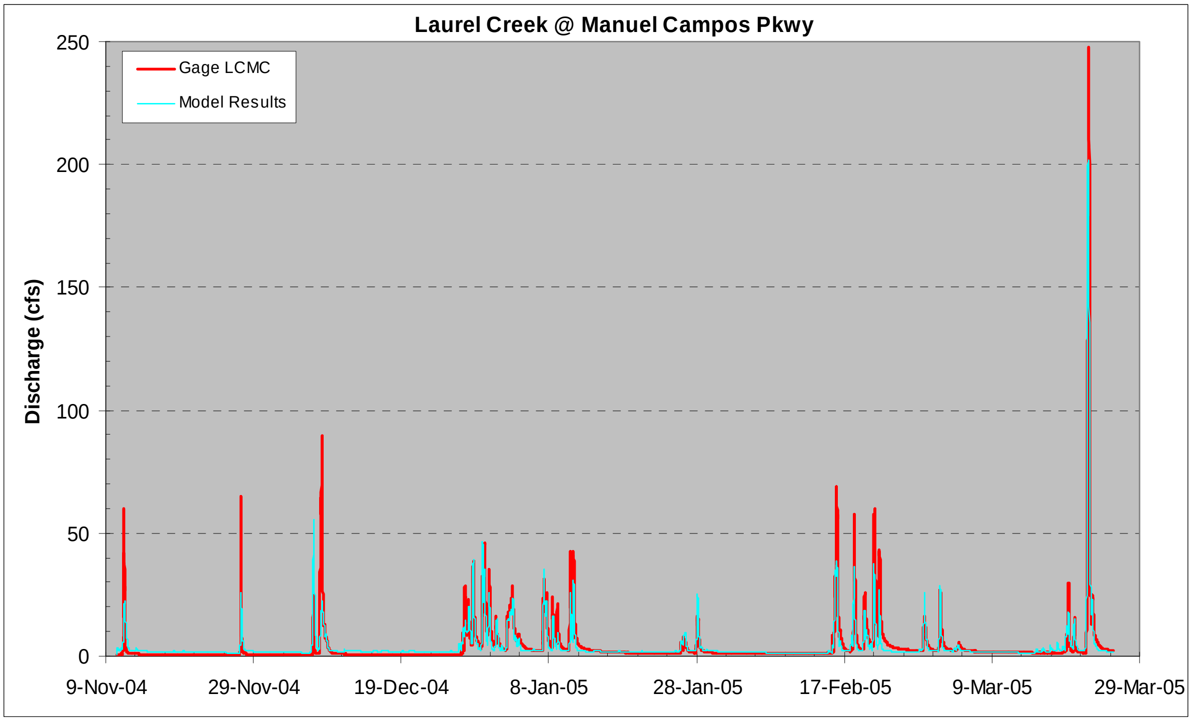


Figure 2-5. Calibration Results for LCMC Gage



2.5 Change in Total Cumulative Percent Imperviousness

Table 2-6 summarizes the total cumulative impervious area (TCIA) in percent for Soda Springs and Laurel Creek. The TCIA has been computed relative to the total drainage area contributing to stream flows at the respective location. The estimated TCIA under existing conditions range from 4.6% to 8.1%.

Table 2-6. Estimated Percent Impervious Surface

	Area	Pre	Existing	Future
	(acre)			
SS80	606.71	0.0%	0.0%	5.3%
SSGC	1011.2	0.0%	8.1%	16.1%
LCGC	1302.0	0.0%	4.6%	11.2%
LCMC	2361.9	0.0%	6.5%	13.9%

Results for the existing conditions suggest a low to moderate chance of hydromodification impacts. Existing percent TCIA falls within the range of uncertainty from 2% to 10%. Given the fact that field observations have discovered little evidence of system wide degradation with only a few areas of localized erosion, it is possible that a threshold based on impervious surfaces for Soda Springs and Laurel Creek could be closer to 10%.

Considering the estimated future percent imperviousness of 11% to 16%, it is possible that future development could exceed local thresholds of imperviousness and cause excessive channel erosion and degradation.

2.6 Critical Shear Stress Values

Table 2-7 summarizes the critical shear stress values selected for this analysis and is assumed to represent the field conditions in Soda Springs and Laurel Creeks. Critical shear stress values are selected to represent exposed banks without much vegetation to protect its surface from shear erosion, and for reaches where dense vegetation makes up a large percentage of the observed channel conditions. Critical shear stress is ultimately used to compute the critical flow (Qc) in the channels and the project partitioned critical flow for management purposes (Qcp).

Table 2-7. Critical Shear Stress Values Selected for Analysis

	Bank Material	**With Dense Vegetation**
SS80	0.32	1.0
SSGC	0.32	1.0
LCGC	0.32	1.0
LCMC	0.32	1.0

3 Results and Discussion

This section summarizes predicted changes in stream flow duration characteristics and the erosion potentials for cross sections SS80, SSGC, LCGC, and LCMC. Results are presented for existing and future development conditions.

3.1 Flow Duration

Recall that flow duration curves illustrate the cumulative frequency distribution of *time* that flows exceed a given magnitude. For example, in Figure 3-1, 100 hours of flows occur at 300 cfs and greater. A comparison between two land use scenarios show the change in the length of time (duration) that flows persist at these magnitudes, which leads to increases in the erosion potential and risks of hydromodification impacts.

3.1.1 Existing Conditions

Figure 3-1 presents the flow duration curves for Laurel Creek in the lower reaches of the study area. Flow duration curves are plotted for pre-development, existing and future conditions to illustrate the change in stream hydrology as a result of development.

Figure 3-1 suggests minor increases in the duration of runoff and runoff volume due to existing development (compared to other studies conducted by GeoSyntec). Although not easily observed in the figure, the number of hours of stream flows increased by 30% and the overall flow volume increased by 20% between undeveloped and existing developed conditions. The largest increase occurred in the low flow range as expected, however these flows are generally less than the critical flow (~40 cfs) expressed by the critical shear stress of 1.0 lbs/sq-ft. Results for cross sections SS80, SSGC and LCGC show similar curves but with somewhat smaller differences.

3.1.2 Future Conditions

Figure 3-1 suggests moderate increases in the duration of runoff and runoff volume due to future development (compared to other studies conducted by GeoSyntec). The total number of hours of stream flow increased by 100% - doubling the total hours of flow before development. The overall stream flow volume increased by 62% between undeveloped and future developed conditions at build-out.

The affect of these increases for existing and future are measured using the work index and the Ep. The force applied to the channel boundary by the flows represented in the flow duration curves is of course a function of the channel slope, geometry, and soil resistance and vegetation density.

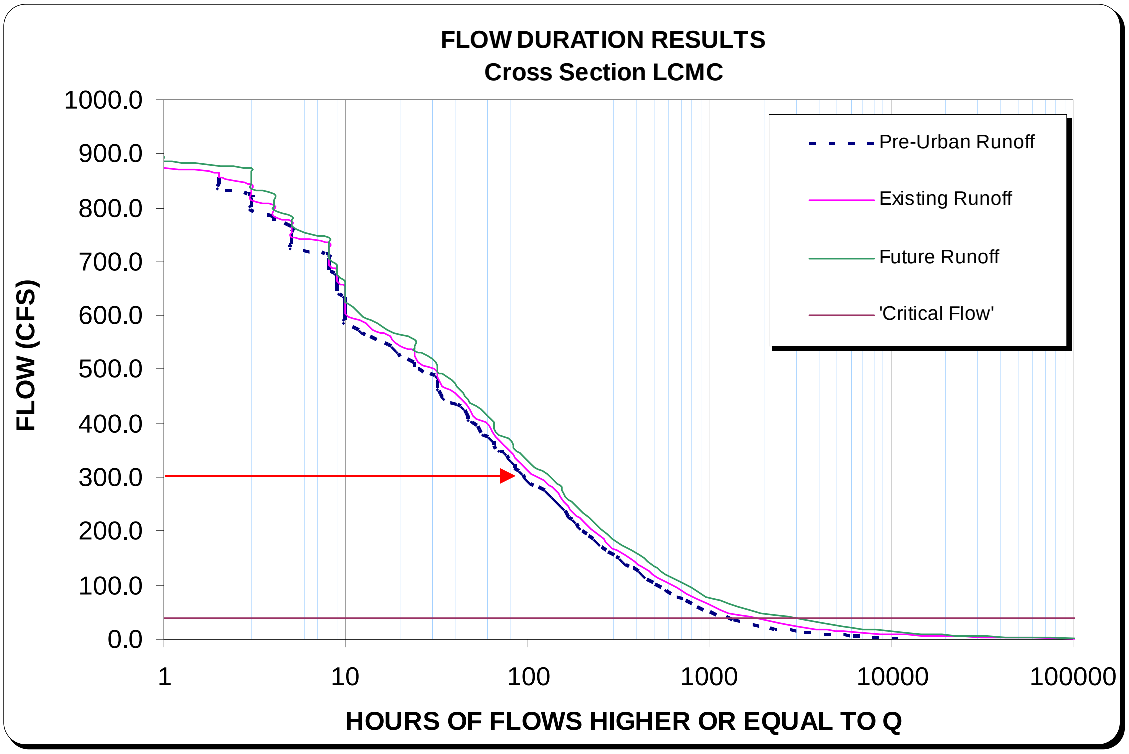


Figure 3-1. Example of Existing Conditions in Laurel Creek

3.2 Erosion Potential

Results are presented for conditions with and without significant riparian vegetation to illustrate the importance of vegetation in maintaining channel stability. These results also illustrate the risk of hydromodification impacts if vegetation was lost in the future.

Recall that the erosion potential is a measure of the change in long-term force applied to the stream channel boundary, and that if this measure exceeds 20% (Ep=1.2) the likelihood of excessive erosion and stream instability increases.

3.2.1 Existing Conditions

Table 3-1 lists the predicted erosion potentials for cross sections SS80, SSGC, LCGC and LCMC. The area on Soda Springs upstream from Highway 80 (SS80) is not currently developed and thus its erosion potential is 1; i.e., no change in work done between pre-development and existing conditions. Results are presented for two different critical shear stress values; $\tau c = 0.32$ and $\tau c = 1.0$ that represent exposed banks without much vegetation to protect its surface from shear erosion, and for reaches with dense vegetation making up the majority of the observed conditions. The selection of the critical shear stress defines the critical flow where bed movement or shear erosion of banks begins.

On the basis of these results for the current vegetated state the predicted erosion potential is less than or equal to 1.2. These results support the field observations that little significant reach-wide excessive erosion or channel instabilities exists under existing conditions. For small localized areas of exposed banks without vegetation the predicted erosion potential exceeds 1.2 at SSGC and LCMC. Using the Probability Curve generated from the Santa Clara Hydromodification Management Plan studies, the *Risk* of stream channel instabilities is predicted to be on the order of 21% and 55%, respectively. Considering LCMC; this means we're predicting that 1 in 2 exposed stream banks in the lower reaches are at risk of excessive erosion due to hydromodification.

Table 3-1. Existing Development Conditions

	Areas of exposed bank; no vegetation	Risk of Instabilities	Current vegetated state	Risk of Instabilities
	$\tau c = 0.32$	%	$\tau c = 1.0$	%
SS80	**1.0**	**9**	**1.0**	**9**
SSGC	**1.3**	**21**	**1.2**	**17**
LCGC	**1.2**	**17**	**1.1**	**12**
LCMC	**1.7**	**55**	**1.2**	**17**

Risk is determined using the Probability Curve shown in Figure 2-1, Chapter 2. Source: Santa Clara Valley Urban Runoff Pollution Prevention Program.

These results illustrate the importance of vegetation in providing apparent strength to stream banks and suggest that a loss of vegetation could initiate a larger scale reach-wide response to hydromodification. A vegetation management program may be appropriate.

3.2.2 Future Conditions

Table 3-2 lists the predicted *future* erosion potentials for cross sections SS80, SSGC, LCGC and LCMC. Results are presented for the two different critical shear stress values. On the basis of these results for the current vegetated state, the future predicted erosion potentials are greater than 1.2 for all areas except on Soda Springs upstream from Interstate 80 (SS80). From the Probability Curve, these predicted erosion potentials (Ep = 1.3, 1.4 and 1.5) result in a *Risk* of instabilities from 21% to 38%.

Table 3-2. Future Development Conditions at Build-Out

	Areas of exposed bank; no veg.	Risk of Instabilities	Current conditions	Risk of Instabilities
	$\tau c = 0.32$	%	$\tau c = 1.0$	%
SS80	**1.2**	**17**	**1.1**	**12**
SSGC	**1.8**	**64**	**1.4**	**30**
LCGC	**1.7**	**55**	**1.3**	**21**
LCMC	**2.6**	**98**	**1.5**	**38**

Risk is determined using the Probability Curve shown in Figure 2-1, Chapter 2. Source: Santa Clara Valley Urban Runoff Pollution Prevention Program.

For localized areas of exposed banks without vegetation the predicted erosion potential are predicted to be 1.8, 1.7 and 2.6 at SSGC, LCGC and LCMC, respectively. Using the Probability Curve the *Risk* of stream channel instabilities are predicted to be 64%, 55% and 98%, respectively.

The hydromodification analysis is predicting that future build-out conditions in Soda Springs and Laurel Creek doubles the *Risk* of causing stream channel instabilities from the current conditions (risk=12% to 17%; Ep=1.1 to 1.2) to the future condition (risk=21% to 38%; Ep=1.3 to 1.5). One way to interpret *Risk* is to consider it in terms of the number of stream segments that could potentially be affected. For example, a 20% *Risk* suggests that 1 in 5 stream segments could show signs of excessive channel erosion due to development.

Another observation is that the stream reaches adjacent to the golf course (SSGC, LCGC) have moved from what is generally interpreted as low risk to higher risk as a result of continued development. What is now observed as generally stable reaches with small isolated incidences of channel erosion could potentially increase to more frequent occurrences of channel erosion. One positive thing to note is that the predicted magnitude of potential hydromodification impacts are still well below the level of 100% *Risk* (Ep=3) of wide spread instabilities. This is due in large part to the existing vegetation density within the riparian corridor.

These results suggest that, even under future development, the risk of wide spread channel degradation is currently low to moderate; and over time we could see increasing pockets of degraded channel segments, especially if the current vegetation density is lost.

Considering the results for exposed banks with no vegetation, the *Risk* jumps to 55% to 98% and stream channel degradation is highly probable. Once vegetation is lost along stream banks the frequency of eroding events may prevent vegetation from becoming re-established.

4 Conclusions of Hydromodification Assessment

On the basis of the total cumulative percent impervious area (TCIA), existing TCIA falls within the range of uncertainty (2% to 10%) of published thresholds for imperviousness. Considering that field observations show little evidence of wide spread erosion problems, any localized real threshold could be in the higher range. On the other hand, much of the current development in this study area is recent, and *time* is a factor between when development occurs and how fast a stream responds to hydromodification. Field observations have suggested possible early signs hydromodification impacts.

Future TCIA however, is predicted to double and reach or exceed any real threshold for Soda Springs or Laurel Creek. On the basis of TCIA, future development could potentially impact Soda Springs and Laurel Creek.

Analysis of flow duration and total stream flow volume shows minor increases in the total hours of flow and volume between pre-developed and existing conditions. The number of hours of stream flow increased by 30% and the overall flow volume increased by 20%. Under future conditions, the number of hours of stream flow is twice (100%) that of pre-development and volume increases by 62%. On the basis of past experience by GeoSyntec these changes are relatively small compared to other development projects in the Bay Area and Southern California.

On the basis of the Ep results for the current vegetated state the predicted erosion potentials are less than or equal to 1.2. These results support the field observations of little significant reach-wide excessive erosion or instabilities under current conditions. For areas of exposed banks without vegetation the predicted erosion potential exceeds 1.2 at SSGC and LCMC. The *Risk* of stream channel instabilities is predicted to be on the order of 21% and 55%, respectively. Considering LCMC; this means we’re predicting that 1 in 2 exposed stream banks in the lower reaches are at risk of excessive erosion due to hydromodification.

Future predicted erosion potentials are greater than 1.2 for all areas except on Soda Springs upstream from Interstate 80 (SS80). These predicted erosion potentials result in a *Risk* of instabilities from 21% to 38%. A 20% *Risk* suggests that 1 in 5 stream segments could show signs of excessive channel erosion due to development. One positive thing to note is that the predicted magnitude of potential hydromodification impacts are still well below the level of 100% *Risk* (Ep=3) of wide spread instabilities. For areas of exposed banks without vegetation the erosion potential are predicted to be 1.8, 1.7 and 2.6 at SSGC, LCGC and LCMC, respectively. The *Risk* of stream channel instabilities is 64%, 55% and 98%, respectively.

These results suggest that the risk of wide spread channel degradation is currently low and over time we could see increasing pockets of degraded channel segments, especially if the current vegetation density is lost. For these reasons, a vegetation management program is recommended and could be part of the hydromodification management plan.

5 Management Strategies

5.1 Solutions Concepts

Recommended management strategies consist of a series of progressive control measures combined into a single integrated solution. The combination will be tailored to fit the specifics of Soda Springs and Laurel Creek development conditions.

Potential solutions consist of on-site project specific strategies that minimize the affects of hydromodification. Any on-site BMP that reduces or eliminates the change in runoff volume created by impervious surfaces reduce the effect of hydromodification. Larger regional flow control type facilities, such as retention basins are possible and could be cost effective depending on the local authorities desire to manage and maintain such facilities. In-stream modifications that help the stream accept the new flow regime can be a solution strategy, but is generally considered to be the last resort for existing healthy stream systems.

The recommended solution philosophy involves the following concepts:

1. Avoid, to the extent possible, the need to mitigate for hydromodification and water quality. Preserve the natural hydrologic conditions and protect sensitive hydrologic features, sediment sources, and sensitive habitats.
2. Minimize the effects of development through conscientious site design techniques and on-site control measures to limit the increase in runoff and pollutant transport.
3. Manage the stream corridor itself by implementing in-stream controls, such as grade controls, biotechnical bank stabilization controls, and restoration. Provide allowances for the modified stream flow characteristics and enhance the beneficial uses of streams.

On-Site Solutions. The main premise of *site design* techniques is to maintain the natural functions of the hydrologic and geomorphic processes as much as possible, to minimize the magnitude of change caused by Group 1 Projects, and to integrate stormwater control measures into the development to mitigate expected impacts. Project controls are applied to individual projects when the site is developed or redeveloped. Project controls include site design features that are integrated into the development and are intended to reproduce, to the extent feasible, the natural processes of infiltration, evapotranspiration, and delayed runoff response. These are also known as “hydrologic source controls” because they have the effect of reducing runoff volumes resulting from development.

The following techniques can be used in the design process:

- Preserve areas of naturally high infiltration to maintain, to the extent practical, stable baseflows and groundwater recharge.
- Reduce and disconnect impervious surfaces such as roofs, parking lots and streets. Allow surface runoff from impervious surfaces to drain to vegetated pervious areas with infiltration volume reduction before discharging to local creeks.

- Integrate water quality and flow controls into the landscape. Control measures can include filter strips, bioswales and bioretention areas, constructed wetlands, shallow infiltration trenches, and permeable pavement.

Site design may be incorporated into the standard features of a development with small to moderate changes in the project design. Appropriately applied site design techniques can reduce the runoff volume, duration and flow rate, and can reduce the infrastructure necessary to control and convey stormwater. Site design controls can be very effective at controlling geomorphically significant flows (i.e., erosive flows) and can be used to fulfill both water quality and flow control objectives. . However, since site design controls retain water on site through infiltration, evapotranspiration and by-pass; and their effectiveness depends on soil properties, groundwater levels, topography, and other site conditions.

Larger Scale Retention Facilities. In areas of the watershed where land is available, larger scale retention facilities can be built that provide flow control and treatment for existing uncontrolled development and/or for Group 1 Projects in newly developing areas. Potential regional retention facilities could include the following:

- Retention and infiltration basins and trenches
- Wetlands, swales and other biological systems that reduce stormwater volume
- Interceptor and bypass systems
- Large scale stormwater recycling systems that store stormwater to be used for irrigation.

In-stream Solutions. The approach of in-stream techniques is to modify the stream channel to convey the new urban stream flow hydrology and reduce potential erosion and aggradation problems. The following in-stream solutions have the effect of reducing the flow energy and imposed shear forces and/or strengthening the stream banks so that they can resist the imposed flow energy:

- Modify the stream channel so that the channel can accept the new urban flows without erosion and bank failures, and damage to habitat. Widening, reducing slope, and roughening channel surface can be used in combinations to achieve solution objectives.
- Maintain flow energy dissipation along the stream channel by installing, or leaving in place, features that add roughness (e.g., root wads, LWD).
- Implement biotechnical stability solutions to increase the resistance of the stream channel to the flow energy.
- Maintain physical and hydrologic connectivity between streams and floodplains. Use floodplains for flood storage, riparian habitat, recreation, and water quality.

5.2 Hydromodification Management Measures

This section provides a brief overview of potential hydromodification management measures and BMP selection strategies. Appendix F provides more details and recommendations for hydromodification management and stormwater controls specific to Soda Springs and Laurel Creek. Two methods are provided that allow developers to size and design hydromodification control BMPs.

Generally, a Group 1 would consider both hydromodification management measures along with water quality BMPs. This integrated approach is more cost and space effective for developers. This section discusses project design features to be incorporated into projects mostly in terms of hydromodification management, although similarities and overlap exists with water quality BMPs. Project design features include on-site design, hydrologic source control, and traditional treatment control BMPs that also have the ability to *retain* stormwater runoff.

On-site design features of the project tend to replicate the pre-development water balance, and thereby minimize the increase in runoff associated with urbanization. Hydrologic source controls are practices designed to capture and retain a certain portion of runoff. The portion to be retained is the increase in surface runoff as a result of adding impervious surfaces to an otherwise pervious watershed. Treatment controls are typically designed to remove pollutants from stormwater runoff, although certain conditions, treatment controls also can also provide volume reduction which can substantially improve performance, and help reduce the affects from hydromodification.

A new strategy has been developed that is specifically designed to address the affects of hydromodification is *Flow Duration Control*. Stream erosion/deposition and sediment transport processes are functions of the long-term cumulative effects of geomorphically significant flows. Maintaining the long-term cumulative duration of geomorphically significant flows maintains the pre-project capacity to transport sediment and promotes long-term stability. Flow duration control appears to have first been proposed in the literature by Derek Booth (1993), University of Washington. Flow duration control maintains the pre-development frequency distribution of hourly runoff as well as the total runoff volume. The captured volume must be infiltrated and/or released at less than the critical flow for bed mobility. The flow duration method is essentially an analysis of distributions of all flows as opposed to using a single design event(s) and assuming that this event correctly captures all the relevant characteristics of hydromodification. A distribution of hourly rainfall is transformed to a distribution of hourly runoff using the hydrologic model. The distribution of runoff is then analyzed for long-term cumulative flow duration. This approach incorporates the full probability distribution of storms; including 2-year through 50-year storms, frequent erosive flows less than 2-year storms, droughts and heavy winters, antecedent conditions, and back-to-back storms.

The remainder of this chapter summarizes site design characteristics, source controls and treatment controls that would be implemented as part of the proposed project.

Table 5-1 lists on-site design concepts that should be considered potential candidates for new development and significant re-development projects. Not all of these concepts are necessarily feasible for all future projects.

Table 5-1: Potential On-Site Design Features

Site Design Feature	To Be Implemented
a. Conservation of natural areas. Use natural drainage systems. b. Maximize canopy interception and water conservation. c. Maximize the permeable area. Minimize the use of impervious surfaces d. Construct on-site ponding areas or retention facilities to increase opportunities for infiltration. e. Where soils conditions are suitable, use perforated pipe or gravel filtration pits for low flow infiltration.	1. Protect sensitive hydrologic features, sediment sources, and sensitive habitats. 2. Provide setbacks and buffers between development and sensitive ecological areas. 3. Conserve natural areas and use natural drainage corridors and swales where possible. 4. Cluster development; in less infiltratable soils if possible. 5. Reserve areas of high infiltration to maintain natural recharge volumes. 6. Construct BMPs in areas to maximize opportunities for infiltration. 7. Minimize the amount of impervious surfaces.

On-site design concepts consist of three measures to *avoid* changes and protect and preserve sensitive hydrologic features, sediment sources, and ecological areas (# 1, 2, and 3). Natural features with important hydrologic functions include streams, wetlands, and areas of native vegetation, high quality habitats, and natural depressions. By taking advantage of these natural features, the scale and complexity of other BMPs can be reduced. Four measures involve *minimizing* the change in the natural hydrologic characteristics and maximizing opportunities for infiltration (# 4, 5, 6 and 7). Reducing and disconnecting impervious surfaces is considered to be the single most important management practice to minimize changes in hydrology.

Infiltration is the primary mechanism used to maintain pre-project hydrologic and runoff characteristics to address hydromodification and pollutant loadings. Preserving areas for infiltration provides stable baseflows, groundwater recharge, reduced flood flows, reduced pollutant loads, and reduced costs for conveyance and storage. When infiltration rates are very low, as is the case for many clay soils, a distributed approach can be effective. A distributed approach retains and infiltrates a portion of the increased runoff volume in smaller discrete units throughout the development, with the aid of soil amendments if necessary. Such practices are sometimes called hydrologic source control.

Table 5-2 lists suggested site design elements that should be considered as candidates for new development and significant re-development projects. The selection of management measures must take into account site constraints associated with the projects. The required control measures in this category involve minimizing the effects of development by minimizing impervious surfaces and draining impervious surfaces to adjacent pervious areas. This approach provides opportunities for infiltration and treatment prior to the stormwater runoff entering the storm drains system.

Table 5-2: Potential On-Site Design Elements

Design Elements	To Be Implemented
a. Construct walkways, trails, patios, driveways, and low traffic areas with open-jointed paving materials or permeable surface b. Reduce widths of street where off-street parking is available. Construct streets, sidewalks and parking lot aisles to the minimum widths necessary. c. Where landscaping is proposed drain rooftops, impervious sidewalks, walkways, trails, and patios into adjacent landscaping. d. Increase the use of vegetated drainage swales in lieu of underground piping or imperviously lined swales. e. Use one or more of the following: • Rural swale system • Urban curb/swale system • Dual drainage system f. Use one or more of the following features: • Design with shared access, wheel strips (pave under tires) • Uncovered temporary, overflow and guest parking may be paved with a permeable surface	1. Integrate water quality and flow control facility into the landscape. 2. Direct runoff from impervious surfaces to vegetated areas, such as swales and rain gardens. 3. Use vegetated swales in lieu of underground piping or lined ditches. 4. Drain driveways, rooftops, sidewalks, walkways, trails, and patios into adjacent landscaping. 5. Construct walkways, trails, patios, driveways, and low traffic areas with open-jointed paving materials or permeable surface 6. Construct streets, sidewalks and parking lot aisles to the minimum widths consistent with building codes. 7. Use an urban curb and swale system design approach, where possible.

Appendix F provides a summary of potential control measures for the Soda Springs and Laurel Creek watersheds, including sizing methods, sizing Charts, and discussion of performance of these BMPs at managing hydromodification.

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APPENDIX D

Guidance for selection and design of hydromodification management measures

Appendix D – DESIGN GUIDANCE FOR HYDROMODIFICATION CONTROL MEASURES

Table of Contents

1 INTRODUCTION

This appendix focuses on the design of volume- and flow-control structures to assist project proponents to meet the hydromodification management standard.

Any facility that can retain and infiltrate runoff from impervious surfaces helps to manage hydromodification. However, the last facility in a "train" of hydromodification controls or treatment measures proposed by a project proponent must match the flow duration curve of the pre-project condition before discharge to the receiving waters. For example, roadside bioretention can reduce runoff volume, but additional measures must be taken to match the pre-project flow duration curve before final discharge to the receiving stream or storm drain.

There are two basic types of control measures that are considered herein: those with surface storage (pond) and those with sub-surface storage. Ponds are built above ground and their entire volume is available to store stormwater, resulting in the smallest area requirements (e.g., 1/2 to 1/3 of a bioretention facility). Surface ponds can be integrated into parks, athletic fields, golf courses, and other multipurpose areas. Sub-surface storage has a portion of its volume filled with soil, sand and gravel mixtures (e.g., bioretention). This facility type results in larger area requirements because only a portion of the facility's total volume is available for stormwater storage; i.e., primarily the free draining portion of the pore space.

Flow Duration Basins (Infiltration Basins): Basins designed with flow duration criteria captures stormwater and retains a portion to be infiltrated into the ground. This portion can also be discharged at a low rate less than Qcp. An outlet structure is designed to detain higher flows and release them at rates according to flow duration criteria. Unlike water quality basins that specify drain time (often 48 hours at full capacity, and 24 hours at half capacity), flow duration control requires longer drain times that can still be acceptable to mosquito control districts[1].

Bioretention: Bioretention areas are vegetated (i.e., landscaped) depressions that provide storage and pollutant removal by filtering stormwater through the vegetation and soils. Infiltration out the bottom of the facility to the underlying soils occurs at the percolation rate assigned to the soils. Pore spaces and organic material in soils help retain water in the form of soil moisture and promote adsorption of pollutants. Plants utilize soil moisture and promote drying through transpiration. However, winter time evapotranspiration rates are very small such that soil moisture is rarely dried out between storms[2]. Because the available capacity of stormwater storage in the soil is small and the catchment area is about 8 times larger than the bioretention area, the first storm of the season is enough to fill available field capacity following summer and fall. The free draining portion of the soil plus a small proportion of field capacity provides storage for subsequent storms. As a result, bioretention-type facilities must be 2 to 3 times larger than basin-type facilities in order to achieve the same volume reductions (depending on design). Bioretention areas can be

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[1] See section 5.4 of the HMP for further discussion of vector control issues.

[2] For the Laurel Watershed, stream monitoring studies suggest that at least ten to twelve days of drying are needed before any appreciable soil water storage is gained. See Figure B-5 and section 4.1.3 in appendix B for full discussion. This estimate also matches modeled estimates using a rainfall analysis program.

installed in common areas and parks where appropriate, and can be designed to meet the flow duration criteria. Combinations of bioretention and surface ponds can be used. Exhibit A in Appendix E summarizes soil physics, soil moisture and its influence on sizing bioretention facilities.

One other interesting finding is that the normalized *Capture Volume*, and to some degree the *Total Volume*, should be about the same regardless of BMP type or project size. That is, the storage volumes reflect the difference between the pre- and post-developed runoff volume, which is the same regardless of how one plans to manage this quantity. A basin-type hydromodification control measure requires the least amount of land area because it contains 100% stormwater storage. Any measure that replaces stormwater storage with soil must require more land area to achieve the same outcome. This additional land area can be calculated using the basin results and the physical properties of the soil to be used.

The above discussion does not mean to imply that bioretention and similar facilities are not beneficial. Any BMP that can reduce the amount of stormwater runoff entering the stream systems is beneficial. Bioretention swales, rain gardens, planter boxes, green roofs, etc. can reduce the quantity of stormwater runoff from impervious surfaces. The advantage of bioretention type facilities is that they can be placed in common areas or at individual homes where open water storage may not be appropriate, or where vector control issues are of particular concern.

Depending on each development, the more cost-efficient solution for hydromodification management is likely a combination of bioretention-type facilities within the development and a surface storage basin at the end-of-pipe meeting the flow duration criteria before discharge to the receiving stream. Bioretention facilities with stormwater volume reduction can reduce the size, or depth, of the flow duration facility. This facility can be designed as a multi-purpose facility – e.g., a community park; they can even address flood control with proper design.

Vegetated Filter Strips and Swales: Vegetated filter strips and swales are vegetation-lined channels that provide water quality benefits in addition to conveying stormwater runoff. Swales can provide some minor volume reduction, but are not very efficient for hydromodification because there is generally no surface storage to retain stormwater for infiltration. Swales with storage would be called bioretention facilities.

2 SIZING AND DESIGN PROCEEDURES

This section discusses the sizing and design procedures required to meet the flow duration criteria. Project proponents can use one of two methods to size and design hydromodification control facilities: 1) perform a hydrologic and flow duration analysis, or 2) use the design charts provided herein.

The design charts are based on matching the flow duration curves from un-urbanized land in the Laurel Creek/Soda Springs watershed using local infiltration rates and stream channel resiliency. The example projects discussed in Section 3 of this appendix illustrate these procedures.

2.1 Method 1 – Hydrologic and Flow Duration Analysis

The hydrologic and flow duration approach involves: 1) simulating runoff from pre- and post-project conditions using a continuous rainfall approach (30 to 50 years in length); 2) generating flow-duration curves at select discharge points; and 3) designing a volume- and flow-control facility such that when the post-development time series of runoff is routed through the facility, the discharge pattern matches the pre-development flow-duration curve. Parameterization of the hydrologic model would be set-up by using calibrated values, where appropriate, from the HEC-HMS model developed for the HMP. Appendix E (Exhibit B) provides an outline of the procedure used to design a flow control facility. Appendix C provides a detailed explanation of the modeling process, calibration and parameters used.

The volume and flow control facility is essentially a detention/retention basin that diverts and retains a certain portion of the runoff. The portion to be retained is the increase in surface runoff created by adding impervious surfaces, or compacting soil. This captured volume must be infiltrated or released at a fraction of the receiving stream's threshold for bed mobility (i.e., Qcp), and/or diverted to a safe discharge location or storage for reuse.

As shown in Figure D-1, the flow duration basin is conceptualized as having two pools, a low flow pool (Zone A) and a high flow pool (Zone B). The low flow pool is designed to hold the "capture volume" (i.e. the difference in volume of runoff between the pre- and post-development conditions). Zone A will capture small storms that typically do not produce runoff from undeveloped lands, the initial portions of larger storms, and dry weather flows. The high flow pool is designed to detain and release higher flows to maintain the pre-project flow duration curves. The flow duration basin can also serve as a stormwater treatment facility and can be designed to treat dry and wet weather flows using a combination of extended detention and natural treatment processes.

The flow duration basin is sized using an iterative process of adjusting basin storage as well as selecting and adjusting the outlet structure. A stage-storage-discharge relationship is defined for the design under consideration. The 30 to 50-year time series of post-development runoff is routed through the facility and the stored volume and discharges are computed for each time increment (i.e., In-Out = Δ Storage), according to the routing methodology defined in *Hydraulics, A Guide to the Extran, Transport and Storage Modules of the USEPA SWMMM4* (1988). Outflow can take the form of infiltration, evapotranspiration, flows <Qcp, diversions, weir and overflow. A wide range of outlet design styles are possible: weirs, orifices, sand filters, risers, etc.

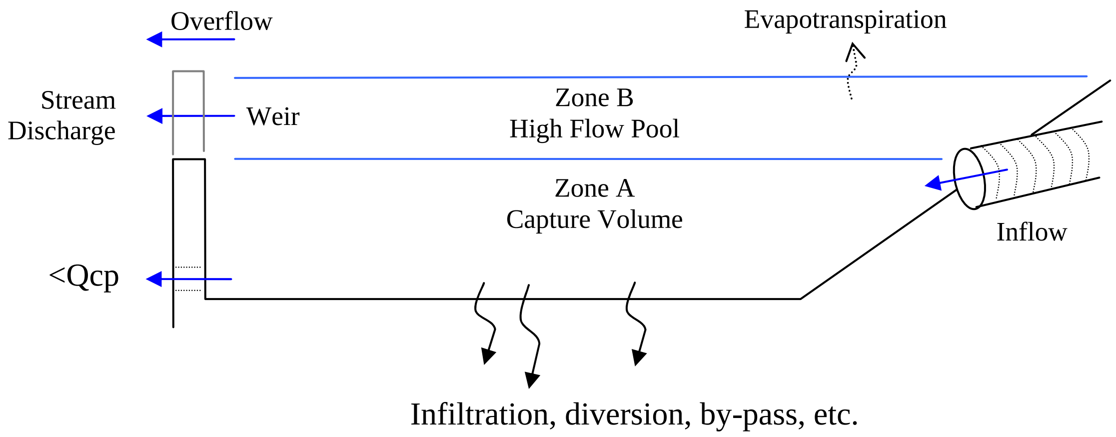

Figure D-1. Conceptualized Configuration of Flow Duration Basin

The low flow pool (Zone A) is sized to capture the increase in runoff volume. This capture volume is dependent on the project's percent imperviousness, soil type and infiltration rates. While the lower pool is sized to capture the correct volume of runoff, the upper pool is sized to detain and discharge larger flows through an outlet structure in such a way as to reproduce the pre-project flow duration curve.

In the Laurel Creek/Soda Springs watershed:

a) <u>The normalized capture volume ranges from 0.6 inches at 25% imperviousness to 1.5 inches at 75% imperviousness.</u>

b) <u>The normalized total required flow duration basin volume ranges from 1.25 inches at 25% imperviousness to about 3.0 inches at 75% imperviousness.</u>

Figure D-5 illustrates these results and is discussed in more detail later in this report. Exhibit B (Appendix E) provides a detailed description of the flow duration basin design process. Exhibit C (Appendix E) provides a summary of site evaluations and percolation tests that are required for proper design and sizing of infiltration type facilities.

2.1.1 Selection of Precipitation

For continuous simulation modeling for the FSURMP HMP, project proponents should use the hourly precipitation record prepared for the hydrologic modeling described in Appendix C. This record, available by request from FSURMP, was based primarily on hourly rainfall recorded at the Fairfield NNE gage near the Laurel watershed between 1942 and 2004, using data from several other locations to adjust and calibrate the record, and to fill in several data gaps.

2.1.2 Selection of Infiltration Rates

Soils in the Fairfield-Suisun area have been defined as Class "C" and "D" soils, with mostly "C" soils in the area where future urbanization is likely to occur (Bates, 1977). Although the percolation rate varies from 0.05 to 0.54 inches per hour, the model-calibrated percolation rate in areas where urbanization is most likely to occur is 0.27 inches per hour. Hydromodification control facility sizing results have been generated for percolation rates of 0.05, 0.27 and 0.50 inches per hour to allow adaptation in areas of varying infiltration rates.

Infiltration is the rate at which stormwater enters the upper soil layer. Percolation is the rate of water loss from the soil surface layer to deeper layers. The percolation rate is used as the rate of infiltration to underlying soils for all hydromodification control facility sizing.

Because infiltration/percolation are such important factors in the effectiveness of hydromodification control facilities, percolation tests must be conducted where the facility is to be located to measure actual percolation rates for design. Exhibit C in Appendix E briefly summarizes the requirements for percolation tests.

2.1.3 Selection of the Low Flow Discharge Rate (Qcp)

The critical flow for stream bed (and/or bank) mobility (Qc) is the threshold flow that creates an applied hydraulic shear stress equal to the defined critical shear stress for the channel boundary (the point at which the bed and/or bank material begins to mobilize). The defined critical shear stress is based on either bed material or bank material, but varies depending on the density of vegetation. Qc is an in-stream, allowable low-flow criteria that cannot be exceeded, (if the stream is to be protected from response to hydromodification) when all sub-areas, including all individual projects or portions of projects, are contributing flow to the stream. Qcp is the fraction of Qc that is proportioned to each project within the watershed and is done to allow project proponents to achieve flow duration control more easily, and to avoid cumulative effects.

It is important to note that Qc and Qcp represent local conditions; i.e., the resilience of the receiving stream. Selecting too high a value for Qcp could concentrate cumulative stormwater discharges above the critical flow and exacerbate erosion problems.

For Laurel Creek, Qc has been estimated for each of the cross sections under study. Table D-1 summarizes the estimated critical flow for two critical shear stress values: 1.0 lbs/sq-ft and 0.32 lbs/sq-ft. The high critical shear stress represents the existing condition where the channel is densely vegetated. The lower critical shear stress value represents the bare soil condition. The existing condition with dense vegetation is used for all analyses and hydromodification control facility sizing. A vegetation management plan would be prudent to maintain this condition indefinitely.

Table D-1. Estimated Critical Flow and Percent of 2-Year Peak Flow

Location	Slope	2-Year Peak Flow	Critical Shear Stress = **1.0** lbs/sq-ft		Critical Shear Stress = **0.32** lbs/sq-ft	
			Qc	% of 2-year peak	**Qc**	% of 2-year peak
		(cfs)	(cfs)	(%)	(cfs)	(%)
SS80	0.006	62	46	74	12	19
SSGC	0.008	101	41	40	7	7
LCGC	0.007	176	43	24	10	6
LCMC	0.009	280	40	14	6	2
Mean Values				**38**		**9**

2-year peak flows estimated from continuous hydrologic model and not a traditional design storm approach. Qc was estimated using normal flow hydraulics at each surveyed cross section. Qc was estimated for the central portion of the channel and not on average channel hydraulics.

For management purposes and ease of implementation the Qc must be generalized and related to the 2-year peak flow. This allows developers and their engineers to determine the low-flow discharge from a project area where the effects of hydromodification (for flows greater than this) become important and must be managed.

Generalizing the results in Table D-1, Qcp for project management is selected to be **20% of the pre-project 2-year peak flow** under the existing conditions of a densely vegetated riparian corridor. A percentage of 20% is based on recommendations by the SF RWQCB. If Qcp were based on soil properties alone (without vegetation), it would be 10% of the 2-year peak[3]. Note that 2-year peak flows were determined from the continuous flow results computed by the calibrated hydrologic model (HMS) and *not* by a design storm approach.

The importance of Qcp in sizing hydromodification control facilities varies depending on the local soil infiltration rates. Qcp is important when local soils are clayey soils. Because Qcp and infiltration are the only means of discharging the increased runoff volume, their relative values determine which is the controlling factor in sizing control facilities. Both infiltration and Qcp are applied in the sizing charts herein.

2.2 Method 2 –Sizing Charts

Method 2 involves using sizing charts for projects (or portions of projects) up to 60 acres. To test the effects of drainage area on the results, the hydrologic and flow duration methodology was applied to projects of 2-acres, 20-acres, and 57.6 acres; with imperviousness ranging from 0% to 100%. This approach has not been verified for projects greater than 60 acres (though larger projects could use this method by dividing the project into multiple drainage areas of less than 60 acres). Sizing charts provided herein were derived using local precipitation, soil type, and receiving stream information in Laurel Creek and Soda Springs. Results are based on the critical shear stress assumptions described above.

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[3] This is similar to the value that SCVURPPP chose to use in their HMP, as many of the streams in that area have already been significantly impacted by hydromodification and have lost the protective vegetative cover.

Sections 2.2.1 through 2.2.5 present the standard sizing charts describe the design process. Section 2.2.6 summarizes the sizing procedure in a step-by-step outline to allow for ease of implementation.

2.2.1 Sizing Hydromodification Control Facilities

This method is used for two types of volume and flow control: 1) a flow duration control basin and 2) a bioretention facility. The flow duration control basin provides above ground storage of stormwater, whereas the bioretention facility has a portion above ground and a portion sub-surface. Note that these designs DO NOT account for flood control requirements. However, flow duration basins can be adapted to meet appropriate peak flow controls specified by local flood control agencies. If flood control and hydromodification control facilities are combined, the resulting basin must meet both flood control and hydromodification control standards (i.e. one regulation does not supersede the other).

Though there are a large number of possible configurations for the flow duration basins, some features were held constant to prepare the sizing charts. Depths are limited to 3-feet to 6-feet so that these BMPs can be integrated into multi-purpose community facilities and/or landscaping areas. The outlet structure is limited in type and size, and held constant as much as possible to facilitate adequate outlet design by others.

The easiest way to convey the modeled facility configuration is to illustrate the design pictorially. Figure D-2 presents an illustration of the flow duration basin designed to match the flow duration curves from undeveloped lands. The basin has a width and length that varies by project size and percent imperviousness. The basin has 2:1 side-slopes and a constant depth at 3-feet. Infiltration occurs everywhere the surface is inundated. In this example, the high flow weir is 6 feet wide and 6-inches deep, and contains a 6-inch by 6-inch notch. The bottom 2 feet of the basin represents Zone A (the capture volume), whereas the top 1 foot represents Zone B, the flow duration matching volume.

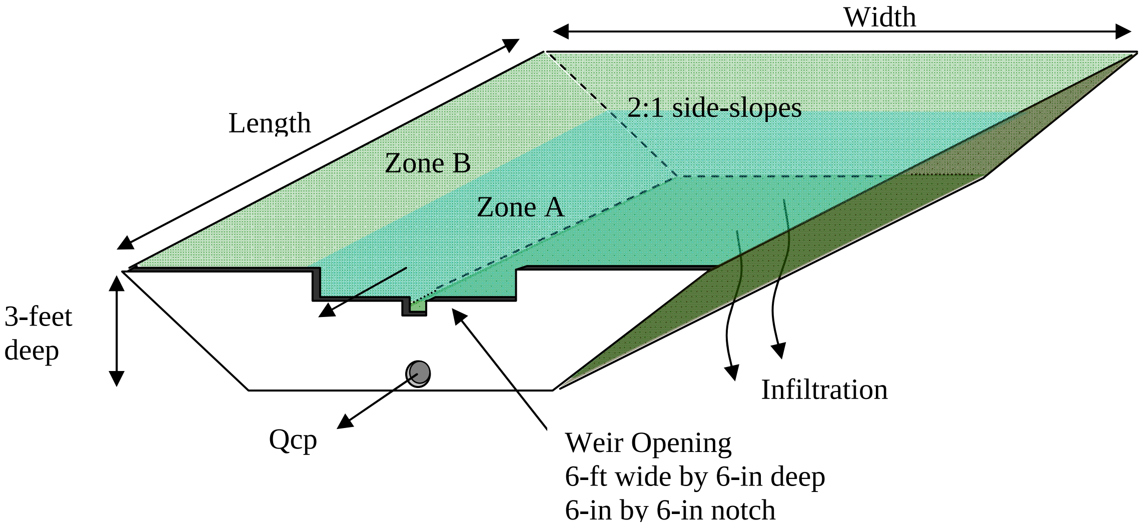


Figure D-2. Illustration of Flow Duration Basin

Figure D-3 presents an illustration of a bioretention facility designed to match the pre-project flow duration characteristics. The basin has a width of 10-feet overall and a length specified in the sizing process (*Area* is provided in sizing charts). The basin has 4:1 side-slopes and a surface water depth of 12-inches at its middle section. Considering the side-slopes, the average water depth is 7.2-inches. The high flow weir is 1-foot wide and 6-inches deep.

The bottom 24-inches of the basin are filled with soil. The selected hydraulic conductivity of this media for the design charts is 1.5 in/hr (3 ft/day). The rate at which water percolates through this media increases as ponding occurs on the surface according to Darcy's Law. The representative capture volume is the volume below the crest of the weir. Exhibit A in Appendix E summarizes soil physics, soil moisture and its influence on sizing bioretention facilities.

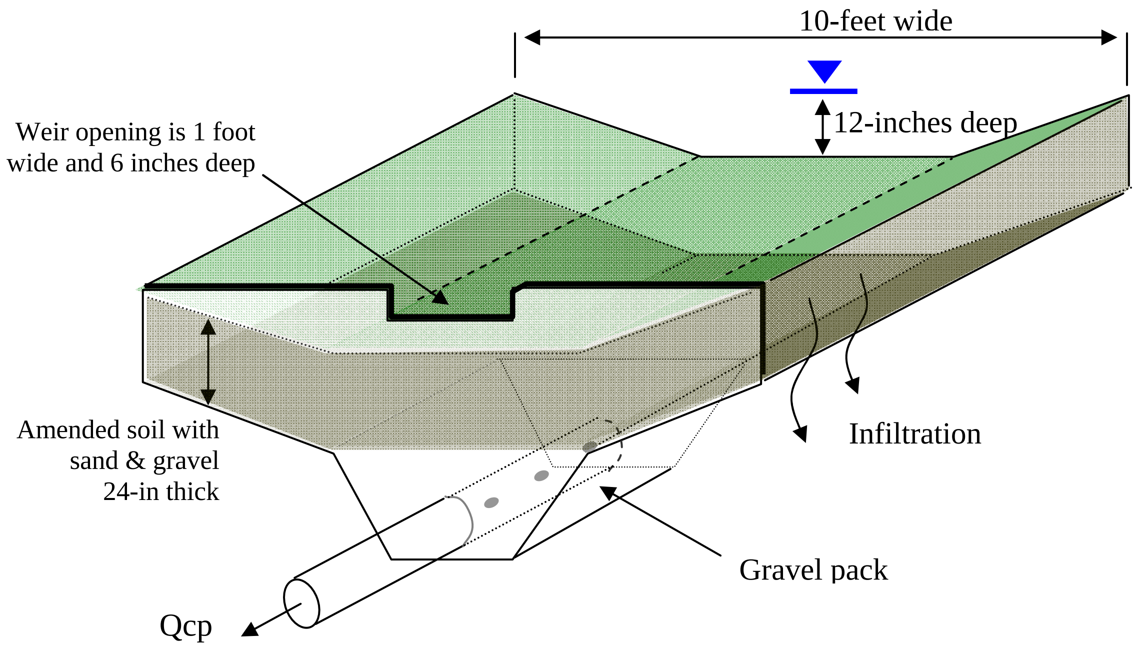


Figure D-3. Illustration of Bioretention Facility

2.2.2 Normalized Sizing Charts

Figures D-4 through D-8 provide the sizing charts generated from the Fairfield-Suisun HMS model. Figures D-4 and D-5 summarize the volume requirements and Figure D-6 summarizes the area requirements for hydromodification management. Figures D-7 and D-8 provide additional details for basin design.

Figures D-4 and D-5 provide the resulting Capture Volume and Total Volume sizing charts for hydromodification management in the Fairfield-Suisun area. These curves provide results using a drainage area of 60 acres. It should also be noted that the drainage area is the same for both pre and post-developed conditions. In other words, the BMP is placed outside the drainage area, which is held constant.

Curves are provided for three infiltration rates (or more correctly percolation rates) observed in the Fairfield-Suisun area; and are based on using 20% of the 2-year peak flow criterion (for Qcp). Exhibit C (in Appendix E) describes the percolation tests required for proper selection of the sizing curve. For intermediate infiltration rates, interpolation between curves is acceptable.

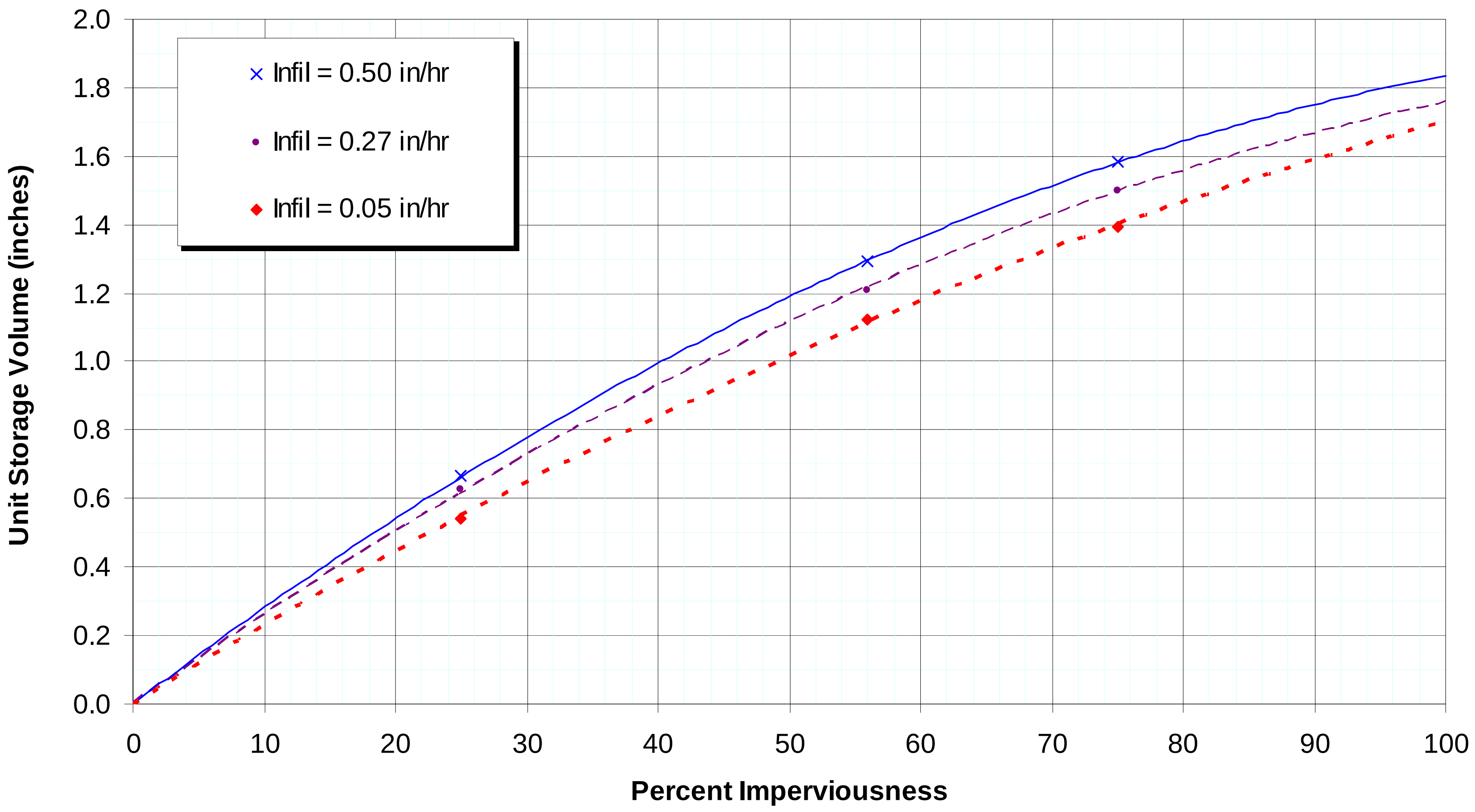
These facilities are predicted to have 2 to 3 overflow events within the 56-year period of record used in the analysis. The design engineer will be required to show that these large flood events will not cause local flooding and property damage, and that discharges will meet all local flood control requirements.

Using a project's estimated percent imperviousness, a project proponent multiplies the *Unit Storage* requirements from Figure D-4 and D-5 times the total project area to derive the total required stormwater storage volume and capture volume for BMP design. For example, a project with 60 percent imperviousness and an infiltration rate of 0.27 in/hr; requires 1.3 inches of capture volume and 2.6 inches of total stormwater storage per unit area of catchment draining to the basin.

$$BMPCaptureVolume(cf) = 1.3 inches \cdot \left(\frac{1 ft}{12 in}\right) \cdot CatchmentArea(acres) \cdot \left(\frac{43560 sqft}{acre}\right)$$

$$BMPTotalVolume(cf) = 2.6 inches \cdot \left(\frac{1 ft}{12 in}\right) \cdot CatchmentArea(acres) \cdot \left(\frac{43560 sqft}{acre}\right)$$

Figure D-4 Required Capture Volume for Hydromodification Management Measures



Fairfield-Suisun local precipitation and watershed characteristics
Qcp = 20% of Pre-Project 2-year peak flow from continuous hydrologic model.

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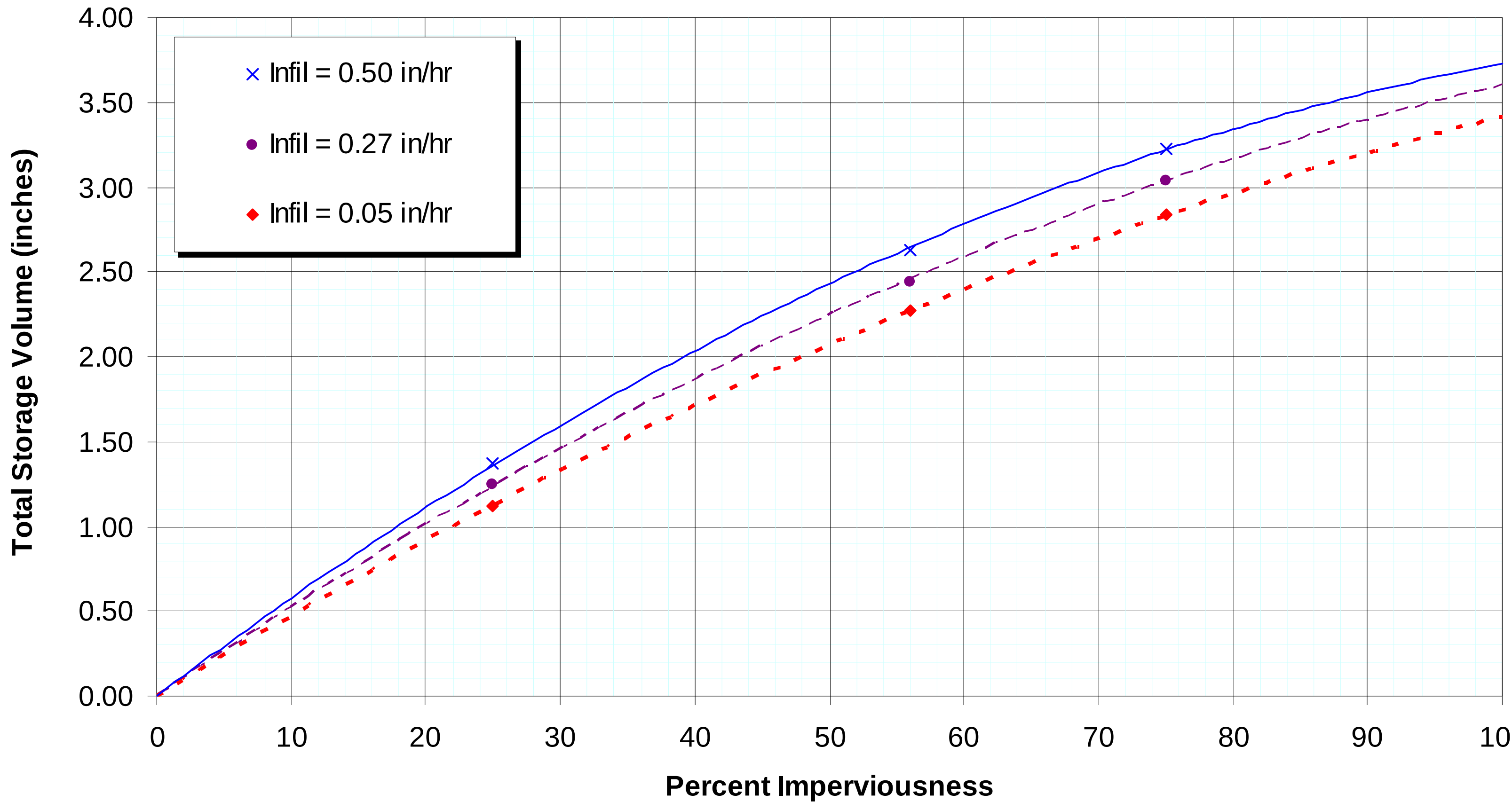
Figure D-5 Required Total Volume for Hydromodification Management Measures



Fairfield-Suisun local precipitation and watershed characteristics
Qcp = 20% of Pre-Project 2-year peak flow from continuous hydrologic model.

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AREA REQUIREMENTS

Control facilities designed to address hydromodification require separate *Area* sizing charts. A deeper basin will result in smaller surface area requirements. Area can be adjusted between 2 and 6-feet deep as long as the capture volume and total volume remain as specified above.

Figure D-6 provides the *Area* requirements for hydromodification management for the three infiltration rates under study. Both the Area requirements for a flow duration basin (100% water storage) and a bioretention facility are provided. Area requirements for a FDC basin, based on 3-feet deep facilities, range form zero up to 11% depending on percent imperviousness and infiltration rates. Area requirements for a bioretention facility ranges from zero to 19%.

Using a project's estimated percent imperviousness and control type, a project proponent multiplies the *Unit Area* requirement from Figure D-6 times the total catchment area to derive the total required land area for flow duration control. For example, a project with 60 percent impervious requires the equivalent of 7.4% of the catchment area for hydromodification management.

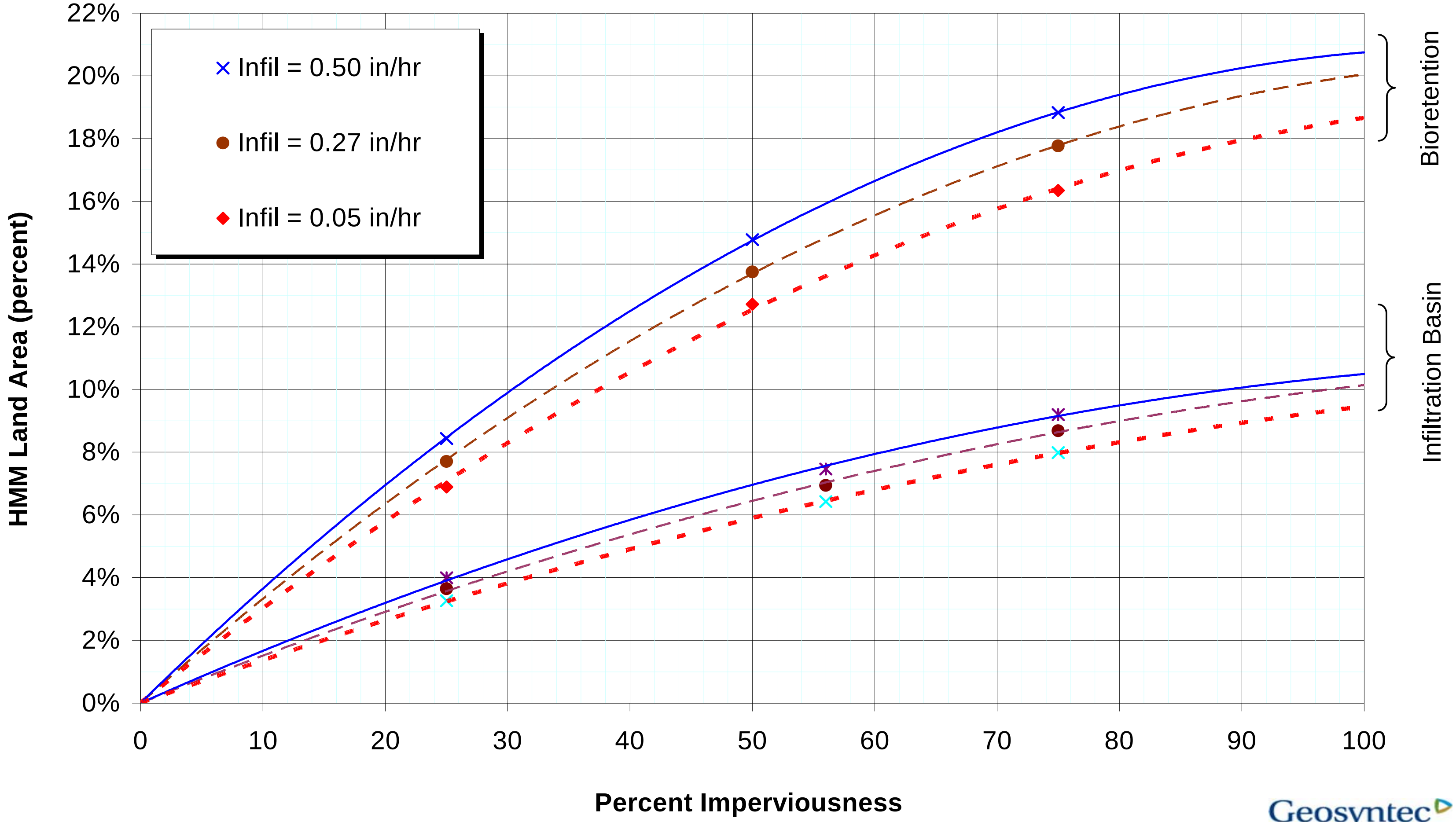
$$ControlArea(acres) = 7.4\% \cdot CatchmentArea(acres)$$

Figure D-6 also provides sizing curves for a bioretention facility. The flow duration basin is 3-feet deep with 2:1 side-slopes, while the bioretention facility is 10-feet wide overall and has 4:1 side-slopes. Excluding the underlying filter outlet for Qcp discharges, the bioretention facility is also 3-feet deep. Also, these sizing results for a bioretention facility are based on using a drainage area of 2-acres and shouldn't be extended to areas much larger than this (perhaps up to 4 acres would be OK).

The difference between areas for the two BMP types is a consequence of the amount of sub-surface water storage in the soil matrix. In other words, we have filled a large percentage of the BMP volume with soil sacrificing some storage to the soil mass. The remaining total storage is the porosity, which ranges from 38% to 55% depending of soil type. However, 10% to 40% is held in the pores of the soil matrix by capillary forces (the so-called sponge effect) and does not drain by gravity. The sponge is referred to as the field capacity and can only be dried by evapotranspiration. Winter time evapotranspiration rates range from 1 to 2 inches per month and is much less than the infiltration rates used in the sizing. As a consequence, ET from the soil matrix is assumed to be negligible.

The only portion of the soil column emptied between storms is the free draining portion (porosity – field capacity). In the sizing of the bioretention facility, we have assumed that the soil column only has 20% pore space as free draining storage available from storm to storm during the winter season.

Figure D-6 Area Requirements for Hydromodification Management Facilities



Fairfield-Suisun local precipitation and watershed characteristics
Qcp = 20% of Pre-Project 2-year peak flow from continuous modeling.

2.2.3 Determining the Outlet Structure Configuration

Many outlet configurations and basin sizes are possible, which makes it difficult to standardize the outlet design. To assist developers and agency personnel, the sizing charts have been based on a constant outlet configuration, as much as possible. These outlet designs must be reproduced in order to achieve the correct flow control.

The low flow discharge (Qcp) can be controlled by an orifice hole in a headwall or by using a sand filter and perforated pipe design. Any other design that controls the low flow discharge to below Qcp would be acceptable, provided adequate demonstration is made that the orifice design meets this requirement. Figure D-2 illustrates the orifice low-flow outlet. Figure D-3 illustrates the sand filter outlet. The orifice is sized so that it discharges Qcp at maximum water depth. The sand filter area is sized so that the discharge into the perforated pipe is equal to Qcp. The rate at which water passes through the soil matrix is defined by Darcy's Law. Once the filter size is determined, it is held constant while the bioretention area is sized accordingly. In the examples used to derive the sizing charts, an orifice hole was applied for 20-acre and above projects. The 20-acre project has a 4-inch diameter orifice, while the 60 acre project has a 7.5-inch orifice. For 2-acre projects using the bioretention facility, the rate at which water passes through the soil times the horizontal area is used to control the low flow discharge. The perforated drain pipe is not the controlling factor.

The weir outlet is designed so that its crest occurs at the top of Zone A, the capture volume; and is used to discharge the high flow pool. The geometry of the weir outlet shall be as shown in Figure D-7 and shall be capable of discharging the 10-year peak flow[4]. For project sizes in between the ones shown in Figure D-7, weir dimensions may be interpolated.

2.2.4 Selecting the low-flow discharge rate (Qcp)

Qcp is the maximum rate at which the capture volume of the hydromodification control facility can be released to the receiving stream without inducing erosion. As described in section 2.1.3 above, we have defined Qcp to be 20% of the 2-year flow, as calculated using the continuous model, based on the test study results in the Laurel Creek watershed. Because the use of the sizing charts does not require the development of a continuous model for facility sizing, we provide an alternate method of estimating the 2-year flow, as shown in Figure D-8. This figure shows 2-year peak flow as a function of project size and infiltration rate. Note that the flows shown on Figure D-8 are based on continuous modeling, and therefore may not be the same with design storms or other methods to produce a 2-year storm.

2.2.5 Resulting Flow Duration Curves for Sizing Charts

Exhibit D in Appendix E provides the resulting flow duration curves generated when developing the Sizing Charts. These figures show flow duration curves for the pre- and post-project runoff and the resulting post-project runoff with controls.

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[4] As described above, the outflow from the project may need to meet both flood control and hydromodification control standards.

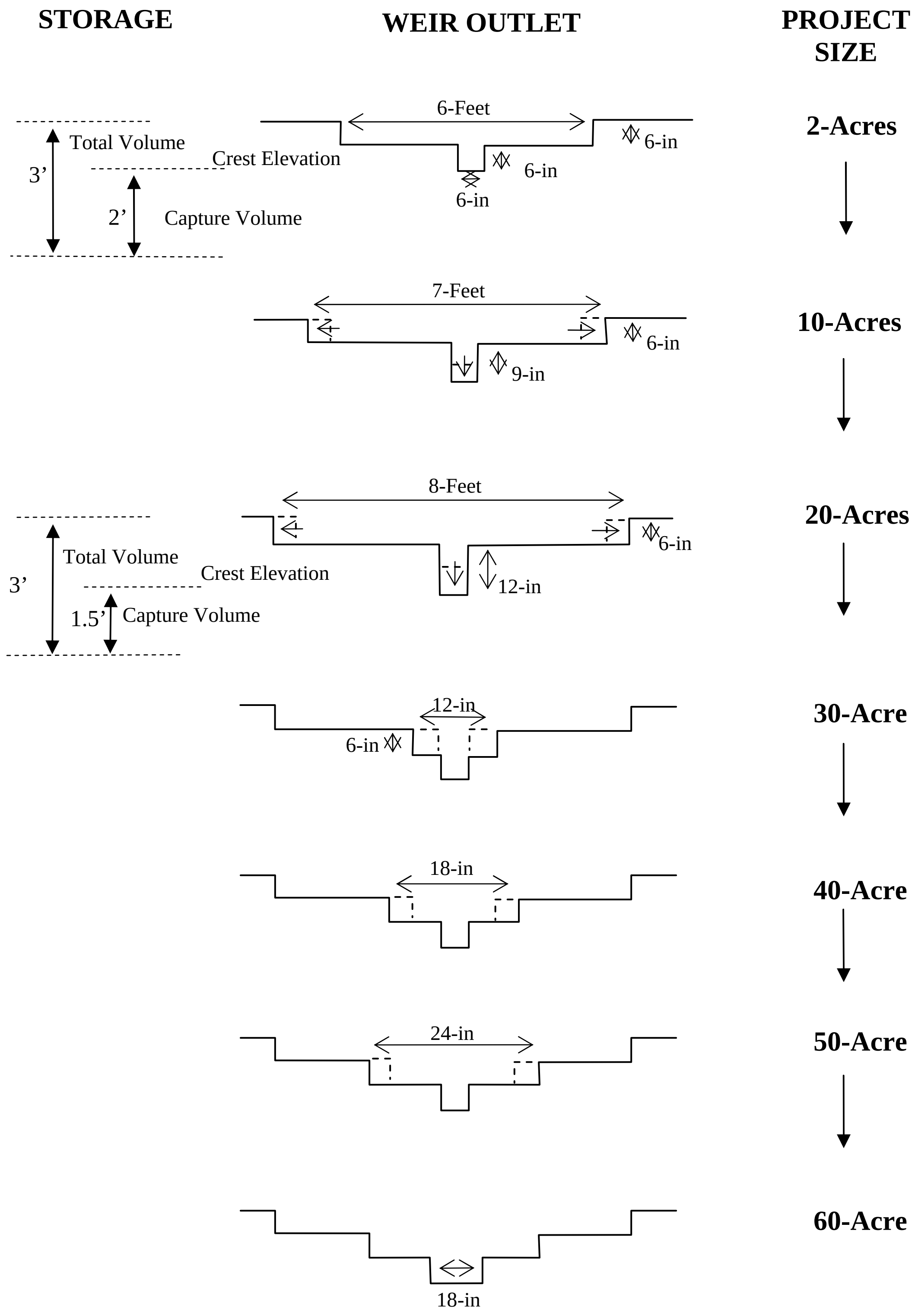

Figure D-7. Example Basin Outlet Configurations

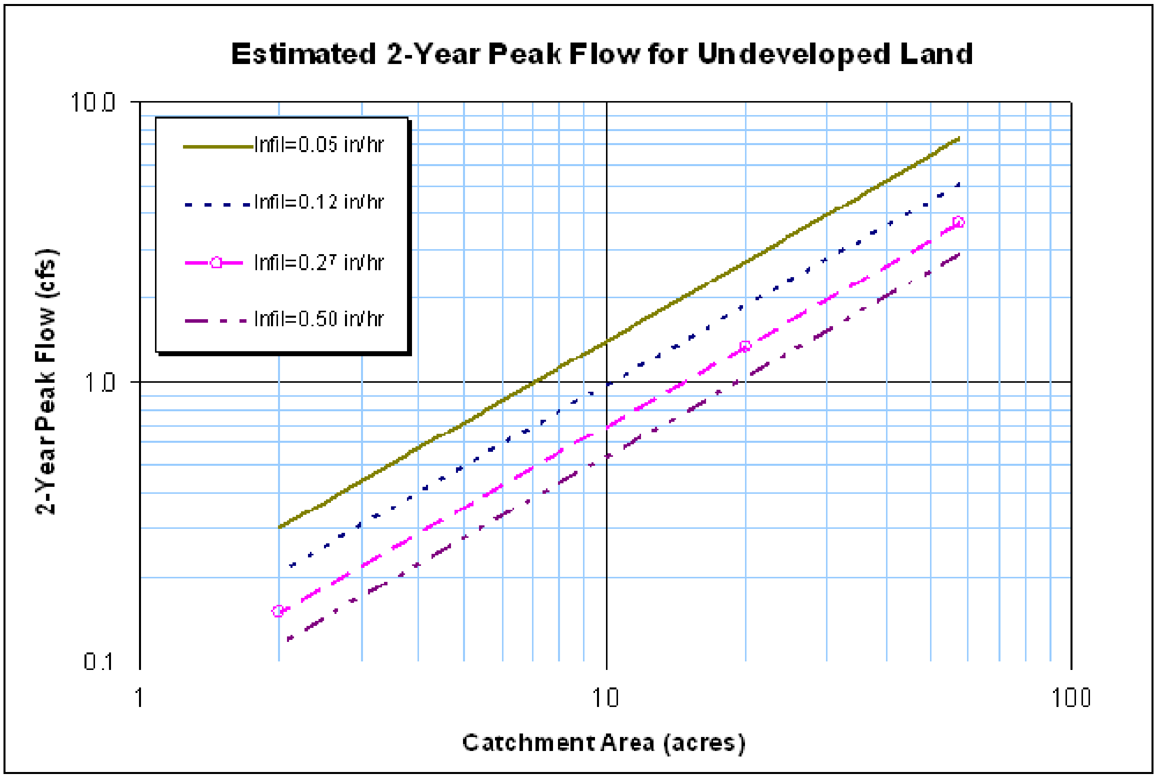

Figure D-8. Two-year peak flow as a function of catchment area and infiltration rate. Qcp for the FSURMP HMP is defined as 20% of the 2-year pre-project peak flow.

2.2.6 Summary of sizing chart design procedure

This section summarizes the process for designing hydromodification control facilities using the sizing charts provided above.

Step 1: Delineate the total catchment area draining to the proposed hydromodification control facility, and determine the percent of the area planned to be covered by impervious surfaces (streets, walkways, rooftops, compacted earth, etc.)[5].

Step 2: Estimate the average infiltration rate of the soils within the catchment. For initial planning purposes, the soil properties listed in USDA soil survey are appropriate. However, these estimates must be tested in the field, following

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[5] Total catchment area includes the area planned for the hydromodification control facility. For example, if an entire 10-acre project is planned to drain to a single flow duration basin, use 10 acres as the total catchment area. The resulting basin, then, would be incorporated into the 10-acre project.

Solano County percolation test guidelines (see Appendix E, Exhibit C for summary), and adjusted as necessary for preparation of final designs.

Step 3: Using Figures D-4 and D-5, determine the required "capture volume" and "total volume" of the hydromodification control facility for the infiltration and percent imperviousness of the catchment area.

Step 4: If designing a flow duration basin, use Figure D-6 to determine the area requirements for the flow duration basin. These area requirements assume a total depth of three feet, with 2:1 side-slopes, and can be applied to catchment sizes between one and sixty acres. See section 2.2.1 for design requirements.

Step 5: If designing a bioretention facility, use Figure D-6 to determine required area. Bioretention basins are limited to catchment areas less than or equal to 4 acres. These area requirements assume a depth of surface ponding (below the weir outlet) of one foot, two-feet of amended soil, and 4:1 side-slopes. See section 2.2.1 for specific design requirements.

Step 6: Slight modifications can be made to the standard designs, making adjustments in length, width and depth. However, the resulting facility must maintain the capture and total volume as determined in Step 3.

Step 5: Design outlet structure using standard configurations shown in Figure D-7. For project sizes between those shown in Figure D-7, interpolate the required outlet dimensions.

Step 6: Estimate the non-urbanized two-year peak flow from the project site using Figure D-8. Calculate Qcp as 20% of the 2-year peak flow, and design the low-flow outlet to discharge no greater than this rate at maximum ponding depth.

Step 8: Summarize results in a table, including area of project draining to facility, the percent imperviousness of the project area, the "capture" and "total" volume required for hydromodification control, the type of control facility, and the dimensions of the facility and the outlet structure. Supply maps and diagrams showing the location of the proposed facility, the contributing drainage area, and facility design (including outlet structure).

3 EXAMPLE PROJECTS

3.1 Example project for a large Hydromodification Basin

This example highlights the sizing process for a 57.6 acre project, consisting of primarily residential development. This example reflects the anticipated urbanization within the upper Soda Springs/Laurel watershed, and could be used for planning a regional hydromodification basin in that area. This area has been described in Appendix C and is part of the overall calibrated hydrologic model (Sub-catchment 11). Future development is assumed to be residential with 56 percent as impervious surfaces. The soil deep infiltration rate is 0.27 inches per hour and is used for the hydrologic calculations as well as the basin sizing. The 2-year peak flow, as determined from the continuous model results[6], is 3.44 cfs and therefore Qcp is estimated to be 0.69 cfs (i.e., 20% of the 2-year peak flow). The 10-year peak flow is estimated to be 9 cfs.

Table D-2 lists the resulting flow duration basin *Area* and *Volume* requirements, as well as the Unit Area and Volume. Results are provided for a 3-foot deep and 6-foot deep basin. The capture volume and total BMP volume are 5.9 acre-feet and 11.6 acre-feet respectively. The required land area is 4.0 acres assuming a 3-foot deep storage basin and 2.1 acres assuming a 6-foot deep basin. Side-slopes are 2:1. This is equivalent to 7% and 3.5% of the project area (with 57.6 acres) dedicated to stormwater management facilities, respectively.

Table D-2. Summary of Basin Sizing for 57.6 acre Development

Unit Volumes		Basin Dimensions			
Capture Vol. (Inches over catchment)	Total Vol. (Inches over catchment)	Depth (feet)	Area (acres)	Capture Volume (ac-ft)	Total Volume (ac-ft)
1.22	2.42	3	4.0	5.86	11.62
		6	2.1	5.86	11.62

Table D-3 summarizes the outlet configuration and dimensions derived when sizing the flow duration basin for flow duration control. The outlet consists of a weir and orifice hole as described previously.

Figure D-9 presents the resulting flow duration curves for the existing (pre-project), future and future with FDC scenarios. The existing condition has about 2000 total hours of runoff, and the future condition is predicted to increase the total to 10,000 hours or more. High flows under existing conditions are about 15 cfs while under future conditions the maximum flow increases to about 22 cfs.

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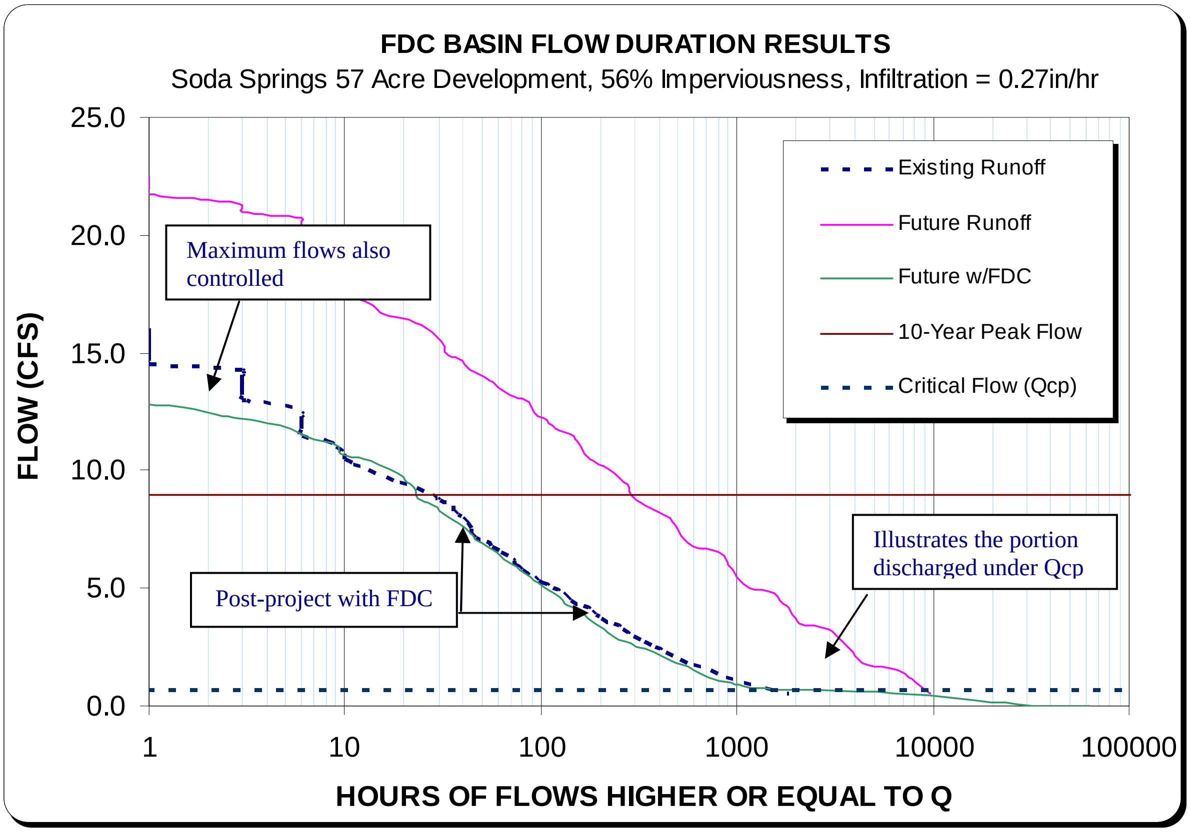
[6] Peak flows were determined from a flood frequency distribution for all runoff events in the period of record using the continuous model results and the plotting position method.

Table D-3. Outlet Configuration and Dimensions for 3-Foot Deep Basin

Weir Dimensions		Orifice Dimension		
Crest Elevation (ft)	**Length** (ft)	**Invert** (ft)	**Diameter** (inches)	**Qcp** (cfs)
1.5	1	0	3.75	0.69
2.0	2			
2.5	8			

This figure also shows the effect of allowing Qcp. The post-project with FDC curve exceeds the existing curve for flows less than Qcp. This part of the curve reflects the portion of stormwater captured but released at rates less than Qcp.



Maximum flows also controlled

Post-project with FDC

Illustrates the portion discharged under Qcp

Figure D-9. Resulting Flow Duration Curves for 57 Acre Development in the Soda Springs Watershed

Figure D-10 illustrates the difference between the pre- and post-project (with hydromodification control) flow duration curves. The post-project with hydromodification control curve shows a close match to the existing curve, being under the existing curve for flows greater than Qcp. A small exceedance is allowable as defined by the “Goodness-of-fit” definition. Note that the number of Bin’s selected when generating the histograms and flow duration curve (frequency distribution) is set to 100 and is best to keep this Bin number constant between land cover scenarios.

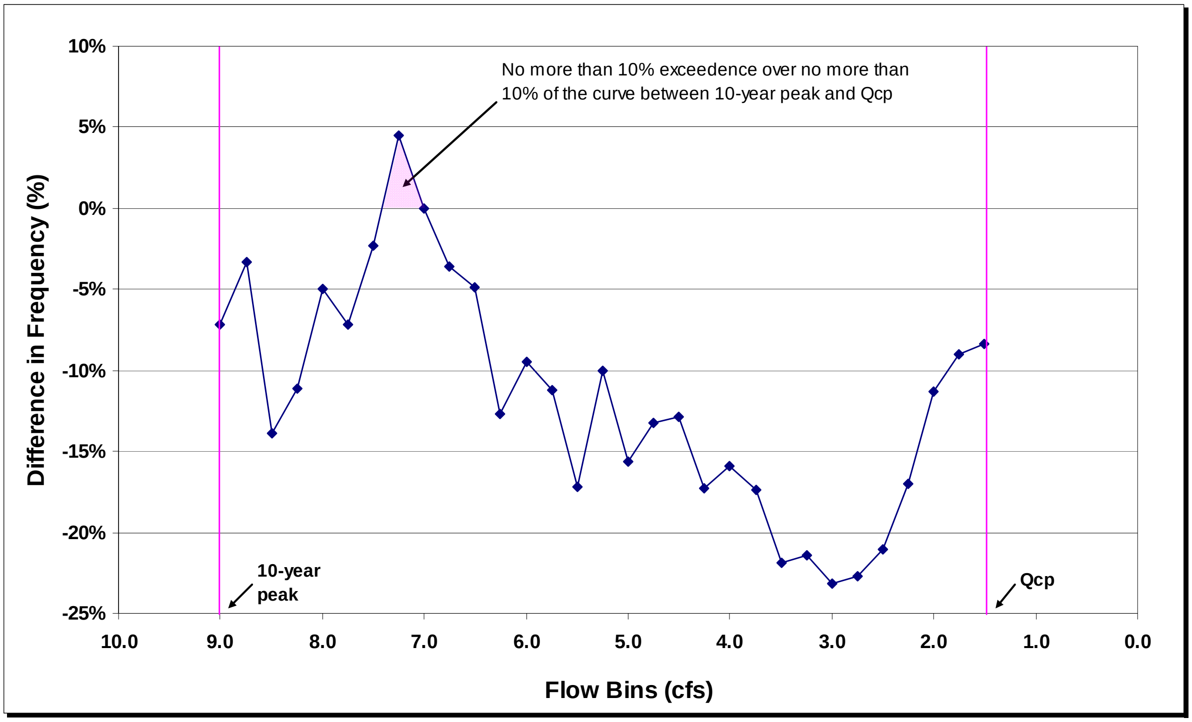


Figure D-10. Goodness-of-Fit Comparison for Pre- and Post-Development with Flow Duration Control BMP Installed

3.2 Sizing Results for a 2-Acre Catchment using Bioretention

This example is for a small, 2-acre catchment, using three different estimates of imperviousness—25%, 50%, and 75%. Table D-4 lists the resulting bioretention *Area* and *Volume* requirements. The 2-year peak flow, as determined from the continuous model results[7], is 0.15 cfs and therefore Qcp is estimated to be 0.03 cfs (i.e., 20% of the 2-year peak flow). The 10-year peak flow is estimated to be 0.5 cfs.

Table D-4. Summary of Bioretention Sizing for 2-acre Development

Percent Imperviousness	Unit Volumes		Bioretention Dimensions		
	Capture Vol. (inches over catchment)	Total Vol. (inches over catchment)	Area (acres)	Capture Volume (ac-ft)	Total Volume (ac-ft)
25	0.62	1.25	0.16	0.10	0.21
50	1.12	2.25	0.28	0.19	0.38
75	1.50	3.05	0.32	0.36	0.51

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[7] Peak flows were determined from a flood frequency distribution for all runoff events in the period of record using the continuous model results and the plotting position method.

Note that the *Area* requirements are about 2 times that for the flow duration basin mention above. The required area for bioretention ranges from 7.8%, 13.8% and 18% for development for 25%, 50% and 75% imperviousness, respectively.

Table D-5 summarizes the outlet configuration and dimensions derived when sizing the bioretention facility for flow duration control. The outlet consists of a weir and infiltration through soil as described previously.

Table D-5. Outlet Configuration and Dimensions

Weir Dimensions		Under Drain Dimensions			
Length (ft)	Crest Depth (ft)	Width (ft)	Length (ft)	Depth (ft)	K ft/day
1	0.5	2	250	1.5	3

Figure D-11 presents the flow duration curves for existing (pre-project), future and future with FDC scenarios. The existing condition has about 1400 total hours of runoff, and the future condition is predicted to increase the total to 5,000 hours. High flows under existing conditions are about 1.6 cfs while under future conditions the maximum flow increases to about 5 cfs (not shown). In this example, there are no exceedances of the undeveloped land. The curves do show the exceedance below Qcp, which increases the total hours of flows in the channel to 11,000.

Figure D-12 illustrates the difference in the resulting flow duration curves. In this case, there is No exceedance of the pre-project curve for flows between the 10-year peak flow and the project Qcp. It would be possible than to shave a small amount off of the bioretention area and re-run the analysis until a small amount of exceedance occurs as allowed under the Goodness-of-Fit test.

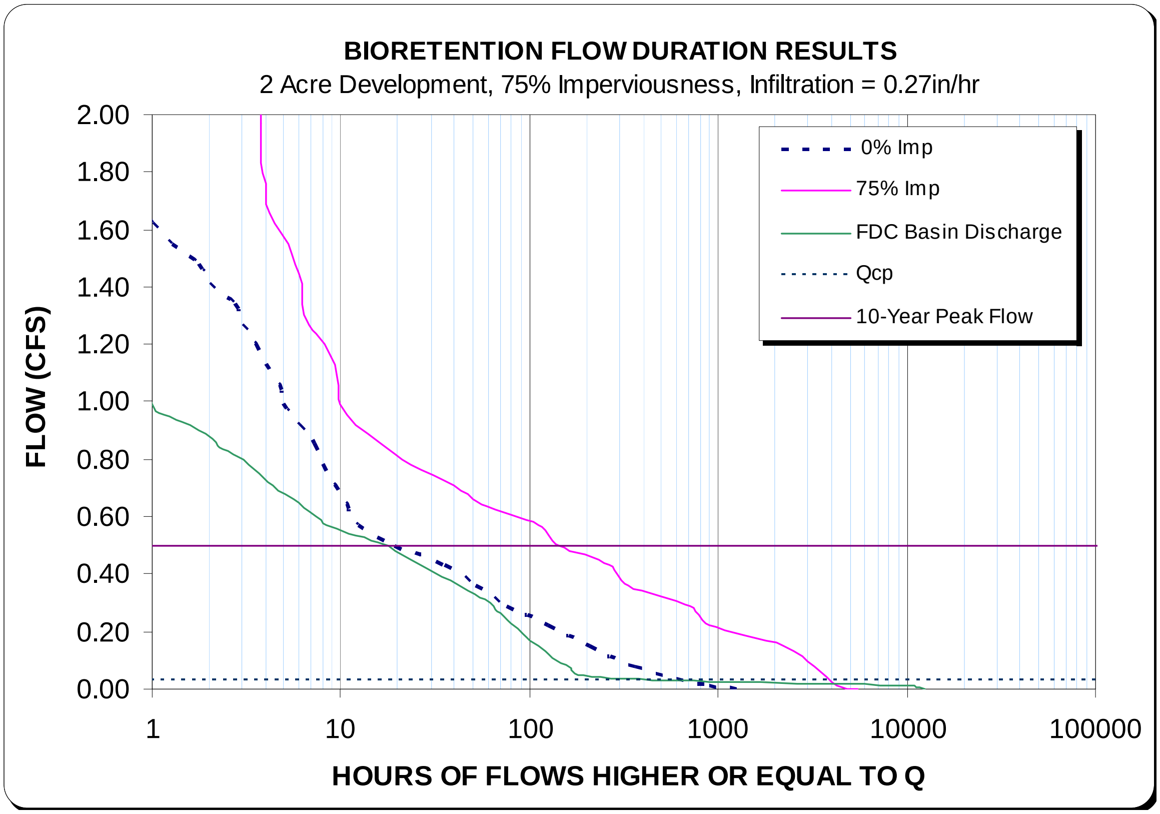

Figure D-11. Resulting Flow Duration Curves for 2-Acre Development with 75% imperviousness using Bioretention

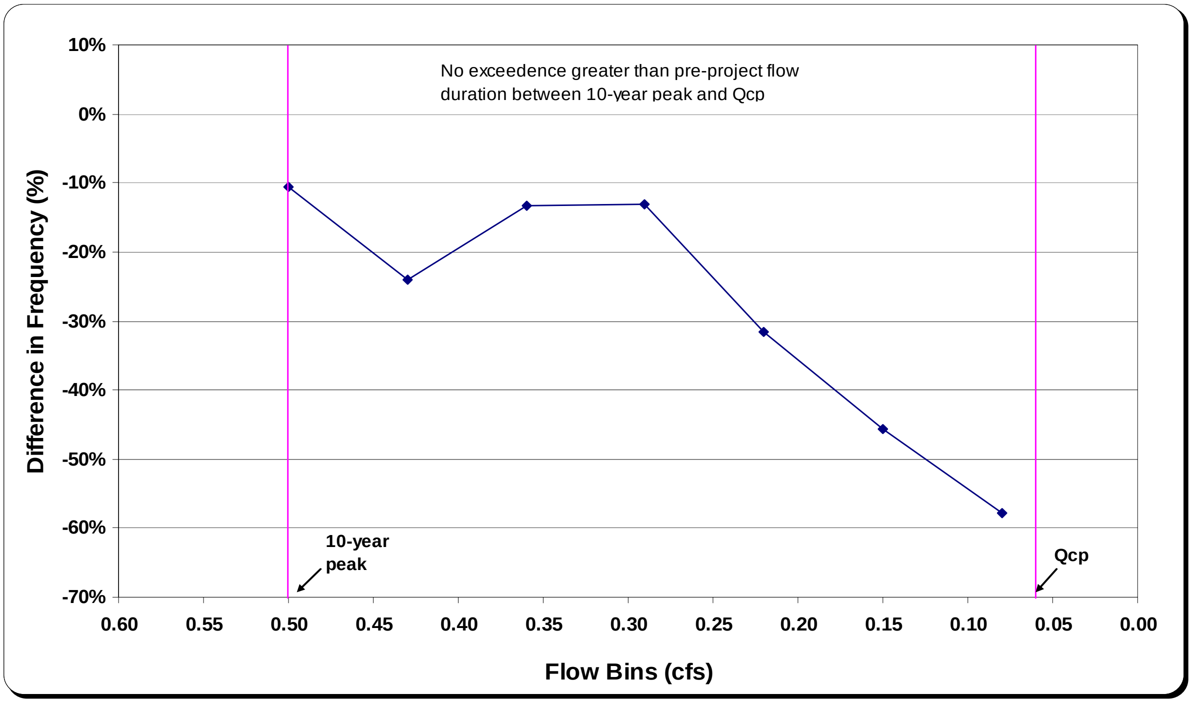

Figure D-12. Goodness-of-Fit Comparison for Pre- and Post-Development with Bioretention BMP Installed

APPENDIX E

Technical memoranda and attachments

APPENDIX E

Technical memoranda and attachments

EXHIBIT A

TO: SCOTT BROWN
BALANCE HYDROLOGICS

FROM: GARY PALHEGYI
GEOSYNTEC CONSULTANTS

SUBJECT: **MODELING OF BIORETENTION BMPS FOR HYDROMODIFICATION**

DATE: APRIL 10, 2006

This exhibit outlines GeoSyntec's understanding of soil and plant physics as it relates to evapotranspiration and modeling of bioretention facilities for hydromodification. This understanding led to the choices GeoSyntec made while modeling the bioretention facility for hydromodification management and preparation of the Area Requirement Charts. Bioretention and other similar BMPs constructed with soil and plants will generally follow these conditions.

Bioretention areas are vegetated depressions that provides storage and pollutant removal by filtering stormwater through the vegetation and soils. Pore spaces and organic material in soils help retain water in the form of soil moisture and promote adsorption of pollutants. Plants utilize soil moisture and promote drying of soil through transpiration. However, winter time evapotranspiration (ET) rates are very small such that the component available to plants (field capacity) is rarely dried out between storms (average of 10 to 12 days between storms in Bay Area). For this reason, stormwater modelers often neglect ET.

Because the available capacity of stormwater storage in the soil is small, the first storm of the season is likely to fill any available field capacity following summer and fall. If plants are to be kept alive during the summer, property owners must irrigate these areas, so field capacity will already be partially full and above the wilting point. Generally, it's the free draining portion of soil (porosity – field capacity) plus a tiny bit of field capacity (winter ET) that provides storage for subsequent storms. As a result, GeoSyntec is finding that bioretention facilities <u>must be 2 to 3</u> times larger[1] than the basin type facility (flow duration or infiltration basin) in order to achieve the same volume reductions and flow control.

One other interesting finding is that the normalized *Capture Volume*, and to some degree the *Total Volume*, should be the same regardless of BMP type or project size. That is the capture volume represents the difference between the pre- and post-developed flow duration curves, which is the same regardless of how one plans to manage this quantity. A basin type BMP requires the least amount of land area because it contains 100% stormwater storage. Any BMP type that replaces stormwater storage with soil must require more land area to achieve

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[1] This of course depends on the depth of surface water storage and the depth of soil used in the BMP.

the same outcome. This additional land area can easily be determined by proportion using the basin results and the physics of soil.

GeoSyntec does not mean to imply that bioretention and similar facilities are not beneficial. Any BMP that can reduce the amount of stormwater runoff entering our stream systems is beneficial. Bioretention swales, rain gardens, planter boxes, green roofs, etc. can reduce the quantity of stormwater runoff from impervious surfaces. The advantage of bioretention type facilities is that they can be placed in common areas or at individual homes where open water storage may not be appropriate.

Depending on each development, the more likely solution for hydromodification management is a combination of bioretention type facilities within the development and a surface storage basin, flow duration basin, at the end-of-pipe meeting the flow duration criteria before discharge to the receiving stream. The bioretention facilities would reduce the size, or depth, of the flow duration facility, which could be designed as a multi-purpose facility – e.g., a community park.

SOIL PHYSICS

The figure below helps illustrate the proportions of water storage in a column of soil and the mechanism by which this water is lost. The range of values presented represents different soil and plant types.

Soil Porosity: The amount of open-space, or voids, in the soil matrix that can be filled with water. The porosity of a BMPs soil represents the total amount stormwater storage possible.

Field Capacity: The field capacity of soil is the amount of water that is retained in the soil column by capillary forces and adhesion to minerals and cannot drain from the soil. This is the portion often referred to as the *sponge*. This portion does not drain as percolation to the underlying soils, but can only be depleted by ET.

Wilting Point: The wilting point is a measure of soil moisture below which plants will die. If soil moisture drops below this level capillary forces are greater than the plants ability to draw moisture from the soil and as a result plants cannot obtain this water for transpiration.

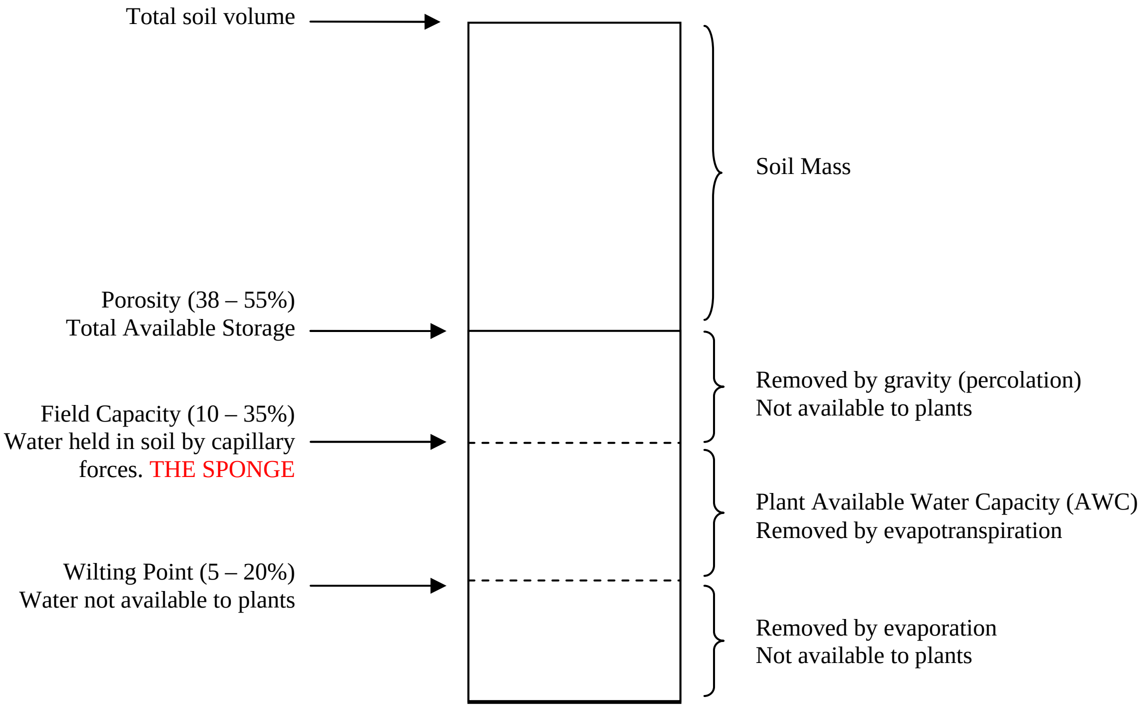
The difference between total amount of storage possible (Porosity) and the Field Capacity drains by gravity as percolation and is too rapid for plant use. The difference between Field Capacity and the Wilting Point is that portion of water available for plant uptake and ET. This portion is defined as the plant Available Water Capacity (AWC). Water at and below the wilting point is too difficult for plants to extract.

In summary, starting at saturation:

1) 20% to 28% of the total water stored at saturation drains as percolation to underlying soils (Porosity – Field Capacity). This is the modeled percolation rate and is usually the same as the developing area percolation rate.
2) 10% to 35% makes up the so-called SPONGE; i.e., Field Capacity.
3) 5% to 15% can be removed by evapotranspiration (AWC)

4) 5% to 20% can be removed by evaporation. This portion can be lost to the atmosphere by heating of the soil surface by the sun and drying by wind. This occurs after the plants have died.

Once the soil becomes saturated, water flows through the soil column at the percolation rate, or what ever the limiting factor is.



EVAPOTRANSPIRATION RATES

This section briefly summarizes measured evapotranspiration rates at CIMIS stations in the Bay Area, which are compared to the percolation rates used in the modeling.

According to NRCS, percolation rates are around 0.02 inches per hour to 0.20 inches per hour for Class "D" soils (no specific location just generally speaking). According to CIMIS, reference Evapotranspiration rates (ETo) for three Bay Area locations in the winter time are:

	Nov	Dec	Jan	Feb	March	April	Avg
Suisun Valley	1.41	0.88	0.60	1.34	3.01	4.67	2.0
Morgan Hill	1.77	0.98	1.22	1.65	3.42	4.84	2.3
Brentwood	1.76	1.01	0.95	1.75	3.48	5.37	2.4

ETo is a reference evapotranspiration rate that allows agricultural folks to compute the rates for specific crops (ETc). The simplest equation is:

$$ETc = Kc\ ETo$$

Exhibit A

Kc is a crop coefficient that ranges from 0.3 to 1.2 for different crop types; where 1.2 occurs in the summer time for high water use crops. As an example for Bermuda grass (a warm season grass), Kc = 0.85. During the low growing winter season Kc can drop to 0.75.

	Dec	**Jan**	**Feb**
Bermuda grass	1.02	1.19	1.62

The point is that vegetation ETc rates are around 1.0 to 2.0 inches per month during the low growing winter season, and have only minor affects on the modeling results for bioretention facilities. These rates do go up during other months of the year.

Now how do we convert inches/month to inches/hour for comparison to percolation rates and modeling? Two options are considered here: divide equally throughout period (24 hours a day) or divide into day light hours only. Of course this could be complicated by considering cloudy days with no rain, high humidity, less sun, less heat and very little ET.

	24 hours day	**11 hours day light**
ETo = 1.0	0.00137	0.00298
ETo = 1.5	0.00206	0.00447
ETo = 2.0	0.00274	0.00596

Note that once the soil column becomes saturated, it will stay moist throughout most of the winter. Balance Hydrologic field data shows that about 6.5 inches of rainfall occurred before the watershed soils reached saturation and began producing runoff.

For a BMP example, given 24-inches of soil (bioretention depth) at 30% field capacity provides 7.2 inches of sponge water storage, but only 1 to 2 inches can be evapotranspired from this portion in a month between Dec through Feb. GeoSyntec’s rainfall analysis of several Bay Area gages shows that storms arrive on average every 10 to 12 days, or in other words there are roughly 10 to 12 dry days between storms. If we get several storms each month, the soil's field capacity barely dries out between storms; i.e., about one-third of 1 to 2 inches per month is evapotranspired between storms on average. Therefore, the amount of soil storage available for stormwater (following the first storm of the year) is the free draining portion (15% to 28%) plus one-third of say 2 inches from field capacity.

Does this mean that stormwater following initial saturation mostly passes through the soil column at the percolation rate of the underlying soil? Probably Yes. In the modeling done for the bioretention facility, GeoSyntec assumed that stormwater stored in the bioretention facility is lost to percolation to the underlying soils and as Qcp.

Exhibit A

Organic Matter (Soil Amendments)

We also found a paper describing the relationship between Organic Matter and Field Capacity and discovered that amending the soil with organic matter may not help BMP performance from a hydromodification management point of view. For example:

1) Adding organic matter increases Field Capacity.
2) Adding organic matter to sand can raise it FC from 10% to 30%.
3) Adding organic matter to silty-loam raises its FC from 25% to 40%.

If we raise the Field Capacity and the plant AWC, which is good for plants, more water is held in the sponge and less stormwater is free draining. In other words, less stormwater drains out the bottom as percolation and more water is held in storage that can only be depleted by ETc. This in affect reduces the soil columns available storage following the first storm of the season.

Would it not make sense to create a sand/gravel mixture so more stormwater is removed at the percolation rate of the underlying soils?

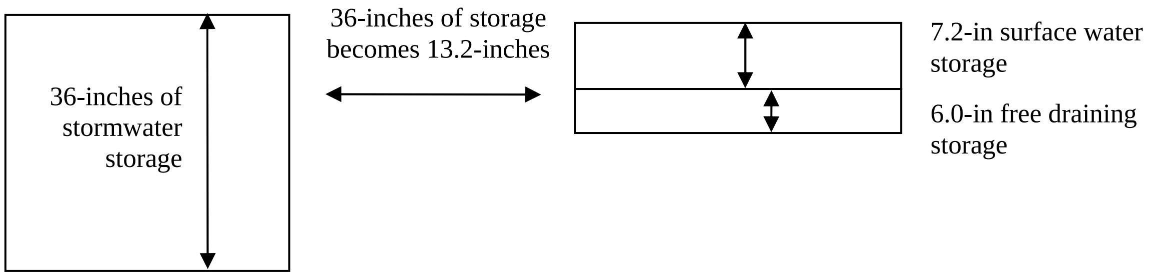
PREDICTING THE BENEFITS OF MODELING EVAPOTRANSPIRATION

A simple analysis can be conducted that illustrates how much larger bioretention facilities must be from a basin type facility with and without the affects of evapotranspiration. For this analysis, a comparison is made between a basin having 100% water storage and a bioretention facility, where everything is constant between facilities (e.g., depth, percolation rate, and Qcp) except that the bioretention facility is partially filled with soil. The required land area will be used to measure differences.

Consider a 3-foot deep flow duration basin (or infiltration basin); how much land area would be required to achieve the same storage (i.e., capture volume)?

Assume the bioretention facility has the following characteristics:

- An average of 7.2-inches of water depth[2].
- An average of 24-inches of soil with 25% of free draining storage equals 6.0-inches of available storage.



Therefore:

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[2] A typical bioretention design is 10-feet wide with 12-inch of water depth in the middle but having 4:1 side slopes all along its length. So, 8 out of 10 feet in width averages 6-inches of water depth and 2 out of 10 feet average 12-inches. Thus the result is an average of 7.2-inches.

Exhibit A

$$36 - in \cdot \left(Ba\sin - acres \right) = 13.2 - inches \cdot \left(Bio - acres \right)$$

$$\frac{36 - in}{13.2 - in} \cdot \left(Ba\sin - acres \right) = \left(Bio - acres \right)$$

or, for the given sizing scenario:

Bioretention area = 2.7 times the Basin area

Next, if we add in ETc at one-third of 2-inches (i.e., 0.67 inches), then 13.2-inches of available storage becomes 13.9-inches. 36-in/13.9-in = 2.6, or a reduction in the required bioretention area of 4%. In other words, given the assumptions made herein, the bioretention facility area requirement could be reduced by about 4% by incorporating ETc into the sizing analysis.

Note that 2-inches is the winter time average Eto in the Fairfield-Suisun area. The average winter time ETo for Morgan Hill is 2.3-inches, resulting in a 5% reduction in required bioretention area for hydromodification management.

Also note that different design assumptions in terms of shape, depth of water and soil will result in different area requirements and reductions due to ETc.

CONCLUSIONS

We could certainly debate the details, but this simple analysis illustrates the following:

- The available storage for stormwater in a column of soil is the free draining portion plus a small fraction of the field capacity.
- ETo and ETc rates are 1 to 2 orders of magnitude smaller than percolation rates for class "D" soils and 2 to 3 orders of magnitude smaller than class "A/B" soils.
- During winter, the amount of stormwater removed from the BMP via evapotranspiration is roughly one-third of 2-inches. This water is removed from the AWC.
- Bioretention facilities have 2 to 3 times the area requirements of surface storage basins, because a portion of the total storage is filled with soil.
- Bioretention area requirements can be 4% to 5% smaller by incorporating ETc into the sizing method/modeling.
- For these reasons, modelers often neglect ETc when sizing bioretention BMPs and use this assumption as a means to be slightly conservative in specifying normalized sizing criteria.

EXHIBIT B

TO: SCOTT BROWN
BALANCE HYDROLOGICS

FROM: GARY PALHEGYI
GEOSYNTEC CONSULTANTS

SUBJECT: **PROCEDURES FOR SIZING A FLOW DURATION BASIN**

DATE: APRIL 10, 2006

1. Data file preparation
   a. Need long-term (30 to 50-years) stormwater runoff records for pre- and post-development conditions. These are generated using hydrologic programs, such as HEC-HMS, SWMM, and HSPF. Input to these programs is a long-term precipitation record, project area and development information, and soils information, to produce a long-term continuous runoff record. Because the FSURMP HMP applies to a relatively small area with annual precipitation variation of only a couple of inches, the use of the composite rainfall record (described in Appendix C) is appropriate.
2. Compute Pre- and Post- Flow Duration Curves
   a. For each of the runoff records, compute a histogram[3] and cumulative frequency distribution of the hourly runoff values. Use the post-project record to select histogram flow range and Bin increments. Use consistent increments for the pre-project flow histogram and the post-project with control measures in place histogram. The post- condition with highest flow defines the maximum flow Bin.
   b. When generating the cumulative frequency distribution it is preferable to begin the count with the largest flow Bin proceeding downwards to the smallest value. The cumulative frequency distribution is the flow duration curve.

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[3] A histogram is a graphical representation of the frequency distribution of a series of data. The histogram provides a visual impression of the shape of the distribution as well as the amount of scatter. A histogram is developed by dividing the range of values in the data set into 100 equal intervals (**Bin**). The procedure is to count the number of data points that fall into each interval, thereby counting the frequency of occurrence of flows with similar magnitudes for each interval.

Exhibit B

3. Select Initial Estimates for Basin
    a. Area: set the starting area at ~2% to 7% of the catchment area. Flow duration basins in catchments with clay soils are about 2%, while basin collecting runoff from sandy soils can be up to 7%. This seems to be a reasonable starting point.
    b. Depth: range from 2 to 6 feet. The storage of the basin will be determined from the iterative analysis; however, local jurisdictions may have limitations on depth of a basin. Depths of 6-feet or more or in excess of 15 acre-feet of storage fall under the jurisdiction of the Department of Safety of Dams (DSOD). Shallow depths may be preferred for multi-purpose facilities, such as parks and golf courses.
4. Select Initial Estimate for Outlet Structure
    a. Start with ONLY a bottom orifice, which is sized to discharge at a maximum rate equal to the critical flow rate (Qcp) when the basin is full. The volume of the initial flow duration basin can be approximated by routing post-project flows through this basin with the bottom orifice and weir overflow, and then comparing the total number of hours of the resulting flow duration curve at Qc to the pre-project curve at this flow magnitude. Adjust the volume of the initial flow duration basin so that these curves match in total number of flow hours at Qc. Increasing the basin storage volume moves the flow duration curve to the left. Decreasing storage volume moves the curve to the right.
    b. After adjusting the basin storage volume, then add one orifice at ¾ of the effective depth of the basin. Set the orifice diameter at 6 inches. The lowest orifice corresponds to the lowest arc of the flow duration curve.
    c. After adjusting the basin storage volume and adding the first orifice, then add a second orifice at ⅞ of the effective depth of the basin. The combined first and second orifice corresponds to the second arc of the flow duration curve, and represents the combined flows.
    d. Increasing the lower orifice diameter will adjust the slope and curvature of the lowest arc of the flow duration curve. Increasing orifice diameter increases the range of flow magnitude that can be discharged through this orifice, which shifts the arc upwards. Decreasing orifice diameter reduces the lowest arc.

   e. Increasing or decreasing orifice elevation shifts the transition point between arcs along the flow duration curve. Increasing the elevation moves the transition point left and upwards, while decreasing the elevation moves the point right and downwards.
   f. Increasing storage volume also helps match the curve in the upper high flow range. In most cases, the facility can be sized so that a small amount of overflow occurs during infrequent large flows.
   g. Refinements should be made in small increments and performing one change at a time. It is best to begin with sizing the storage volume and then adjusting the number/size of the lowest orifice to match the lowest part of the flow duration curve first. Then proceed upwards by adding and adjusting the next highest orifice discharges to match the remaining portion of the flow duration curve.
5. The range of discharge capacity should approx. match the range of pre-urban discharge
   a. Orifice diameters should be selected such that the range of flows, given the range of hydraulic head on the orifice, approximates the range of flows discharging from the site under pre-project conditions.
6. Stage-Discharge Relationship
   a. The stage-discharge relationship is defined by the sum of all the outflows from the basin. Discharge by infiltration through the wetted bottom of the basin, through a small orifice discharging at the critical flow rate (Qcp) and through the outlet structure designed to match the pre-project flow duration curve.

EXHIBIT C

TO: SCOTT BROWN
BALANCE HYDROLOGICS

FROM: GARY PALHEGYI
GEOSYNTEC CONSULTANTS

SUBJECT: **PERCOLATION TESTS FOR DESIGN AND SIZING OF INFILTRATION TYPE BMP FACILITIES**

DATE: APRIL 10, 2006

All soils types will require percolation testing to determine the design parameters for sizing and design of flow duration control basins, infiltration basins, bioretention facilities, or any BMP intended to provide infiltration of stormwater.

The Solano County Code (Chapter 6.4, Sewage Standards, Article VIII) summarizes the site evaluation and percolation test requirements to be considered for stormwater infiltration BMPs. One major difference between the regulations and the proposed BMPs is that the regulations apply to waste water disposal and as such would be more restrictive than necessary for stormwater infiltration.

Limitations on locating infiltration-type facilities shall generally be as specified in Article VIII. On-site and regional infiltration systems shall not be installed in areas subject to erosion or landslide. Installations in low swampy areas, in areas with permanent or intermittent springs, in areas with a high groundwater within two feet of the ground surface shall not be acceptable.

A site evaluation report shall include all data relative to the proper placement, design and operation of an on-site infiltration system, including, but not limited to, percolation tests, soil profiles, depth to groundwater, slope measurements and surface water flow for each basin.

Soil characteristics shall be evaluated by profile observation within the boundaries of each proposed infiltration basin location. At least one excavation using a backhoe (or similar equipment) in the basin location shall be required. Section 6.4-81.2 describes the soil profile characteristics to be reported and the classification schedule to be used. Percolation tests shall be performed as described in Section 6.4-81.2, performed or supervised by a registered engineer in compliance with Solano County’s approved percolation test procedures. Percolation test holes shall be placed uniformly into the undisturbed soil horizons in the proposed location of the infiltration basin. At least three holes shall be placed in each proposed basin location. Test holes shall be constructed to the depth of the bottom of the proposed basin. Direct observation of groundwater shall utilize performance wells or piezometers. At least one well shall be constructed in the infiltration basin area. The location of the well(s) shall be accurately depicted on all site plans.

Exhibit C

Because the proposed BMPs apply to infiltrating stormwater runoff from primarily residential neighborhoods and some commercial areas, some limitations specified for waste water disposal do not apply. Some interpretation of these regulations will be required by the design engineers. For example, sandy and loamy soils with high percolation rates are ideal for stormwater infiltration, but are less than ideal for waste water treatment. According to Section 6.4-81.2, Table 1, if pre-treatment of the waste water is performed the limiting depth to groundwater can be reduced to 2-feet. Depths-to-groundwater or other limiting factors could be set at 3-feet for stormwater infiltration facilities.

EXHIBIT D

TO: SCOTT BROWN
BALANCE HYDROLOGICS

FROM: GARY PALHEGYI
GEOSYNTEC CONSULTANTS

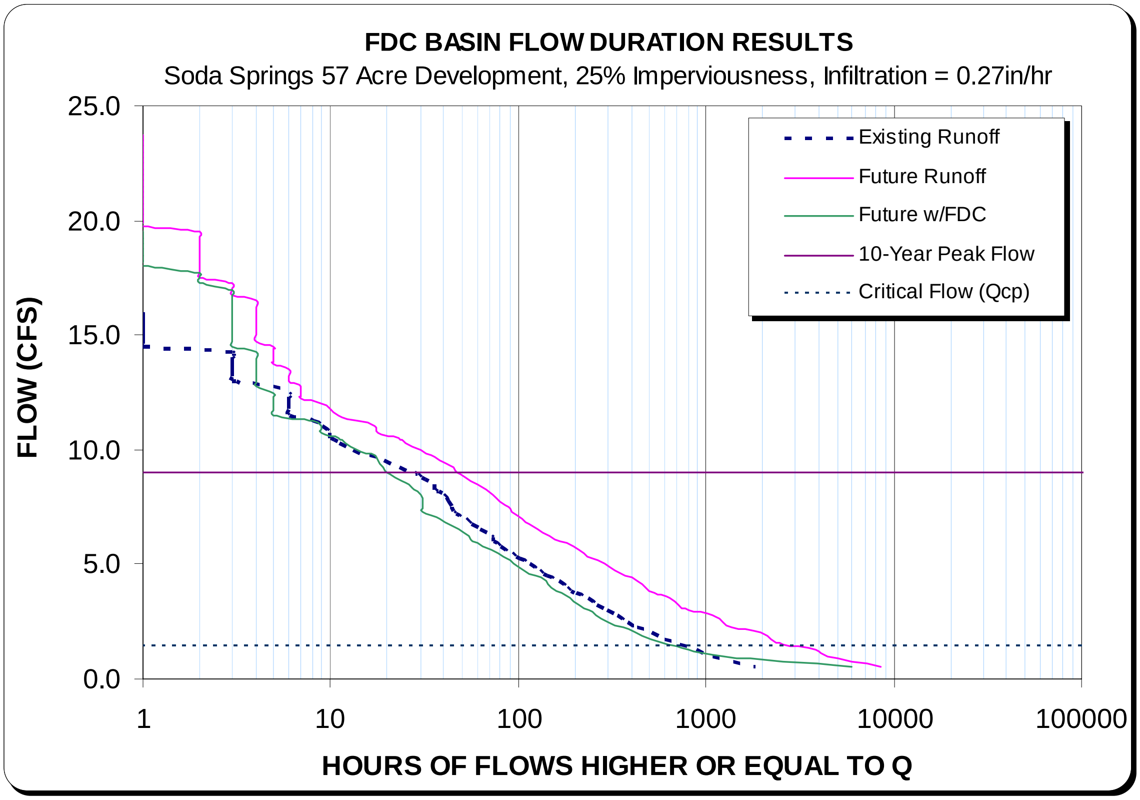
SUBJECT: **RESULTING FLOW DURATION CURVES FOR SIZING CHARTS AND EXAMPLES**

DATE: APRIL 10, 2006

Exhibit D provides the resulting flow duration curves used in generating the hydromodification control measure sizing data. These sizing data led to the Sizing Charts presented in Appendix F.

Flow duration curves are provided for the sizing of FDC basins for 2 acre, 20 acre and 57.6 acre developments; and for soil infiltration rates of 0.05 in/hr, 0.27 in/hr and 0.50 in/hr. Curves are also provided for bioretention facilities capturing runoff from 2 acre developments.

Exhibit D


FDC BASIN FLOW DURATION RESULTS
Soda Springs 57 Acre Development, 25% Imperviousness, Infiltration = 0.27in/hr
FLOW (CFS)
25.0
20.0
15.0
10.0
5.0
0.0
1
10
100
1000
10000
100000
HOURS OF FLOWS HIGHER OR EQUAL TO Q
Existing Runoff
Future Runoff
Future w/FDC
10-Year Peak Flow
Critical Flow (Qcp)

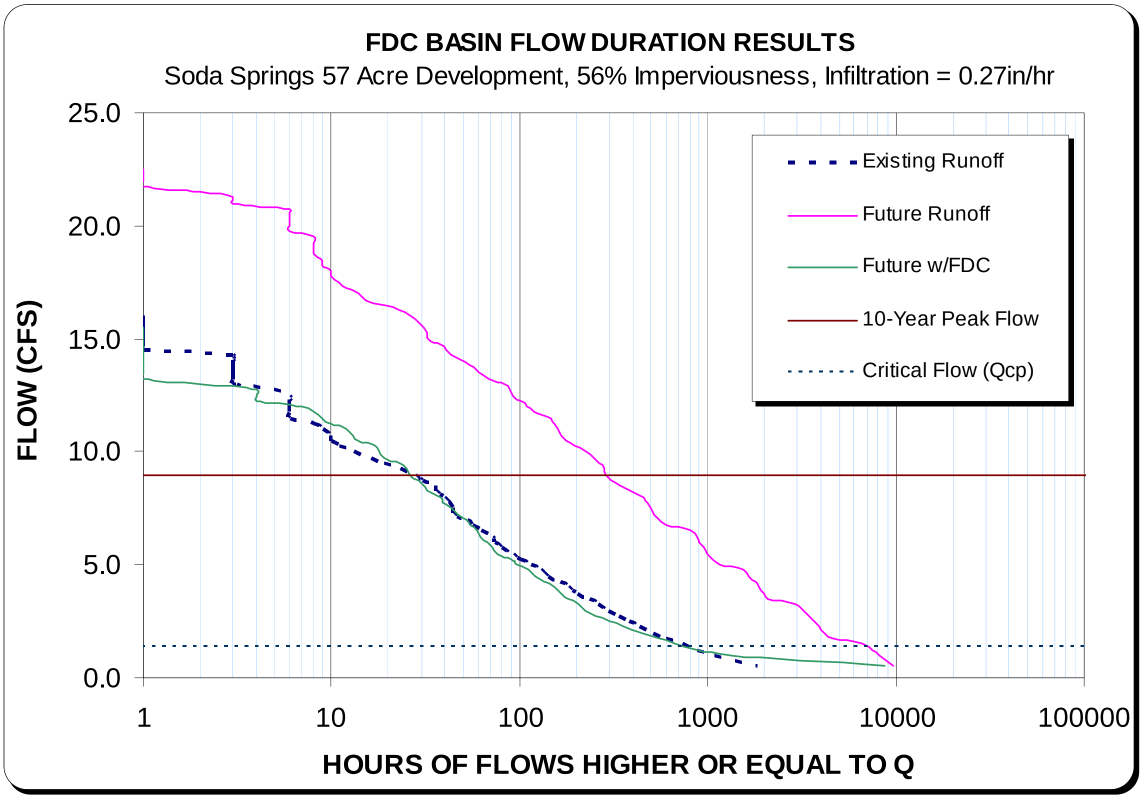
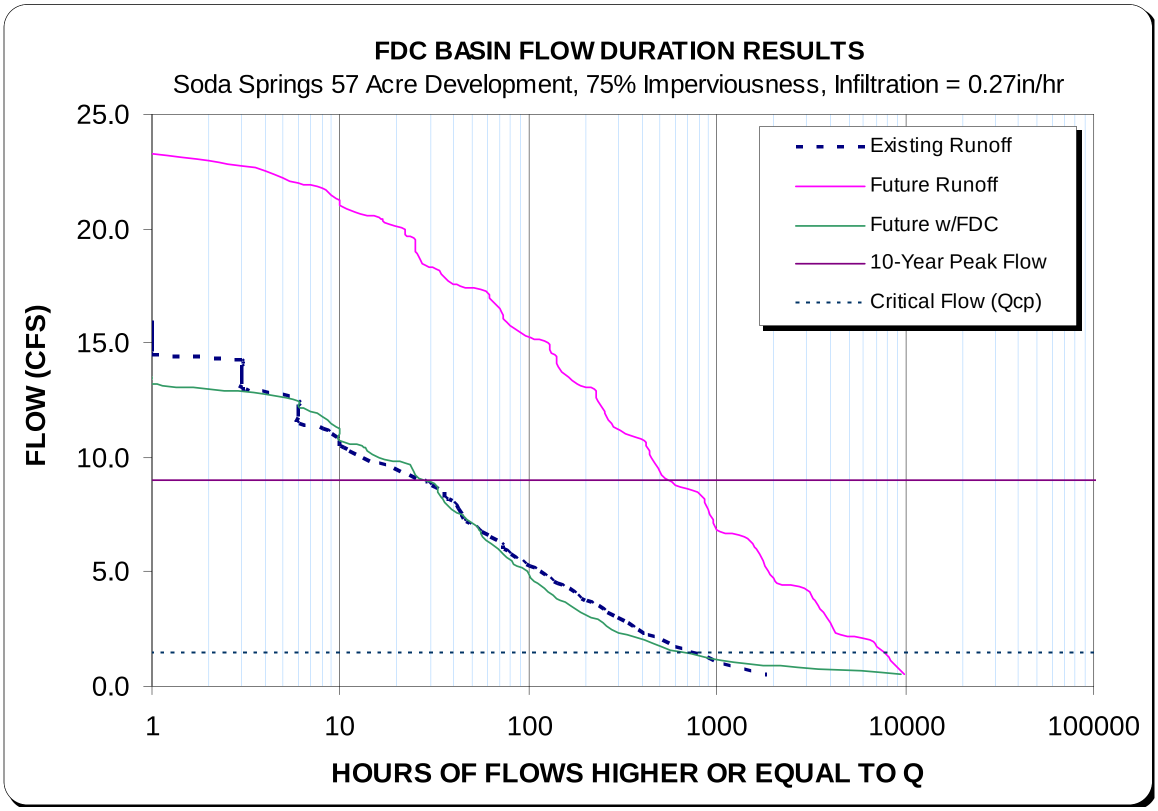

FDC BASIN FLOW DURATION RESULTS
Soda Springs 57 Acre Development, 56% Imperviousness, Infiltration = 0.27in/hr
FLOW (CFS)
25.0
20.0
15.0
10.0
5.0
0.0
1
10
100
1000
10000
100000
HOURS OF FLOWS HIGHER OR EQUAL TO Q
Existing Runoff
Future Runoff
Future w/FDC
10-Year Peak Flow
Critical Flow (Qcp)

Exhibit D


FDC BASIN FLOW DURATION RESULTS
Soda Springs 57 Acre Development, 75% Imperviousness, Infiltration = 0.27in/hr
FLOW (CFS)
25.0
20.0
15.0
10.0
5.0
0.0
1
10
100
1000
10000
100000
HOURS OF FLOWS HIGHER OR EQUAL TO Q
Existing Runoff
Future Runoff
Future w/FDC
10-Year Peak Flow
Critical Flow (Qcp)

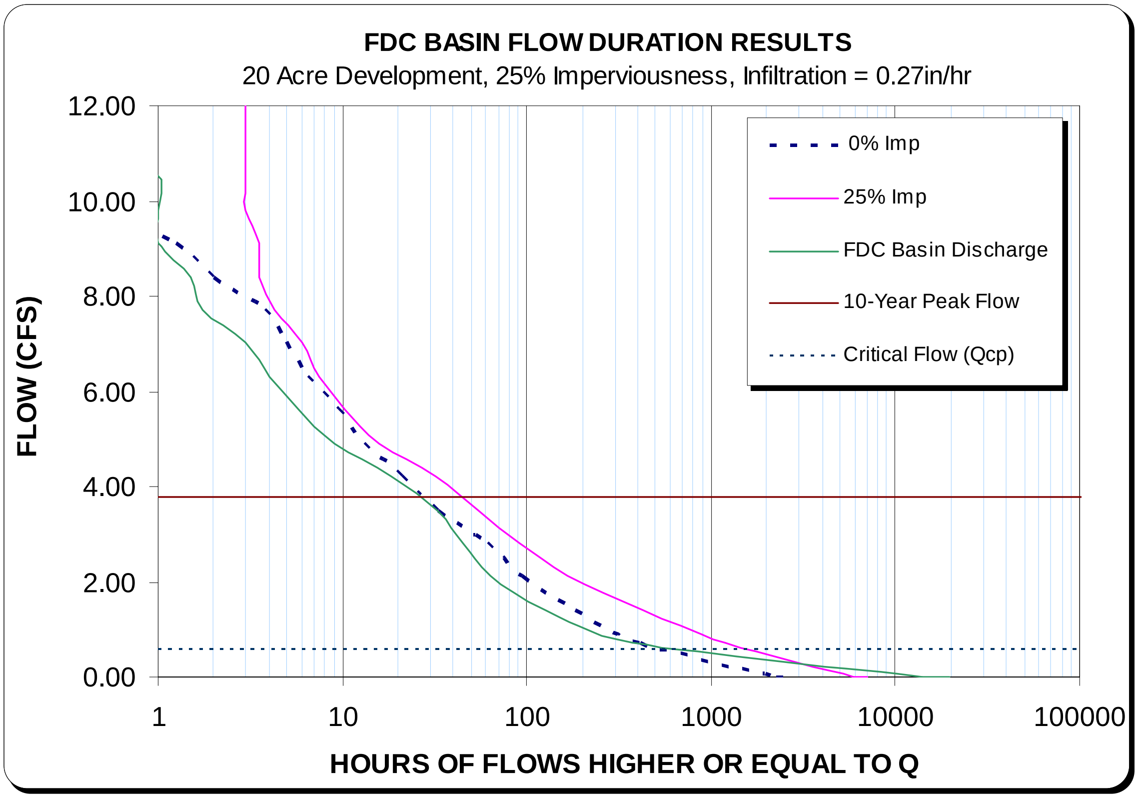
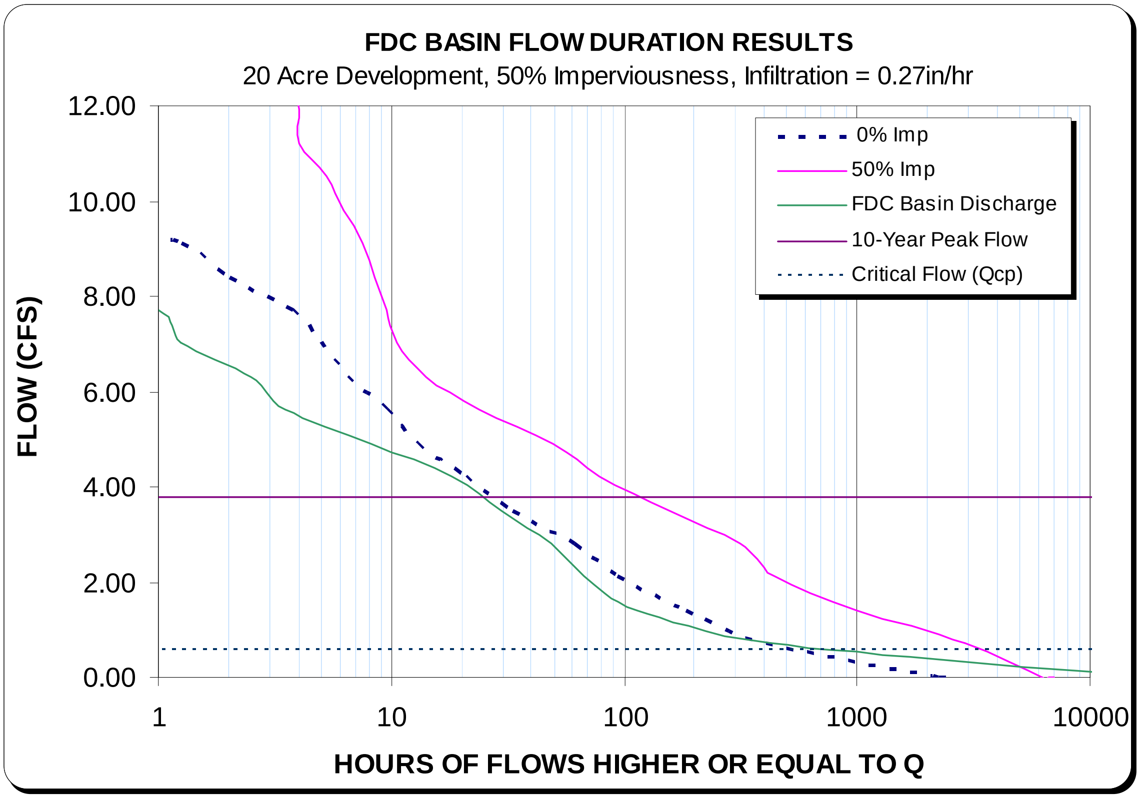

FDC BASIN FLOW DURATION RESULTS
20 Acre Development, 25% Imperviousness, Infiltration = 0.27in/hr
FLOW (CFS)
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1
10
100
1000
10000
100000
HOURS OF FLOWS HIGHER OR EQUAL TO Q
0% Imp
25% Imp
FDC Basin Discharge
10-Year Peak Flow
Critical Flow (Qcp)

Exhibit D


FDC BASIN FLOW DURATION RESULTS
20 Acre Development, 50% Imperviousness, Infiltration = 0.27in/hr
FLOW (CFS)
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1
10
100
1000
10000
HOURS OF FLOWS HIGHER OR EQUAL TO Q
0% Imp
50% Imp
FDC Basin Discharge
10-Year Peak Flow
Critical Flow (Qcp)

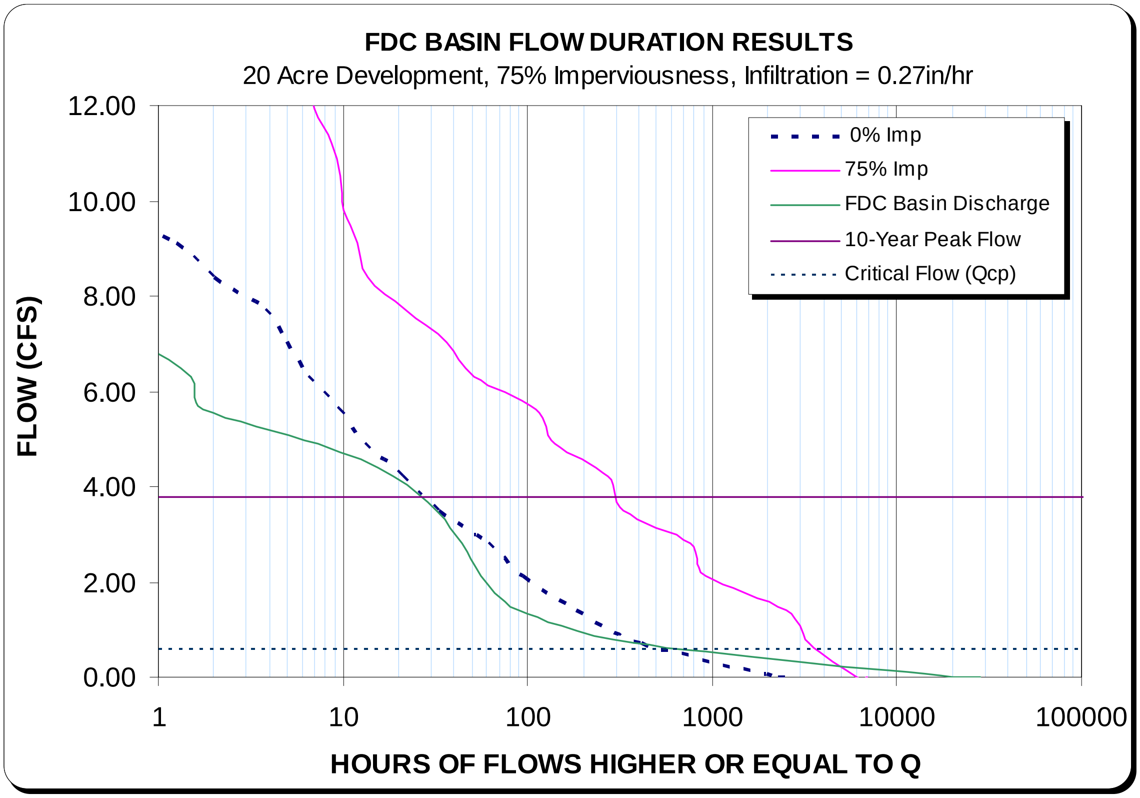
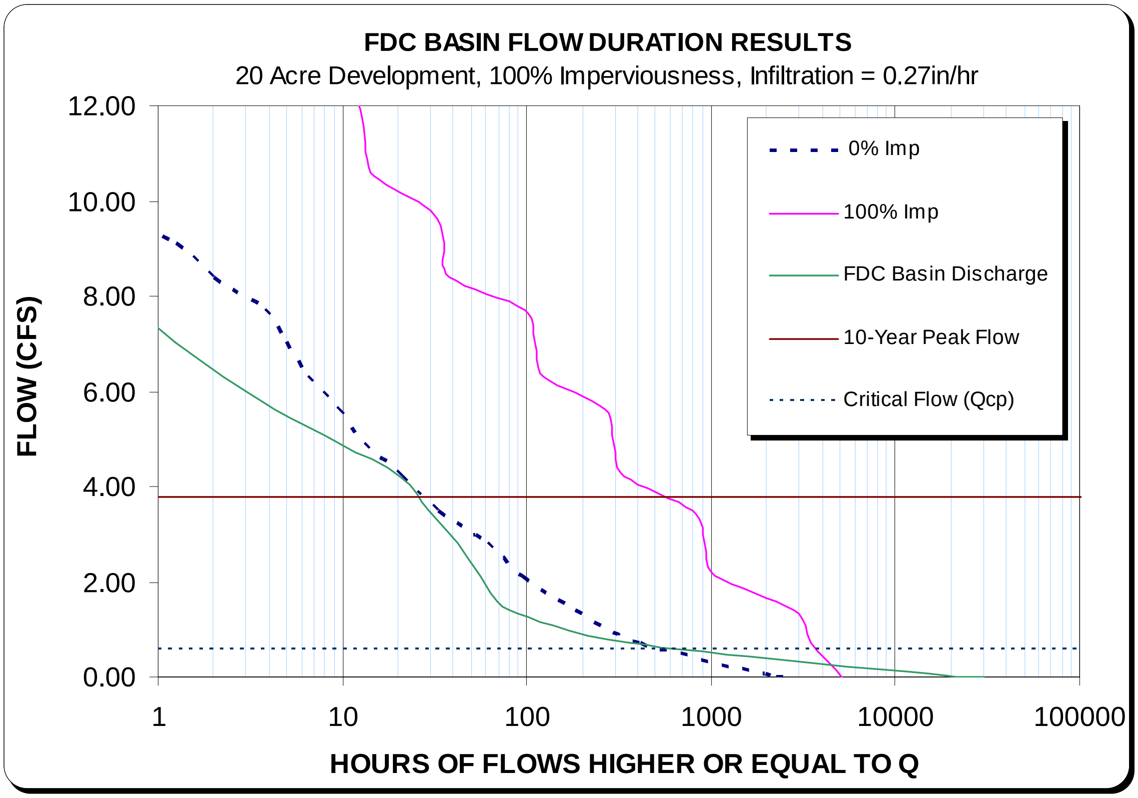

FDC BASIN FLOW DURATION RESULTS
20 Acre Development, 75% Imperviousness, Infiltration = 0.27in/hr
FLOW (CFS)
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1
10
100
1000
10000
100000
HOURS OF FLOWS HIGHER OR EQUAL TO Q
0% Imp
75% Imp
FDC Basin Discharge
10-Year Peak Flow
Critical Flow (Qcp)

Exhibit D


FDC BASIN FLOW DURATION RESULTS
20 Acre Development, 100% Imperviousness, Infiltration = 0.27in/hr
FLOW (CFS)
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1
10
100
1000
10000
100000
HOURS OF FLOWS HIGHER OR EQUAL TO Q
0% Imp
100% Imp
FDC Basin Discharge
10-Year Peak Flow
Critical Flow (Qcp)

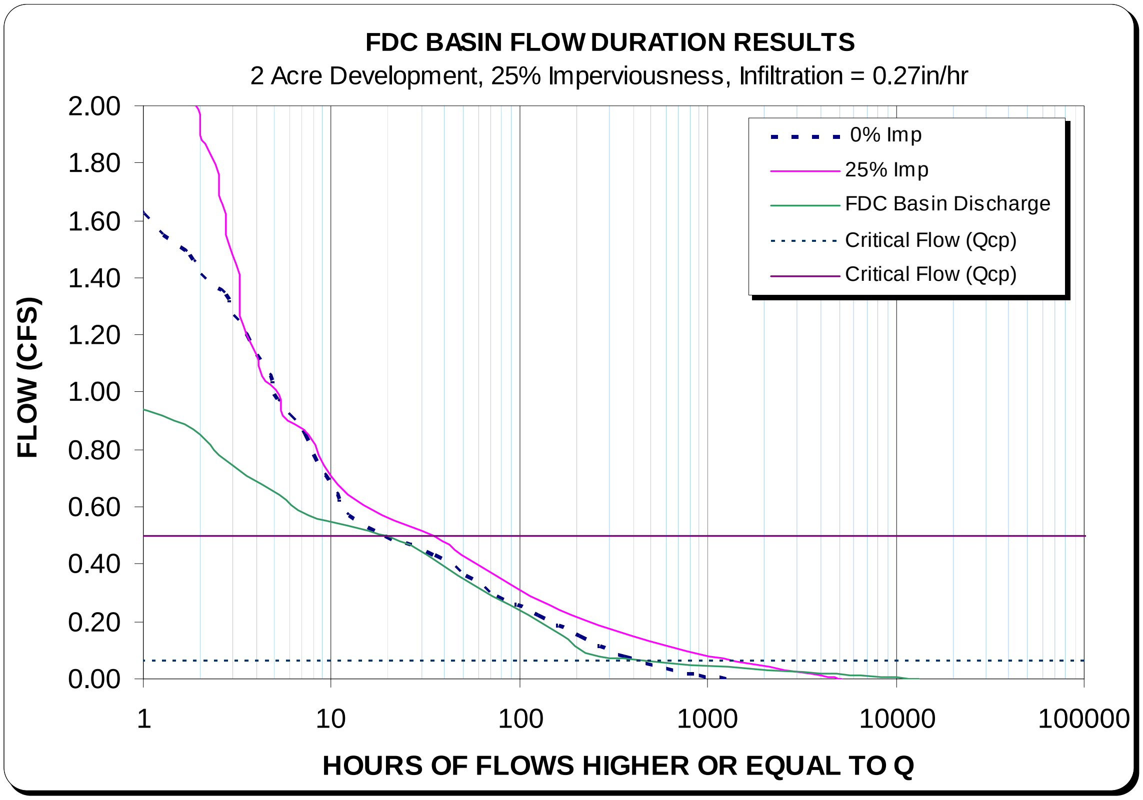
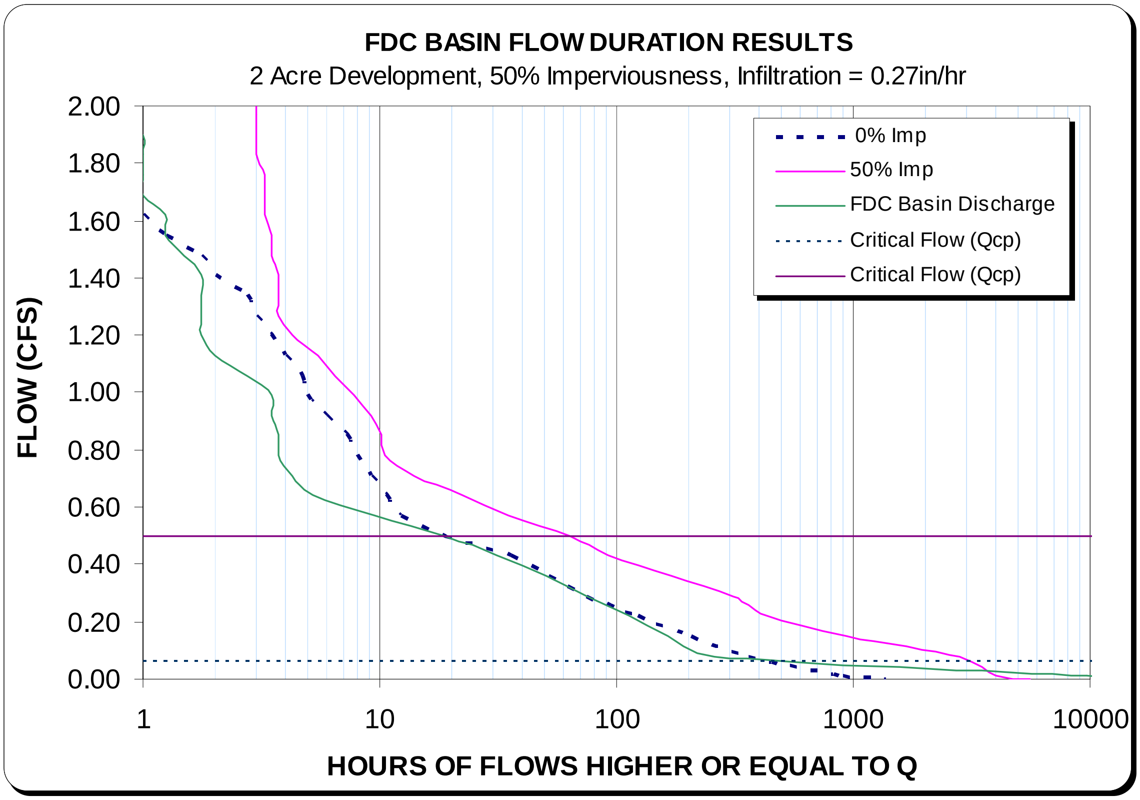

FDC BASIN FLOW DURATION RESULTS
2 Acre Development, 25% Imperviousness, Infiltration = 0.27in/hr
FLOW (CFS)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
10
100
1000
10000
100000
HOURS OF FLOWS HIGHER OR EQUAL TO Q
0% Imp
25% Imp
FDC Basin Discharge
Critical Flow (Qcp)
Critical Flow (Qcp)

Exhibit D


FDC BASIN FLOW DURATION RESULTS
2 Acre Development, 50% Imperviousness, Infiltration = 0.27in/hr
FLOW (CFS)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
10
100
1000
10000
HOURS OF FLOWS HIGHER OR EQUAL TO Q
0% Imp
50% Imp
FDC Basin Discharge
Critical Flow (Qcp)
Critical Flow (Qcp)

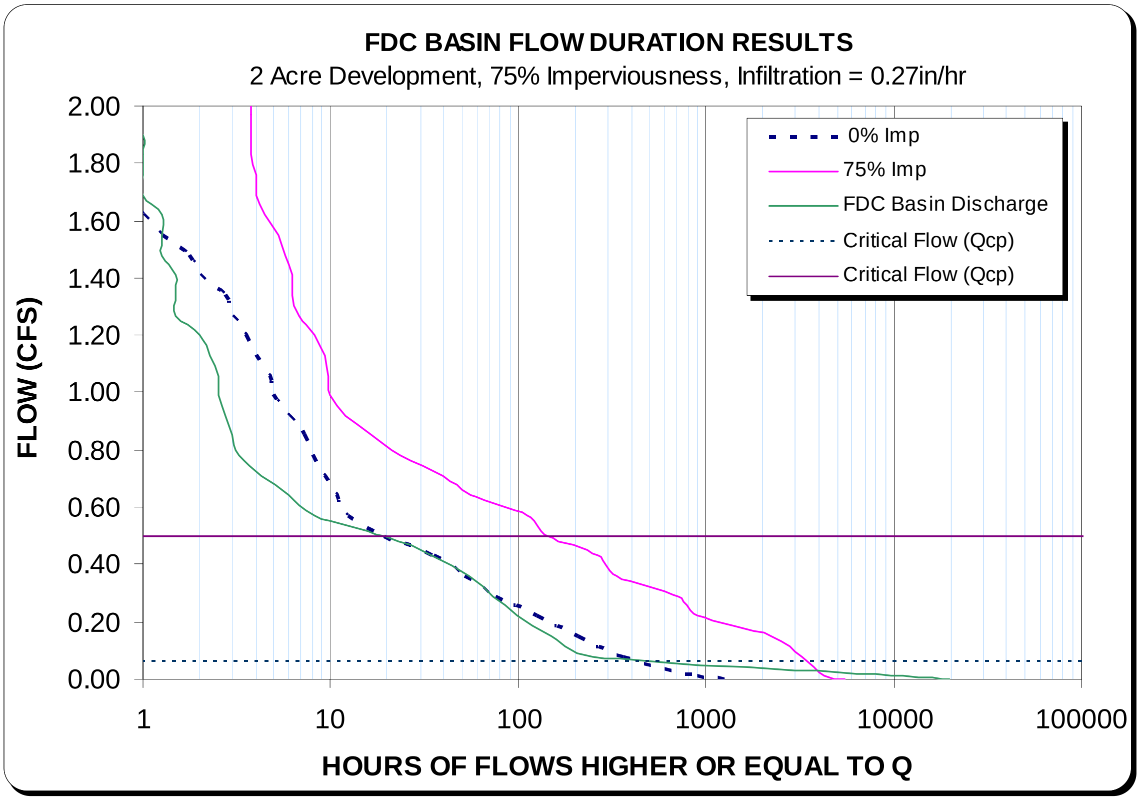
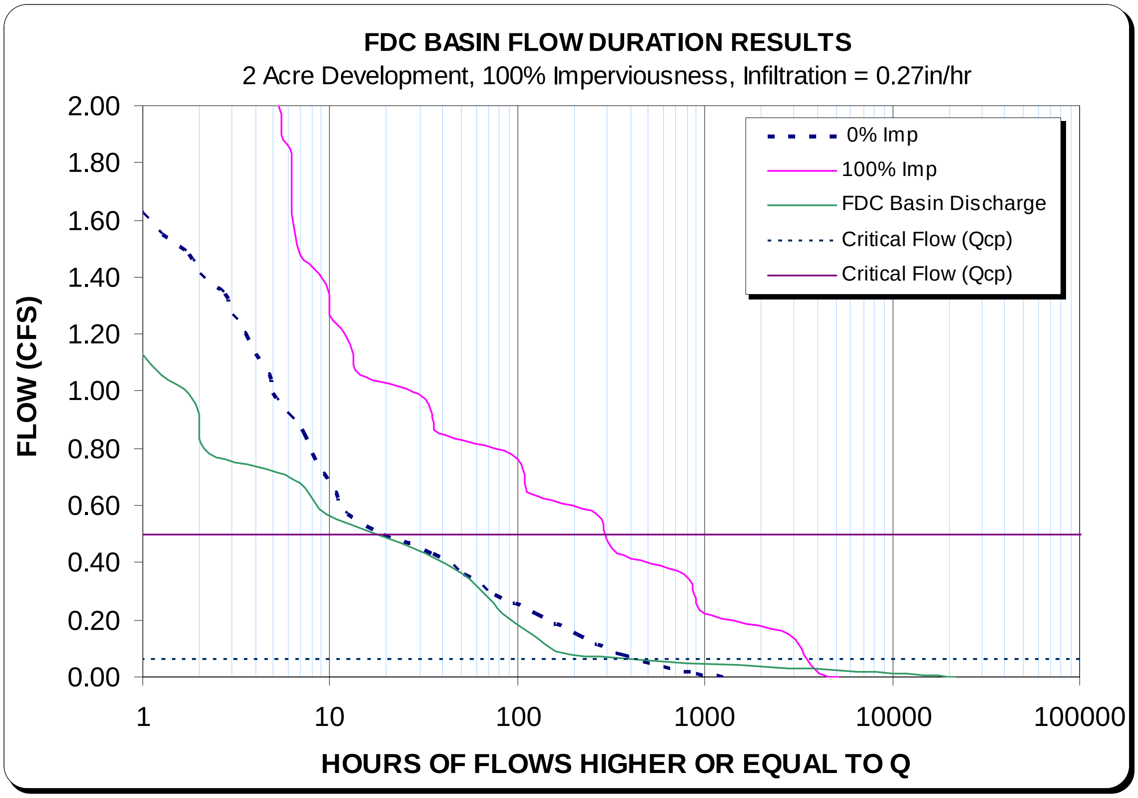

FDC BASIN FLOW DURATION RESULTS
2 Acre Development, 75% Imperviousness, Infiltration = 0.27in/hr
FLOW (CFS)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
10
100
1000
10000
100000
HOURS OF FLOWS HIGHER OR EQUAL TO Q
0% Imp
75% Imp
FDC Basin Discharge
Critical Flow (Qcp)
Critical Flow (Qcp)

Exhibit D


FDC BASIN FLOW DURATION RESULTS
2 Acre Development, 100% Imperviousness, Infiltration = 0.27in/hr
FLOW (CFS)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
10
100
1000
10000
100000
HOURS OF FLOWS HIGHER OR EQUAL TO Q
0% Imp
100% Imp
FDC Basin Discharge
Critical Flow (Qcp)
Critical Flow (Qcp)

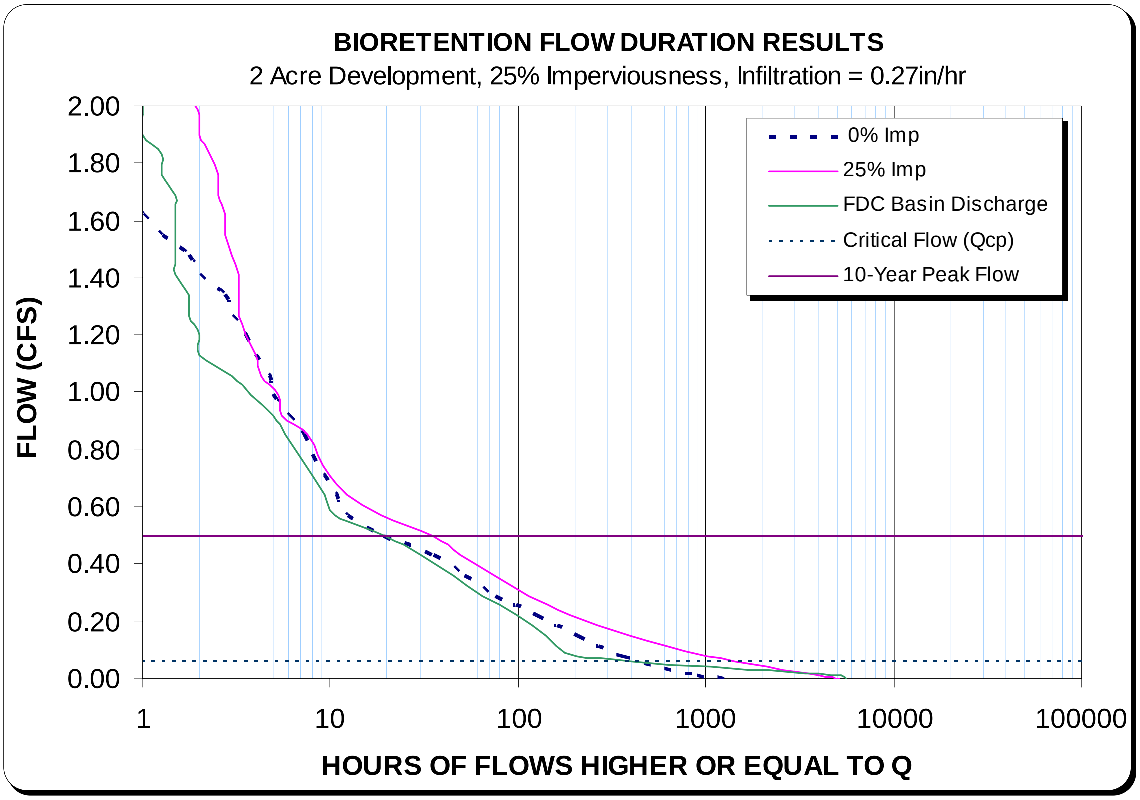
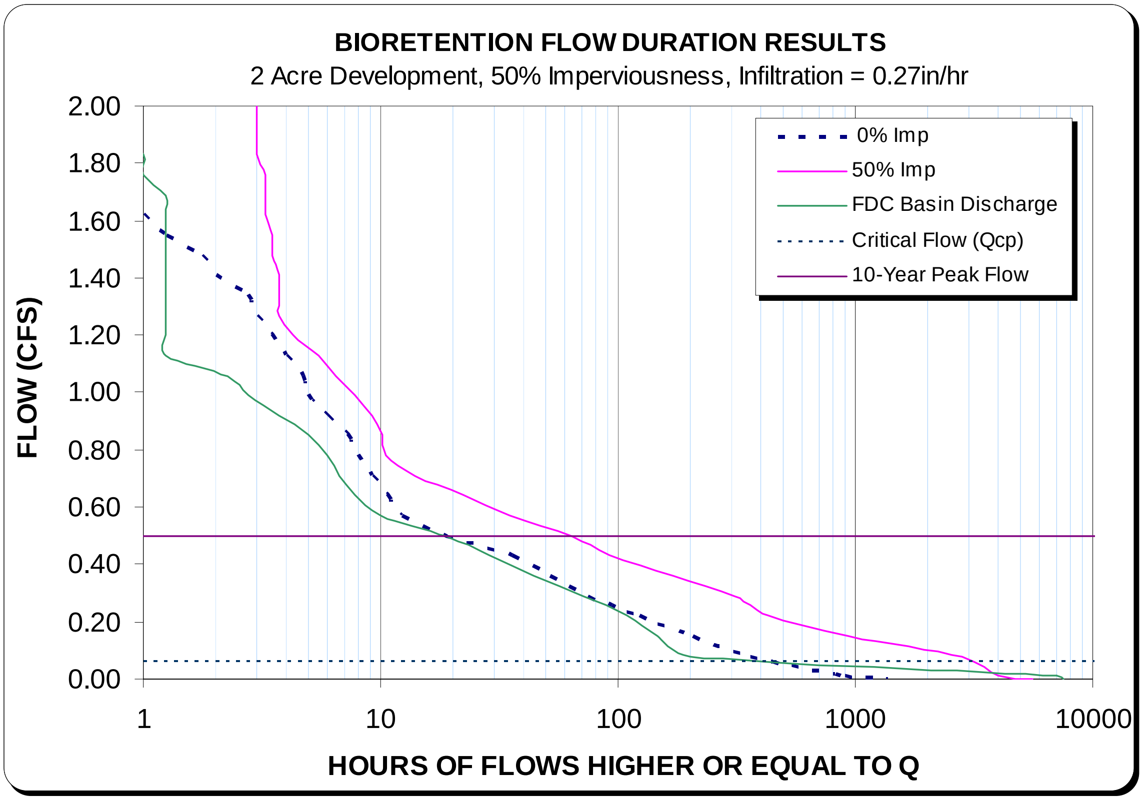
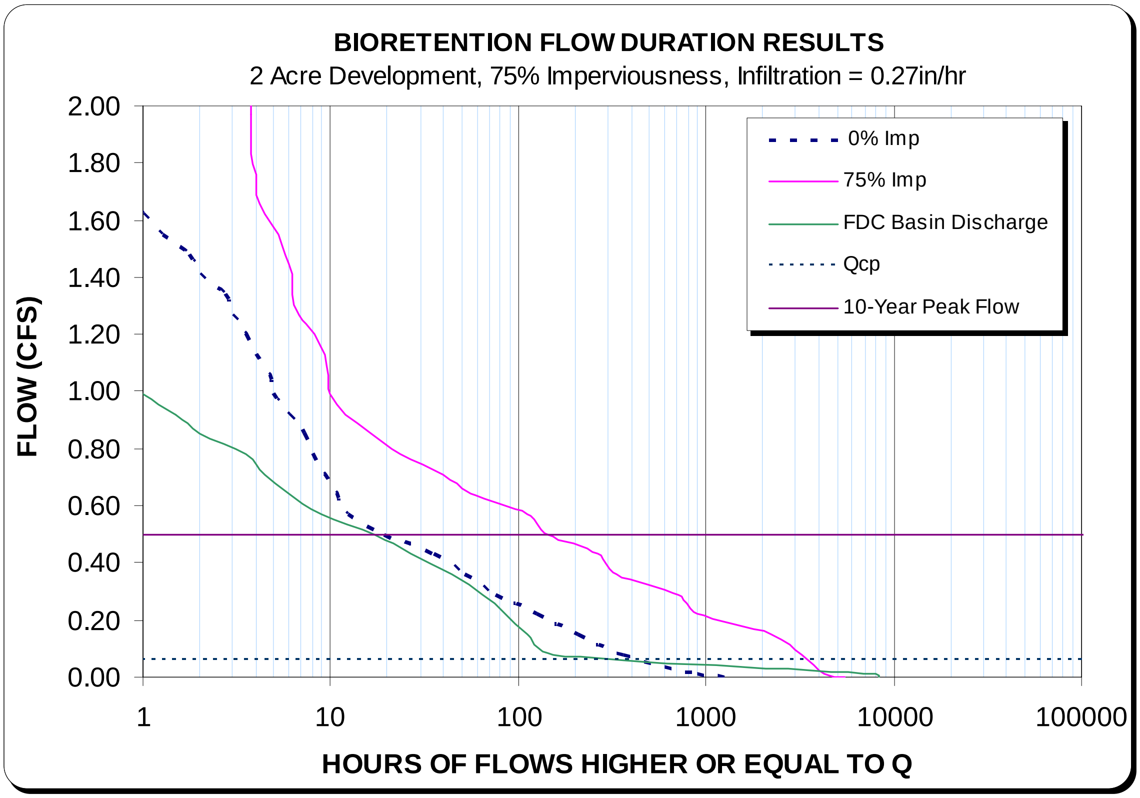

BIORETENTION FLOW DURATION RESULTS
2 Acre Development, 25% Imperviousness, Infiltration = 0.27in/hr
FLOW (CFS)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
10
100
1000
10000
100000
HOURS OF FLOWS HIGHER OR EQUAL TO Q
0% Imp
25% Imp
FDC Basin Discharge
Critical Flow (Qcp)
10-Year Peak Flow

Exhibit D



BIORETENTION FLOW DURATION RESULTS
2 Acre Development, 50% Imperviousness, Infiltration = 0.27in/hr
FLOW (CFS)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
10
100
1000
10000
HOURS OF FLOWS HIGHER OR EQUAL TO Q
0% Imp
50% Imp
FDC Basin Discharge
Critical Flow (Qcp)
10-Year Peak Flow



BIORETENTION FLOW DURATION RESULTS
2 Acre Development, 75% Imperviousness, Infiltration = 0.27in/hr
FLOW (CFS)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
10
100
1000
10000
100000
HOURS OF FLOWS HIGHER OR EQUAL TO Q
0% Imp
75% Imp
FDC Basin Discharge
Qcp
10-Year Peak Flow