City of
VALLEJO
California

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April 22, 2013
Bruce H. Wolfe, Executive Officer
California Regional Water Quality Control Board
San Francisco Bay Region
1515 Clay Street, Suite 1400
Oakland, CA 94612

Attention: Mr. Dale Bowyer, Senior Water Resources Engineer

SUBJECT: CITY OF VALLEJO – Final Hydromodification Management Plan (HMP)

Dear Mr. Wolfe:
Enclosed please find the City of Vallejo's Final HMP in fulfillment of MRP Provision C.3.g.v, which requires the City of Vallejo to submit the Final HMP for Water Board approval by July 1, 2013. No Water Board comments were received for the Draft HMP, which was submitted on March 30, 2012, so no responses to comments are provided.

Sincerely,

DAVID A. KLEINSCHMIDT
Public Works Director

Attachments
CC: PW CHRON

Prepared for

City of Vallejo
555 Santa Clara Street
Vallejo CA 94590

FINAL

Hydromodification Management Plan (HMP)

Municipal Regional Stormwater NPDES Permit Provisions C.3.g.v.

Prepared by

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engineers | scientists | innovators

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WW1538

April 2013

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1. INTRODUCTION

1.1 Problem Statement and Objective

Land development modifies natural watershed and stream hydrologic (water) and geomorphic (landform) processes by introducing impervious surfaces and drainage infrastructure that in turn changes runoff. Potential changes may include increases in runoff volumes, frequency of runoff events, and long-term cumulative duration, as well as increased peak flows. Development may also introduce dry weather flows where only wet weather flows previously existed. These changes to runoff patterns caused by land use modifications are referred to as "hydromodification." Unless managed, hydromodification can cause channel erosion, migration or sedimentation, and can result in biologic impacts to stream systems (referred to as "hydromodification impacts"). Such impacts may be associated with impairment of beneficial uses and degradation of stream conditions. Potential consequences, including injury, monetary losses, and disruptions to private citizens and businesses, carry significant liability. Both private property owners and governmental entities may be liable for downstream impacts, as determined by a California Supreme Court ruling in 1994 (CASQA, 2009).

The Vallejo Permittees[1] have developed this Hydromodification Management Plan (HMP) with the objective of minimizing hydromodification impacts associated with future new development and redevelopment in the City of Vallejo. This objective will be achieved through complying, in a cost effective manner, with the Hydromodification Management (HM) criteria stipulated in the San Francisco Bay Region Municipal Regional Stormwater NPDES Permit (MRP)[2] as outlined in this HMP.

1.2 Overview of MRP Requirements

The MRP requires the Vallejo Permittees to submit a HMP to the California Regional Water Quality Control Board, San Francisco Bay Region (RWQCB) as described in Provision C.3.g[3] (see Appendix A). The central function of the HMP is to provide a tool for implementing the Hydromodification Management (HM) Standard provided in Provision C.3.g.ii of the MRP. The HM Standard states:

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[1] Vallejo Permittees include the City of Vallejo (the City) and the Vallejo Sanitation and Flood Control District (VSFCD).

[2] At the time this HMP was authored, the active MRP was Order No. R2-2009-0074, NPDES permit number CAS612008, adopted by the Regional Water Board on October 14, 2009 and effective on December 1, 2009.

[3] While Provisions C.3.g.i-iv include the general HM criteria for the Alameda, Contra Costa, Fairfield-Suisun, San Mateo, and Santa Clara Permittees, Provision C.3.g.v, includes specific requirements for the Vallejo Permittees.

> *Stormwater discharges from HM Projects shall not cause an increase in the erosion potential of the receiving stream over the pre-project (existing) condition. Increases 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 on beneficial uses due to increased erosive force.*

This HMP does not address existing creek channel erosion problems. Rather, the HMP focuses on preventing an increase in the amount of erosion, sedimentation, or other detrimental impacts to beneficial uses associated with increases in the rates and durations of stormwater runoff from new development and redevelopment projects.

1.3 Organization of HMP Report

This HMP utilizes similar concepts and builds off of the HMPs that have been adopted by the other MRP permittees (i.e., the Alameda Countywide Clean Water Program (ACCWP, 2005), Contra Costa Clean Water Program (CCCWP, 2005), Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP, 2005), San Mateo Countywide Water Pollution Prevention Program (SMCWPPP, 2005), and Fairfield-Suisun Urban Runoff Management Program (FSURMP, 2009)). This report is organized into the following seven chapters.

Chapter 1: Introduction

This chapter provides information about creek channel erosion problems, the objective of this HMP, and information about MRP permit requirements

Chapter 2: Physical Setting

Chapter 2 provides background information on the Vallejo watersheds, geology, climate, land cover, and HMP boundary. Anticipated growth patterns within the HMP boundary are also discussed in Chapter 2.

Chapter 3: HMP Applicability Map

Chapter 3 presents the HMP Applicability Map, which depicts the geographic areas subject to and exempted from the HM Standard as required by MRP Provision C.3.g.v.2.a. The definition of a Regulated Project and the HMP Effective Date are also provided in Chapter 3.

Chapter 4: Methods to Meet HMP Performance Standard

Chapter 4 defines the HM Performance Standard, identifies exemption criteria, and describes implementation methods (on-site, regional, and in-stream controls) that may be used to meet the HM Performance Standard, as required by MRP Provision C.3.g.v.2.b.

Chapter 5: Land Use Planning Measures

Chapter 5 describes land use planning measures the Vallejo Permittees will take to allow for potential changes in-stream without adverse impacts on stream beneficial uses, as required by MRP Provision C.3.g.v.2.c.

Chapter 6: Incorporating Into Local Approval Process

Chapter 6 contains information to assist the Vallejo Permittees in implementing the HMP. This chapter includes information on how to incorporate the HMP requirements into the local development project approval processes and also provides guidance on inspections, maintenance, monitoring and reporting, as required by MRP Provision C.3.g.v.2.d.

Chapter 7: Guidance to Project Proponents

Chapter 7 contains information to assist project proponents with meeting the HMP requirements, as required by MRP Provision C.3.g.v.2.e. Chapter 7 also provides guidance on using an integrative approach to meet all of the MRP C.3 requirements for the proposed project.

2. PHYSICAL SETTING

2.1 Location and HMP Boundary

The City of Vallejo is located on the northeastern shore of San Pablo Bay at the southwestern corner of Solano County (Figure 2-1). The primary bodies of water surrounding the City are the Carquinez Strait to the south and the Napa River to the west, although Mare Island, which is within the City, lies west of this tidal river. The HMP boundary includes some of the City's Spheres of Influence (SOIs) because these areas could potentially be annexed by the City in the future. The recently annexed Bordoni Ranch has also been included in the HMP boundary. Figure 2-1 shows the HMP boundary, which includes the City boundary, the Bordoni Ranch annexed boundary, and the SOIs of interest.

2.2 Watershed Characteristics

Major watersheds within the HMP boundary are delineated on Figure 2-2. Topographically, the majority of the City drains from east to west, from the eastern hills to the western tidal flats. This HMP boundary includes the Lake Chabot, Austin Creek, Solano Avenue, and Lemon Street watersheds along with other smaller catchments that drain into the Napa River and Mare Island Strait. Elevations range from below sea level in the tidal channels to 1,112 feet above mean sea level (amsl) in the Sulphur Springs Mountains. Smaller southern catchments within the City drain to the south into Carquinez Strait via Elliot Cove, Glen Cove, and Southampton Bay. In the northeast corner of the City, on the east side of Sulphur Springs Mountain, runoff flows to the south through Sky Valley via Sulphur Springs Creek and eventually into Lake Herman. In the far northeast end of the HMP boundary, within a SOI of interest not currently part of the City, runoff drains east through American Canyon and eventually into tidal Cordelia Slough. Portions of the City near its northern border drain to American Canyon Creek, which flows to the west and is tributary to the Napa River.

2.3 Geology

A regional geology map (USGS, 2006) is provided in Figure 2-3. Parent geology consists primarily of Cretaceous sedimentary rocks of the Great Valley complex, although small portions of the northeast uplands consist of Jurassic volcanic and serpentinite bedrock. Alluvium is prevalent in the valleys of major drainages where eroded material has deposited during the Pleistocene and Holocene. Late Holocene mud deposits exist along tidal areas associated with the Napa River and west Mare Island. Younger Quaternary colluvial deposits also exist, to a limited extent, in the northeast hills. In the last century, artificial fill has been placed in the lowland areas throughout the City, including near White Slough and Lake Dalwigk.

A soils map is provided on Figure 2-4 based on the Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) Database. The Soil Survey is a nationally available dataset completed by the Soil Conservation Service (SCS), now identified as the NRCS, of the US Department of Agriculture in April 1970. The Soil Survey assigned a NRCS Hydrologic Soil Group classification to soil types mapped in the US, including the Vallejo HMP area. Hydrologic Soil Group (HSG) classifications range from more infiltrative (Group A) to less infiltrative (Group D) (for further information, see http://soils.usda.gov/). It is likely feasible to infiltrate a higher proportion of stormwater runoff on sites with NRCS Hydrologic Soil Groups A and B. On sites with NRCS Hydrologic Soil Groups C and D, a much smaller proportion of stormwater runoff can typically be infiltrated. As shown on Figure 2-4, the HMP area consists entirely of Hydrologic Soils Groups C and D, with no A and B soil types.

2.4 Climate

Typical of the western portions of Solano County in the vicinity of the Napa River and San Pablo Bay, Vallejo has a Mediterranean climate with cool summers (Solano County Water Agency, 2009). Average annual precipitation in the City is approximately 20 to 26 inches according to the Solano County Water Agency isohyetal map (Solano County Water Agency, 1999), provided in Figure 2-5. Precipitation is derived from frontal storms originating over the Pacific Ocean (Solano County Water Agency, 1999). A vast majority of this rain falls between October and May.

2.5 Land Cover

The natural vegetative cover in Vallejo consists primarily of herbaceous grassland in the hills and emergent herbaceous wetland in the low lying tidal flats (MRLC, 2001). While there is open space primarily located in the northeastern portions of the HMP study area, much of Vallejo has been urbanized with residential, commercial, and industrial land uses. A map of land cover based on the National Land Cover Dataset (MRLC, 2001) is provided in Figure 2-6.

2.6 Anticipated Future Development

The City of Vallejo is relatively built out compared to other cities in Solano County, in part because of its age; Vallejo was founded in 1851. Consequently, much, but not all, of the near term development is anticipated to be infill and redevelopment. At this time, new development is anticipated on Mare Island, within the downtown area (infill), in the fairgrounds area (i.e., Solano 360), and in the northeast portion of the City (i.e., Hidden Brook subdivisions). With regard to long-term planning, there is a strategic growth strategy to prioritize redevelopment along a designated transit area in downtown. This Priority Development Area (PDA) is supported by the Association of Bay Area Governments (ABAG) and the Metropolitan Transportation Commission (MTC). Zoning maps for the City's western and eastern portions are provided on Figures 2-7 and 2-8, respectively.

3. HMP APPLICABILITY

3.1 Regulated Projects

MRP Provision C.3.g.i. states that HM Projects are Regulated Projects that create and/or replace one acre or more of impervious surface and are not specifically excluded within the Permittee-specific HM requirements in MRP Attachments B-F. A project that does not increase impervious surface area over the pre-project condition is not an HM project.

MRP Provision C.3.b.ii.(1) defines Regulated Projects as restaurants, retail gasoline outlets, auto service facilities, and uncovered parking lots (stand alone or part of another use) that create and/or replace 5,000 square feet or more of impervious surface. MRP Provision C.3.b.ii.(2)-(4) defines Regulated Projects as public and private development projects that create and/or replace 10,000 square feet or more of impervious surface. Single family homes that are not part of a larger plan of development are specifically excluded.

The MRP became effective on December 1, 2009, and the requirements of C.3.b.ii. became effectively immediately for the majority of MRP co-permittees. However, for the Vallejo Permittees, Provisions C.3.b.ii.(1)–(3), which defines Regulated Projects in the Special Land Use, Other Development, and Other Redevelopment categories, became effective on December 1, 2010; while Provisions C.3.b.ii.(4)(a)-(c), which defines Regulated Projects in the Road Project category, became effective on December 1, 2011.

MRP Provision C.3.b.ii.(1) states that the due date for full implementation of all elements of the provision is December 1, 2011, the date when all references to 10,000 square feet changed to 5,000 square feet. Depending on where a project proponent is in the permitting process, the 5,000 square foot impervious surface threshold may or may not apply. The following are the exemptions:

- For a private planning application deemed complete on or before the MRP effective date (December 1, 2009), the 5,000 square foot threshold (for classification as a Regulated Project) shall not apply as along as the project proponent is diligently pursuing the project. If between the MRP effective date (December 1, 2009) and December 1, 2011, the project applicant has not taken action to obtain the necessary permits, then 5,000 square foot shall apply;

- For a private planning application deemed complete after the MRP effective date (December 1, 2009), 5,000 square foot shall not apply, if the project proponent has received final discretionary approval for the project before December 1, 2011.

- For public projects for which funding has been committed and construction is scheduled to begin by December 1, 2012, 5,000 square foot shall not apply.

3.2 HMP Effective Date

The Hydromodification Management (HM) requirements contained in Provision C.3.g of the MRP will become effective upon the Regional Water Board's adoption of this HMP. After the HMP Effective Date, all applicable projects, except those identified below, must comply with the HM requirements contained in Provision C.3.g of the MRP.

The HM requirements contained in Provision C.3.g of the MRP shall not apply to the projects described in paragraphs 1 through 4 below. Projects meeting any one of the criteria listed in paragraphs 1 through 4 below are exempt from meeting the HM requirements:

1. Projects or phases of projects that have a final or substantially final drainage concept or a site layout that includes water quality treatment in compliance with the MRP as determined by the City of Vallejo and the project's applications have been "deemed complete for processing" (or words of equivalent meaning), prior to the HMP Effective Date, including projects with ministerial approval, by the City of Vallejo in accordance with the City's applicable rules.
2. Projects that are the subject of an approved Development Agreement and/or an adopted Specific Plan; or an application for a Development Agreement and/or Specific Plan, where the application for the Development Agreement and/or Specific Plan has been "deemed complete for processing" (or words of equivalent meaning), prior to the HMP Effective Date, by the City of Vallejo in accordance with the City's applicable rules, and thereafter during the term of such Development Agreement and/or Specific Plan unless earlier cancelled or terminated; or any project, phase of a project, or individual lot within a larger previously-approved project, where the application for such project has been "deemed complete for processing" (or words of equivalent meaning) prior to the HMP Effective Date. Additionally, such projects must have a final or substantially final drainage concept or a site layout that includes water quality treatment in compliance with the MRP as determined by the City of Vallejo.
3. All private projects in which, prior to the Effective Date, the private party has completed public improvements; commenced design, obtained financing, and/or participated in the financing of the public improvements; or which requires the private party to reimburse the City of Vallejo for public improvements upon the development of such private projects. Additionally, such projects must have a final or substantially final drainage concept or a site layout that includes water quality treatment in compliance with the MRP as determined by the City of Vallejo.
4. Projects included in a Tentative Map or Vesting Tentative Map that was deemed complete or approved by the City prior to the HMP Effective Date, and subsequently a Revised Map is submitted, and the change requested under the

Revised Map is solely initiated by the City or other public agency, and the City has determined that the revisions substantially conform to original map design, consistent with Subdivision Map Act requirements. Additionally, such a Tentative Map or Vesting Tentative Map must have a final or substantially final drainage concept or a site layout that includes water quality treatment in compliance with the MRP as determined by the City of Vallejo.

The intent of these guidelines is to ensure that projects for which the applications have been deemed "complete" or the applicants have worked with the City of Vallejo staff to develop a final, or substantially final, drainage concept and site layout that includes water quality treatment based upon the performance criteria set forth prior to the HMP Effective Date, are not required to redesign their proposed projects for purposes of complying with the HM requirements contained in Provision C.3.g of the MRP.

3.3 HMP Applicability Map

The Vallejo HMP applicability map is required by MRP Provision C.3.g.v.2.a., which states that the Vallejo Permittees shall include in their HMP:

> *A map of the City of Vallejo, delineating areas where the HM Standard applies. The HM Standard shall apply in all areas except where a project:*
>
> - *Discharges stormwater runoff into creeks or storm drains that are concrete-lined or significantly hardened (e.g., with rip-rap, sackrete) downstream to their outfall in San Francisco Bay;*
> - *Discharges to an underground storm drain discharging to the Bay; or is*
> - *Located in a highly developed watershed.*[4]

The steps used to develop the HMP applicability map provided in Figure 4-1 are described in Appendix B. Areas within the HMP boundary have been designated with one of five colors, according to the following:

- Purple areas drain to continuously hardened conveyances (channels and pipes) that extend to the San Francisco Bay. The HM standard does not apply to projects in these areas.
- Red areas represent subcatchments that are currently highly developed to a level of 65% imperviousness or greater and that do not drain to continuously hardened

[4] Provision C.3.g. defines "highly developed watersheds" as catchments or subcatchments that are 65% impervious or higher.

conveyances extending to the Bay. The HM Standard does not apply to projects in these areas.

- Light Blue areas represent open water. A majority of this area is the Bay, but open water reservoirs are included as well. The HM Standard does not apply to these areas.

- Dark Blue areas represent bayland areas which are considered tidally connected to the Bay, but are not classified as open water. These areas have a ground elevation generally less than the mean high tide elevation and are considered a part of the Bay. The HM Standard does not apply to projects in these areas.

- Green areas represent those areas within the HMP boundary that are not purple, red, light blue, or dark blue. The HM Standard applies to projects in these areas[5].

[5] Further exemptions to the HM Standard can be granted in these applicable areas if one of the exemption criteria listed in Section 4.2 applies to the project.

4. METHODS TO MEET HMP PERFORMANCE STANDARD

4.1 Hydromodification Management Performance Standard

The Performance Standard for hydromodification management (HM) is provided in Provision C.3.g.ii of the MRP, which states:

> *Stormwater discharges from HM Projects shall not cause an increase in the erosion potential of the receiving stream over the pre-project (existing) condition.*

Erosion potential (Ep) is expressed as the ratio of post-project to pre-project "work done" on the creek. In other words, an Ep of up to 1.0 shall be maintained for creek segments downstream of the project discharge point. Projects shall meet the performance standard using on-site HM controls, regional HM controls, and/or in-stream HM control measures[6].

4.2 Exemptions to the HM Performance Standard

The HM Performance Standard does not apply to Regulated Projects that meet one of the following exemption criteria:

- The project creates and/or replaces less than 1 acre of impervious area.
- The project does not increase impervious area over the pre-project condition.
- The project is located in an area where the HM Standard does not apply (purple, red, light blue, or dark blue areas), according to the HMP Applicability Map.
- The project's receiving streams are demonstrated as having "low risk" to channel erosion impacts, per Section 4.2.1 below.

It is important to note that Regulated Projects[7], even if they are not HM projects, need to comply with the VSFCD flood control design criteria, including peak flow matching, as well as all other applicable requirements of the MRP, such as implementation of Low Impact Development (LID).

4.2.1 Evaluating "Low Risk"

The last exemption criteria is applicable to projects located within the green area of the HMP Applicability Map that discharge to creeks which have low risk of in-stream erosion and hydromodification impacts. The HMP Applicability map does not specifically consider aggrading channels, natural threshold channels, or future project

[6] The definition of each of these three types of HM controls is provided in the MRP Provision C.3.g.iii (see Appendix A).
[7] Regulated Projects are defined in MRP Provision C.3.b.

runoff diversions to drainages exempt from the HM Standard. To demonstrate that the low risk criteria are met, the project applicant must provide a report or letter report, signed by a licensed engineer or qualified environmental professional, demonstrating that all downstream channels between the project site and the Bay fall into one of the following "low-risk" categories:

- Enclosed pipes.
- Channels with continuous hardened beds and banks engineered to withstand erosive forces and composed of concrete, engineered riprap, sackcrete, gabions, mats, etc. Channels where hardened beds and banks are not engineered continuous installations (i.e.. have been installed in response to localized bank failure or erosion) are excluded.
- Channels subject to tidal action.
- Aggrading channels (i.e., those consistently subject to the accumulation of sediments).
- Natural channels with bed and banks consisting of bedrock, boulders, or other natural materials which have a critical threshold for erosive flow (Qc) greater than or equal to the 10-year peak flowrate (Q_{10}).

4.3 Implementation Methods to Meet the HM Standard

HM Projects shall use one of the following three implementation methods to comply with the HM Performance Standard:

4.3.1 Method 1 - On-Site HM Control

On-site HM controls that are designed to provide flow duration control to the pre-project condition, at the point(s) where stormwater runoff discharges from the project site, meet the erosion potential performance standard and comply with this HMP. Flow duration controls shall be designed such that post-project stormwater discharge rates and durations match pre-project discharge rates and durations from 10% of the pre-project 2-year peak flow from the project site (or an alternative low flow discharge determined based on a stream-specific critical threshold analysis) up to the pre-project 10-year peak flow. The post-project flow duration curve shall not deviate above the pre-project flow duration curve by more than 10 percent over more than 10 percent of the length of the curve corresponding to the range of flows to control.

Discussion:

Creek channel erosion is caused by an increase in the duration of small and moderate magnitude flows above the threshold for sediment transport and creek bank erosion. Flow duration control maintains the flow duration pattern of the pre-project condition.

Effectively maintaining the pre-project flow duration also maintains the pre-project runoff volume and sediment transport capacity for the full distribution of flows from the critical threshold for erosive flow (Qc) in a creek up to the selected upper limit (the 10 year peak flow in this case). Qc is defined as the creek flow that produces the critical shear stress that initiates bed movement or that erodes the toes of creek banks. Applying flow duration control to achieve the pre-project condition is considered to be fully protective of the existing condition of the creek segment to which the project discharges. These concepts are described in more detail in the SCVURPPP's HMP Appendix C.

Flow duration matching does not require additional watershed and creek analyses to ensure that Ep is being maintained in the downstream creek segments, but it does not prohibit it either. The allowable low flow discharge from the project site (Qcp) can be estimated as 10% of the pre-project 2-year peak flow from the project site ($0.1Q_2$) if additional analyses are not performed. Additional analyses needed to evaluate an alternative Qcp, expressed as a percentage of the 2-year peak flow, would require an incipient motion analysis of the receiving creek segments downstream of the project discharge point and a hydrologic analysis to evaluate the 2-year peak flowrate at each creek location analyzed. Guidance for such an analysis is provided in Appendix C (Section 4.1).

Design of stormwater controls for flow duration matching requires continuous long-term hydrologic modeling of the project site. If different portions of the project site discharge to different receiving creeks downstream, then a separate flow duration control analysis is needed for each associated outlet and tributary area on-site. If, however, two or more outlets from the project discharge to the identical receiving creeks downstream, then flow duration control analysis can be applied to the combined associated tributary areas.

On-site flow duration control can be demonstrated in any of the following ways:

- For projects up to ten acres, the project proponent may select and size LID-type Integrated Management Practices (IMP) to provide hydromodification management using the design procedure, criteria, and sizing factors specified by the Contra Costa Clean Water Program and incorporated in the Program's Stormwater C.3 Guidebook – 6th edition and IMP Sizing Calculator[8]. An additional multiplication factor, provided in Table 5-1 below, shall be applied to the resulting footprint area and storage volumes obtained from the IMP sizing tool to adjust the low flow discharge (Qcp) from $0.2Q_2$ to $0.1Q_2$. The low flow orifice diameter must be divided by $\sqrt{2}$ (or 1.414) to also account for the reduction in

[8] The CCCWP Stormwater C.3 Guidebook – 6th edition and IMP Sizing Calculator are available at: http://www.cccleanwater.org/c3-guidebook.html.

Qcp. Documentation of the methods used to obtain the multiplication factors is provided in Appendix E.

Table 4-1: Multiplication Factors to Adjust IMP Sizing Results from a Low Flow Discharge of $0.2Q_2$ to $0.1Q_2$

Soil Type	Infiltrating BMP	Non-Infiltrating BMP
C	1.21	1.72
D	1.38	1.76

- The project proponent can perform a system specific continuous hydrologic simulation analysis to design on-site HM controls that provide flow duration control to the pre-project condition at the points of compliance. Modeling software appropriate for this type of simulation includes USEPA's Storm Water Management Model (SWMM), USGS's Hydrological Simulation Program – Fortran (HSPF), and the US Army Corps of Engineers' Hydrologic Modeling System (HMS). Design guidance for flow duration control facilities using a system-specific continuous simulation is provided in Appendix C. Detailed suggestions for matching the pre-project flow duration curve using a single facility is provided in the SCVURPPP's HMP Report Appendix F.
- If the Bay Area Hydrology Model (BAHM) is expanded to include the Vallejo HMP area, then the project proponent can use BAHM to size on-site HM Controls to provide flow duration control. BAHM has already been adopted for use in Alameda, San Mateo, and Santa Clara Counties. ACCWP, SMCWPPP, and SCVURPPP have jointly sponsored the development of the BAHM to facilitate flow duration control design by providing a user-friendly software tool for automated modeling and facility sizing.

4.3.2 Method 2 – Regional HM Control

Regional HM controls may be implemented in lieu of, or in combination with, on-site HM controls, where an approved plan, including an appropriate funding mechanism, is in place that accounts for the stream changes expected to result from changes in the project's runoff conditions. The regional HM controls (or combination of controls) shall be designed to achieve the hydromodification management objective threshold of $Ep \leq 1.0$ from the point of discharge to the receiving water body to as far downstream as potential impacts could occur. Regional HM controls that are designed to provide flow duration control to the pre-project condition, at the point where the regional HM control discharges, meet the erosion potential performance standard and comply with this HMP.

<u>Discussion</u>:

When a combination of on-site and off-site, out-of-stream HM control measures is proposed for hydromodification management, applying flow duration control to achieve the pre-project condition is considered to be fully protective of the existing condition of the creek segment to which the project discharges. Flow duration matching for regional HM controls can be implemented similarly as for on-site HM controls, except instead of the point of compliance being at the project outlet, it is at the point where the regional HM control discharges. Thus, existing detention facilities can be modified for flow duration control if it is feasible. Also, regional HM controls can allow multiple projects to meet the HM Performance Standard with one mitigation facility.

Regional flow duration control can be demonstrated in any of the following ways:

- Project proponents can perform a system-specific continuous hydrologic simulation analysis to design regional HM controls that provide flow duration control to the pre-project condition at the point of compliance. Design guidance for flow duration control facilities using a system-specific continuous simulation is provided in Appendix C. Detailed suggestions for matching the pre-project flow duration curve using one facility is provided in the SCVURPPP's HMP Report Appendix F.
- If the BAHM is expanded to include the Vallejo HMP area, then the project proponent can use BAHM to design regional HM Controls to provide flow duration control.

Designing out-of-stream controls using the Ep method involves a hydrologic and geomorphic evaluation of the creek system downstream of the project. The method requires computing creek flows at several locations within a creek system and the work done on the creek channels before and after development. A continuous hydrologic model is required as well as channel geometry and bed/bank material strength data at each computation point. Design guidance for HM controls using the Ep methodology is provided in Appendix D.

4.3.3 Method 3 – In-Stream HM Control

In-stream measures may be implemented to address potential project impacts in lieu of or in combination with on-site and regional HM controls, where an approved plan, including an appropriate funding mechanism, is in place that accounts for the stream changes expected to result from changes in the project's runoff conditions. Additionally, in-stream measures shall be an option only where the stream channel which receives runoff from the project is already impacted by erosive flows and altered land use (i.e., shows evidence of excessive sediment, erosion, deposition, or is a hardened channel). The in-stream measures (or combination of controls) shall be designed to achieve the hydromodification management objective threshold of Ep ≤ 1.0 from the point of discharge to the stream to as far downstream as potential impacts would occur.

<u>Discussion</u>:

When a combination of out-of-stream and in-stream control measures is proposed for hydromodification management, the amount of increase in erosive work done on the creek from the site's discharge (i.e., after the application of any on-site and off-site measures) is used to design the in-stream measures. A project with on-site and/or off-site measures may be allowed to discharge runoff at higher rates and durations than a flow duration matching criterion would allow, as long as the creek is protected using in-creek measures downstream of the project discharge point.

Designing in-stream controls using the Ep method involves a hydrologic and geomorphic evaluation of the creek system downstream of the project. Creek flows are computed at several locations within a creek system as well as the work done on the creek channels before and after development. A continuous hydrologic model is required with channel geometry and bed/bank material strength data at each computation point. Design guidance for HM controls using the Ep methodology is provided in Appendix D.

4.4 HM Control Measures

The following section provides a discussion of potential HM Control Measures. Table 5-2 at the end of this section summarizes these options in terms of structural versus non-structural measures, as well as location and scale of structural options, namely: on-site, regional, or in-stream. On-site distributed refers to the use of control measures on a small, local scale throughout a given parcel or several parcels. Regional refers to a use of control measures on a somewhat larger scale to serve multiple parcels.

4.4.1 Non-Structural Measures

The following non-structural measures can be considered for use in addressing hydromodification impacts.

Minimization of Impervious Areas / Preservation of Open Spaces (On-Site)

Project design to minimize impervious areas will reduce the increase in runoff volumes and rates that need to be managed. Undeveloped areas with un-compacted soils also provide opportunities for infiltration of impervious area runoff, and help to preserve the pre-development water budget (consisting of infiltration, evapotranspiration, percolation, subsurface flows, groundwater recharge, and surface runoff).

Prioritize Soils for Development and Infiltration (On-Site)

Where possible, development within a project should be located preferentially on existing poorly infiltrating soils, leaving soils with good infiltration rates as areas for flow and volume management and groundwater recharge. If development is to occur on well infiltrating soils, then preservation of infiltration capacity and utilization of on-site infiltration facilities should be prioritized.

Establish Riparian Buffer Zones (In-Stream)

Establishing riparian buffer zones, where no development is allowed, prevents direct impacts to riparian habitat in multiple ways. Benefits of riparian buffer zones include: helping prevent changes to channel geometry or bed and bank materials that can contribute to increase erosion independent of upstream flow changes; sustainably supporting the flora and fauna that existed prior to development; maintaining the degree of native wood and leaf debris input into the creek system; filtering stormwater runoff before it enters the receiving stream; and maintaining the hydrologic connectivity between streams and floodplains. Finally, if runoff can be routed through the buffer, it can provide attenuation and infiltration to reduce the volume of runoff entering the creek.

Pass Through Sediments from Open Spaces (In-Stream)

Where possible, drainage pathways for open spaces upstream of developments should be designed to pass coarse sediments from natural areas to the natural stream channels. Maintaining natural sediment supplies to streams helps to reduce the potential for excess erosion. Additional analysis or maintenance protocols may be required to ensure downstream flood protection.

4.4.2 Structural Measures

Volume and Flow Management (On-Site/Distributed)

A variety of volume / flow management structural measures are available that utilize the following two basic principles:

1. Detain runoff and release it in a controlled way that either mimics pre-development in-stream sediment transport capacity, mimics flow durations, or reduces flow durations to account for a reduction in sediment supply.

2. Manage excess runoff volumes through one or more of the following pathways: infiltration, evapotranspiration, storage and use, discharge at a rate below the critical rate for adverse impact, or discharge downstream to a stream that has constructed channel and is not susceptible to erosion.

Distributed facilities are small scale facilities, typically treating runoff from less than ten acres. These types of facilities include, but are not limited to, bioretention areas, planter boxes, permeable pavement, and rainwater harvesting. These types of facilities will also help to achieve the LID performance standard.

Detention / Retention Basins (Regional)

Regional detention or retention basins are stormwater management facilities that are designed to detain or infiltrate runoff from multiple projects or project areas. These basins are typically shallow with flat, vegetated bottoms. Regional basins can be constructed by either excavating a depression or building a berm to create above ground storage, such that runoff can drain into the basin by gravity. Runoff is stored in the basin as well as in the pore spaces of the surface soils. Pretreatment BMPs such as swales, filter strips, and sedimentation forebays minimize fine sediment loading to the basins, thereby reducing maintenance frequencies.

Regional basins for hydromodification management incorporate outlet structures designed for preservation of in-stream sediment transport capacity or flow duration control. These basins can also be designed to support flood control and LID objectives in addition to hydromodification. If underlying soils are not suitable for infiltration, the basin may be designed for flow detention only, with alternative practices to manage increased volumes, such as storage and use, discharge at a rate below the critical rate for adverse impacts, or discharge to a non-susceptible water body, as well as to meet the MRP’s LID objectives.

To the maximum extent possible, regional basins should be designed to receive flows from developed areas only, for both design optimization as well as to avoid intercepting coarse sediments from open spaces that should ideally be passed through to the stream channel, as reductions in coarse sediment loads contribute to channel instability.

In-Stream Structural Controls

Hydromodification management can also be achieved by in-stream controls, including drop structures, grade control structures, bed and bank reinforcement, increased channel sinuosity, and increased channel width. The objectives of these in-stream controls is to reduce or maintain the overall erosion potential of the stream by modifying the receiving channel hydraulic properties and bed/bank material resistance without fully controlling runoff On-site. In-stream structural controls are only an option where the stream, which receives runoff from the project, is already impacted by erosive flows and shows evidence of excessive sediment, erosion, deposition, or is a hardened channel.

Drop Structures

Drop structures are designed to reduce the channel slope, thereby reducing the shear stresses generated by stream flows. These controls can be incorporated as natural appearing rock structures with a step-pool design which allows drop energy to be dissipated in the pools while providing a reduced longitudinal slope between structures.

Grade Control Structures

Grade control structures are designed to maintain the existing channel slope while allowing for minor amounts of local scour. These control measures are often buried and would entail a narrow trench across the width of the stream backfilled with concrete or similar material, as well as the creation of a “plunge pool” feature on the downstream side of the sill by placing boulders and vegetation. A grade control option provides a reduced footprint and impact compared to drop structures, which are designed to alter the channel slope.

Bed and Bank Reinforcement

Channel reinforcement serves to increase bed and bank resistance to stream flows. In addition to conventional techniques such as riprap and concrete, a number of vegetated approaches are increasingly utilized, including products such as vegetated reinforcement mats. This technology provides erosion control with an open-weave material that stabilizes bed and bank surfaces and allows for re-establishment of native plants, which serves to further increase channel stability.

Channel Sinuosity

Increasing channel sinuosity (ratio of channel distance between two points to straight line distance) can serve to reduce the channel slope, thereby reducing the shear stresses generated by stream flows. As a general rule forcing a channel to a sinuosity that is inappropriately high is likely to lead to subsequent channel avulsion to a straighter course. Channel sinuosity needs to be supported by a geomorphic basis of design that shows the proposed form and gradient to be appropriate for the valley slope and sediment and water regime. This may take the form of reference reaches in similar watersheds that have supported the proposed morphology over a significant period of time, or comparison between the proposed form and typical literature values (San Diego County, 2009).

Channel Widening

Increasing the width-to-depth ratio of a stream’s cross-section is meant to spread flows out over a wider cross section with lower depths, thereby reducing shear stress for a given flow rate. This approach can be a useful mitigation strategy in incised creeks to bring them back to equilibrium conditions once vertical incision has ceased. As with sinuosity, it is important to develop a robust geomorphic basis of design that shows the increase in width-to-depth ratio to be sustainable (San Diego County, 2009).

Table 4-2. Summary of Hydromodification Control Measures

	On Site / Distributed	**Regional**	**In-Stream**
Non-Structural	**Minimize impervious surfaces** **Preservation of open space** **Prioritize Soils for Development and Infiltration**	**Minimize impervious surfaces** **Preservation of open space** **Prioritize Soils for Development and Infiltration** **(measures implemented at the regional planning level)**	**Riparian buffer protection** **Design for sediment pass-through from natural open spaces**
Structural	**Distributed BMPs** ***Providing volume and/or flow reduction through one or more of the following measures*:** Infiltration measures Evapotranspiration measures Rainwater Harvesting Bioretention w/outlet control	**Regional detention / retention basins** *Designed for preservation of in-stream sediment transport characteristics, flow duration control, or for detention and volume reduction through alternatives such as storage and use or discharge to non-susceptible water bodies*	**Grade control structures** **Drop structures** **Bed and bank reinforcement** **Increased Sinuosity** **Increased Width**

5. LAND USE PLANNING MEASURES

Permit Provision C.3.g.v.2.c calls for the Vallejo HMP to provide "a description of any land use planning measures the City of Vallejo will take to allow expected changes in stream channel cross sections, stream vegetation, and discharge rates, velocities, and/or durations without adverse impacts on stream beneficial uses." The examples provided in the provisions include, "stream buffers and stream restoration activities, including restoration-in-advance of floodplains, re-vegetation, and use of less-impacting facilities at points of discharge."

5.1 Beneficial Measures

A key element of hydromodification management strategies is land use planning. The approach is to optimize development project site design to preserve the natural hydrologic conditions and protect sensitive hydrologic features, sediment source characteristics and sensitive habitats. This helps avoid the need to mitigate for hydromodification (SCVURPPP, 2005).

Site design techniques, such as clustering buildings to provide more open space, can be considered effective land use planning measures to reduce the increases in stormwater runoff from the project. However, there are additional planning measures that may be implemented for land use near streams that can further help the stream tolerate or adjust to increases in flow and associated erosion potential (SCVURPPP, 2005).

Some Permittees in the Bay Area have established policy for allowable development and uses near riparian corridors, such as minimum buffer widths in which no development or very little development is allowed. In addition to protection of riparian habitat, large setbacks from streams, where feasible, allow room for the stream channel to widen in response to increased flows and re-stabilize with a larger cross section (SCVURPPP, 2005).

Riparian corridors provide natural vegetative filters for slowing and infiltration runoff and removing pollutants from runoff. For developments that are located near riparian corridors, the conveyance of runoff in sheet flow across these buffer areas instead of piped to an outfall to the creek can be considered. In addition, wide riparian corridors can also provide opportunities for siting shallow infiltration facilities that are intentionally constructed to provide flow control. These regional facilities can be designed to blend in with the surrounding terrain and planted with native vegetation (SCVURPPP, 2005).

5.2 Land Use Planning Measures in Vallejo

VSFCD is the agency that conducts flood protection and most of the environmental restoration projects in Vallejo. Flood protection projects are now typically multi-objective projects that provide valuable habitat, protect endangered species, and allow for open space recreation. In the design of future flood protection projects, District staff will also consider providing stream buffers, bank stabilization, grade controls, and other in-stream measures to protect the stream from hydromodification impacts from future development.

Currently, the Vallejo Permittees do not have a specific stream setback requirement, however, there has not been a clear need for such a requirement because a majority of the natural channels in Vallejo are within areas dedicated as open space. There are easements associated with existing manmade drainage channels owned and operated by VSFCD, to accommodate access roads for maintenance, but there are no currently designated riparian buffer areas for existing natural creeks. If a situation arises where a development project encroaches on a stream channel susceptible to hydromodification impacts, then the City of Vallejo Public Works Department and VSFCD will consider an appropriate stream setback as a condition of approval for the project.

6. INCORPORATING THE HMP INTO THE PROJECT REVIEW PROCESS

This section describes how HM requirements can be integrated into the City of Vallejo's development entitlement process to addresses the general requirements of MRP Provision C.3 and the HM requirements in Provision C.3.g. specifically.

Two tools are provided to assist the City of Vallejo in evaluating whether a Project meets the C.3. requirements. Figure 6-1 shows the City of Vallejo's Development Entitlement Process, which has been modified to incorporate the C.3 and HM requirements. This flow chart steps through the various stages of the development entitlement process, which include: 1) preliminary in-take appointment, 2) planning application, 3) planning application determination letter, 4) condition of approval compliance, 5) plan check, 6) permits, 7) construction, 8) inspections, and 9) permit finalization.

The second tool to assist the City is the HMP Implementation flow chart shown in Figure 6-2. During the preliminary C.3 planning stage, the City should review the HMP Implementation Flowchart with the project proponent to verify whether the project falls under the C.3.g. requirements (i.e., whether the proposed project's impervious area meets the one acre or larger threshold). Within this flowchart, the City can determine if a project is located in a geographic area where the HM Standard applies by using the HMP Applicability Map as discussed in Section 3.3. If a project is located in a geographic area where the HM Standard applies, but the type of project is exempt or excluded based on one of the criteria listed in Section 4.2, the City will still require that the project proponent select feasible site design and LID treatment measures.

It is during the preliminary C.3 planning stage that HM controls should be considered at the same time as source control, site design, and LID treatment measures. Not only does this ensure that the HM requirements are met during the development entitlement process, but it provides the opportunity to consider the combined flow control benefit of all of the measures selected.

Additionally, extra lead time may be needed to coordinate implementation of hydromodification mitigations that are a combination of on-site, regional and/or in-stream HM controls. The City and project proponent may need to meet with multiple agencies, property owners, and other parties to coordinate the planning, design, approval, and construction of the proposed HM controls.

Once the project proponent has submitted the planning application, the City will review the application and development plans to determine the adequacy of the project's source control, site design, LID treatment, HM control, pesticide reduction, and long-term operation and maintenance (O&M) measures. The City will also review whether hydromodification impacts have been addressed in the CEQA environmental review document, through the Initial Study Checklist and any Environmental Impact Reports (if applicable). Once review of the planning documents is complete, the City verifies whether the project meets the minimum C.3 impervious area threshold. If it does, then the project proponent receives approval through either a public hearing or at the staff-level.

The City then prepares Conditions of Approval for the project's various water quality and HM control measures, as well as for any CEQA mitigation measures. The project proponent must submit written responses to the Conditions of Approval prior to the City conducting the Plan Check.

During the Plan Check stage, the City reviews the project's stormwater management plans, construction drawings, and the design and sizing of the proposed facilities to ensure that hydromodification impacts are addressed according to the standards and criteria in Section 4 of this HMP. The City will verify documentation of a long-term O&M agreement and maintenance access agreement or other legal control mechanism from the property owner and provide education about maintenance. The City will also review the project's final impervious area and determine if the project's water quality, HM controls, and CEQA mitigation measures are adequate in complying with the C.3 requirements.

If a project proponent is unable to meet the HM Performance Standard with on-site controls (Implementation Method 1), they will need to look at a combination of on-site and regional controls (Implementation Method 2), and/or in-stream controls (Implementation Method 3). In this case, the City may need to coordinate the planning and design of proposed HM controls with multiple property owners and project applicants, staff from other municipalities (if drainage areas for off-site controls cross jurisdictional boundaries), and/or Regional Water Board staff.

If the project proponent is able to meet the HM Performance Standard and C.3 requirements, then the City will issue the building, grading, public improvement, and connection permits and construction can begin.

During the construction stage, the City will inspect the construction of the water quality and HM control measures to ensure that the facility conforms to the design drawings and specifications. The City will log and track information about the project's water quality and HM measures, for future annual reporting and for use in implementing the O&M verification program. The City will also conduct post-construction inspections to verify ongoing O&M of the measures and compliance with C.3 requirements, implementing enforcement actions as needed.

The last stage in the development entitlement process is that the City finalizes all permits and issues a Certificate of Occupancy.

7. GUIDANCE TO PROJECT PROPONENTS

For a project proponent to meet C.3 requirements, an integrated approach to site design and stormwater management should be considered. Traditional approaches to stormwater management planning are not likely to be cost-effective. The use of site planning, source control, LID, and HM control techniques will help generate a more hydrologically functional site, maximize the effectiveness of BMPs, and integrate stormwater management throughout a project.

The sequential process presented in the following sections begins with assessing site design measures and determining the amount of Self-Treating Areas and Self-Retaining Areas on a project site (Step 1). If a project consists entirely of Self-Retaining Areas, Areas Draining to Self-Retaining Areas, and/or Self-Treating Areas, then it complies with site design and treatment requirements of the MRP.

If there are remaining impervious areas with stormwater runoff to be treated, then the project proponent assesses the feasibility to treat the C.3.d. amount of stormwater runoff via infiltration measures or devices and/or rainwater harvesting measures. If it is infeasible to fully treat the C.3.d stormwater runoff amount using either of the two measures, then a project proponent implements biotreatment (Step 2).

In many cases, LID BMPs provide full or partial compliance with HM control requirements. All on-site retention BMPs provide volume reduction to fully or partially satisfy the volume matching criteria applicable to projects. In addition, both retention and biotreatment BMPs can provide flow control benefits to fully or partially satisfy HM control requirements. In general, once LID BMPs have been selected and sized, the project site can be assessed for compliance with the HM control requirements (Step 3).

This following general step-wise approach is intended to organize the process in a linear way; however, it is not intended to imply that LID requirements must be considered before HM requirements. In most cases, it is necessary to select BMPs for both LID and HM control in a parallel process.

7.1 <u>Step 1: Site Design Measures/Self-Treating and Self-Retaining Areas</u>

Site design is a key tool in affecting the stormwater drainage patterns from a project site. The primary objective of site design principles and techniques is to reduce the hydrologic and water quality impacts associated with land development. The benefits derived from this approach include the following:

- Reduction of the size of downstream BMPs and conveyance systems;
- Reduction of pollutant loading; and
- Reduction of hydromodification impacts to receiving streams.

The following site design concepts should be considered early in the site planning process:

- LID and HM control measures should be considered as early as possible. Hydrology should be an organizing principle that is integrated into the initial site assessment planning phases. Where flexibility exists, conceptual drainage plans should attempt to route water to areas suitable for on-site retention BMPs.
- Individual LID treatment measures may be distributed throughout the project site as feasible and may influence the configuration of roads, buildings and other infrastructure.
- HM control measures should be considered early in the design stages. Even sites with LID measures will still have runoff that occurs during large storm events, but LID facilities can have flood control benefits. It may be possible to simultaneously address HM control requirements through an integrated water resources management approach.
- Allow sufficient space for LID and HM control measures in areas that can physically accept runoff.

The first step in project planning is to assess site design strategies as part of MRP requirements in C.3.c.i.(2)(a). On development projects where they are feasible, these methods are considered the primary and preferred method of implementing LID and achieving compliance with Provision C.3.c. These methods have the greatest potential for controlling stormwater runoff via infiltration and evapotranspiration while also mimicking pre-project site hydrology.

A project proponent should first prepare a conceptual drainage plan that shows the rough delineations of the major drainage areas on a project site, typically defined by the points of discharge from the site. Dividing the project site into drainage management areas (DMAs) is a common step in the preparation of stormwater management plans, and provides a framework for feasibility screening, BMP prioritization, and facilitation of distributed control throughout a project site.

Next, a project proponent should consider the following site design strategies:

- Limit disturbance of natural water bodies and drainage systems;
- Conserve natural areas; and
- Minimize impervious surfaces.

Project proponents should designate Self-Treating Areas to document and credit those areas that are left undisturbed or are being restored to pervious condition. Self-Treating Areas are defined as those portions of a project site in which infiltration, evapotranspiration, and other natural processes remove pollutants from stormwater. Self-Treating Areas may include conserved natural open areas, landscaped areas, green roofs, pervious pavement, and interceptor trees. A Self-Treating Area only treats the rain falling on itself and does not receive stormwater from other areas. These areas may or may not produce stormwater runoff. However, any runoff produced is filtered through vegetation and surface soils before flowing to storm drains.

Provision C.3.c.i.(2)(a) also requires Regulated Projects to implement one or more of the following site design measures:

1. Direct roof runoff into cisterns or rain barrels for reuse;
2. Direct roof runoff onto vegetated areas;
3. Direct stormwater runoff from sidewalks, walkways, and/or patios onto vegetated areas;
4. Construct sidewalks, walkways, and/or patios with permeable surfaces; and
5. Construct driveways, bike lanes and/or uncovered parking lots with permeable surfaces.

Project proponents should designate Self-Retaining Areas and Areas Draining to Self-Retaining Areas to implement and account for items 2 through 5 above, while assuring the rainfall intensity specified in Provision C.3.d. will produce no stormwater runoff from these areas. Self-Retaining Areas are also called “zero discharge” areas and are designed to retain the first one inch of rainfall (by ponding and/or evapotranspiration) without producing stormwater runoff. These areas may include graded depressions with landscaping or pervious pavement. Areas Draining to Self-Retaining Areas are impervious or partially pervious areas that drain to Self-Retaining Areas.

The Self-Treating Areas and Self-Retaining Areas criteria are the following:

- The impervious to pervious area ratio for Areas Draining to Self-Retaining Areas and Self-Retaining Areas should not exceed 2:1 and these areas should be designed to retain one inch of rainfall over these areas.
- Green roofs can be considered Self-Treating Areas or Self-Retaining Areas.
- Pervious pavement can be considered a Self-Treating Area, if the area stores and infiltrates rainfall at a rate equal to immediately surrounding unpaved, landscaped areas, or a Self-Retaining Area, if it receives stormwater runoff from other areas and is designed to store and infiltrate the C.3.d stormwater runoff volume.
- Interceptor Tree credits will be given in terms of square footage of area considered to be self-treating per the method specified in the Construction General Permit (200 sf for new evergreen trees, 100 sf for new deciduous trees, and the average diameter at 4.5 ft above grade for existing trees).

If a project consists entirely of Self-Retaining Areas, Areas Draining to Self-Retaining Areas, and/or Self-Treating Areas, then it complies with site design and treatment requirements of the MRP. If there are remaining impervious areas with stormwater runoff to be treated, then the project proponent moves on the Step 2 below.

7.2 Step 2: LID Treatment Measures

LID treatment measures are required in addition to site design measures to reduce pollutants in stormwater discharges. LID treatment measures are defined as rainwater harvesting and use, infiltration, evapotranspiration, or biotreatment. A biotreatment system may only be used if it is infeasible to implement harvesting and use, infiltration, or evapotranspiration at a project site. LID treatment measures can partially or fully satisfy hydromodification performance criteria, depending on their design and functions.

To evaluate the feasibility of LID implementation, the first step is to select and size either infiltration measures/devices or rainwater harvesting and use, if feasible, for the remaining runoff from DMAs that are not Self-Treating or Self-Retaining. The assessment of feasibility of infiltration or rainwater harvest for a project can start with assessing either infiltration or rainwater harvesting. If either option is found to be feasible and is implemented, the other option does not need to be assessed. If the first option considered is found to be infeasible, then the other option must be assessed before moving to biotreatment.

Infiltration can be implemented on a project site using infiltration measures or devices. The most common infiltration measure that will be used by projects is bioinfiltration.

Factors affecting whether the required amount of stormwater runoff may be infiltrated in a bioinfiltration facility include: 1) the permeability of underlying soils; and 2) the presence or absence of factors which would preclude allowing the open interface of the gravel layer to underlying soils.

The following conditions may preclude the use of infiltration measures or devices on a project site:

- Locations within 100 feet of a groundwater well used for drinking water;
- Development sites where pollutant mobilization in the soil or groundwater is a documented concern;
- Locations with potential geotechnical hazards;
- Locations where policies of local water districts or other applicable agencies preclude infiltration.

In addition, MRP Provision C.3.d.iv. provides feasibility criteria specifically for infiltration devices, which include the following:

- Appropriate pollution prevention and source control measures, including a minimum of two feet of suitable soil to achieve a maximum of 5 inches/hour infiltration rate;
- Adequate maintenance is provided to maximize pollutant removal capabilities;

- Vertical distance from the base of any infiltration device to the seasonal high groundwater mark is at least 10 feet (or greater if the site has highly porous soils or there are other concerns for groundwater protection);
- Unless stormwater is first treated by a method other than infiltration, infiltration devices are not approved as a treatment measure for stormwater runoff from areas of industrial areas, areas of high vehicular traffic or land uses that pose a high threat to water quality;
- Infiltration devices are not placed in the vicinity of known contaminated sites; and
- Infiltration devices are located a minimum of 100 feet horizontally away from any known water supply wells, septic systems, and underground storage tanks (or greater if the site has highly porous soils or there are other concerns for groundwater protection).

If site conditions preclude infiltration, then infiltration (using bioinfiltration, other infiltration measures, or infiltration devices) is infeasible and the feasibility of rainwater harvesting systems must be assessed.

To determine if rainwater harvesting is feasible for the project or DMA, an assessment of use demand for harvested stormwater that will achieve 80 percent capture of the average annual runoff volume is required. Demand estimation should include consideration of requirements for using low water use plumbing fixtures, recycled water for indoor and outdoor uses, and low water use landscaping.

If it is feasible to use either of these types of LID BMPs to fully retain the Design Control Volume (DCV) from the project site, then no additional BMPs are required to treat discharges from the Project area to meet LID requirements.

If it is infeasible to fully retain the DCV using either infiltration BMPs or harvest and use BMPs, then biotreatment BMPs must be selected and sized for the remaining DCV. Biotreatment BMPs should be selected to address the pollutants of concern and must be designed to achieve the maximum feasible infiltration and evapotranspiration rates. If it is infeasible to fully retain or biotreat the DCV on the project site, then Alternative Compliance may be considered.

7.3 Step 3: HM Control Measures

In many cases, LID treatment measures provide full or partial compliance with hydromodification requirements. All retention BMPs provide volume reduction to fully or partially satisfy the volume matching criteria applicable to projects. In addition, both retention and biotreatment BMPs can provide flow control benefits to fully or partially satisfy hydromodification requirements.

In general, once the LID treatment measures have been selected and sized, the project site can be assessed for compliance with the HM control requirements according to Figure 6-2. Discussion of possible exemptions to the HM standard are provided in Section 4.2 and each of the three implementation methods, including appropriate design options, is provided in Section 4.3. A summary of the design options is provided below:

- Method 1 – On-Site HM Controls
    - Contra Costa County IMP sizing charts adjusted for low flow discharge per Table 4-1. Orifice diameter divided by $\sqrt{2}$ (or 1.414) to account for the reduction in low flow discharge.
    - Project-specific flow duration control analysis using custom hydrologic continuous simulation per Appendix C.
    - Project-specific flow duration control analysis using BAHM if Vallejo is added to the model.
- Method 2 – Regional HM Controls
    - Region-specific flow duration control analysis using custom hydrologic continuous simulation per Appendix C.
    - Region-specific flow duration control analysis using BAHM, if Vallejo is added to the model.
    - Erosion potential analysis per Appendix D.
- Method 3 – In-Stream HM Controls
    - Erosion potential analysis per Appendix D.

The recommended project planning approach to address HM requirements depends on the relative magnitude of HM requirements compared to LID requirements. If the volume of water that needs to be reduced to address HM requirements is greater than the treatment volume for LID requirements, then HM controls may satisfy both requirements (or vice versa). Relative magnitudes are a function of the susceptibility of receiving waters and the existing condition of the project site.

7.4 Step 4: Process Iteration for HM Standard Compliance

The step-wise process should be continued until the HM standard has been met. It may be necessary to evaluate whether source controls, site design, and LID treatment measures have been maximized to the full extent possible in order to meet the HM standard.

8. ACKNOWLEDGEMENTS

The Vallejo Permittees would like to acknowledge the other MRP permittees. This HMP utilizes similar concepts and builds off of the HMPs that have been developed by the Alameda Countywide Clean Water Program (ACCWP), Contra Costa Clean Water Program (CCCWP), Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP), San Mateo Countywide Water Pollution Prevention Program (SMCWPPP), and Fairfield-Suisun Urban Runoff Management Program (FSURMP).

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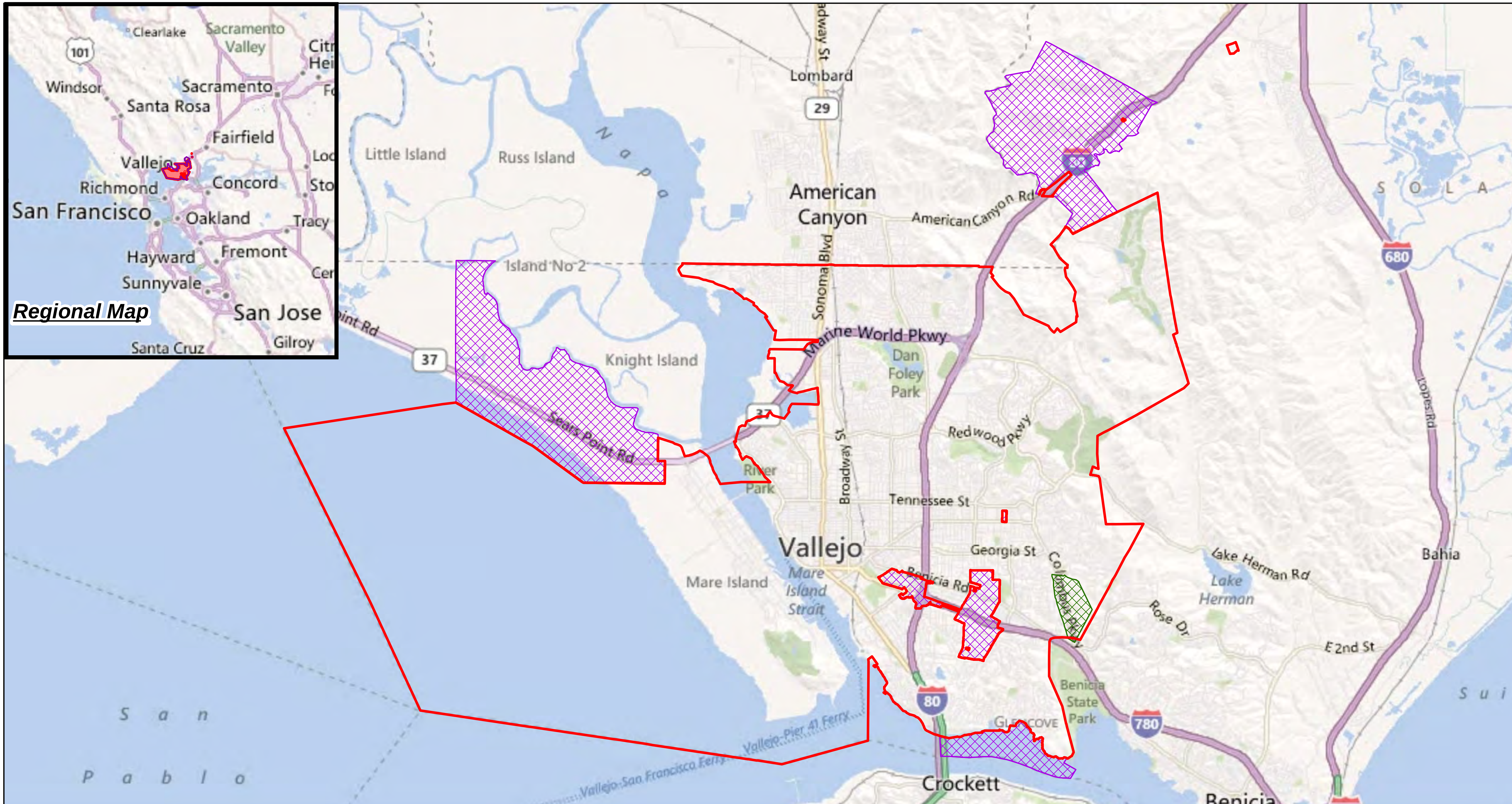
FIGURES



Legend

City of Vallejo, Boundary

City of Vallejo, Sphere Of Influence of Interest

Bordoni Ranch Annexation Boundary

Basemap: Bing Maps, 2009

0 1.25 2.5 3.75 Miles

N

Vallejo HMP Boundary Map

Vallejo HMP

Geosyntec consultants

Figure **2-1**

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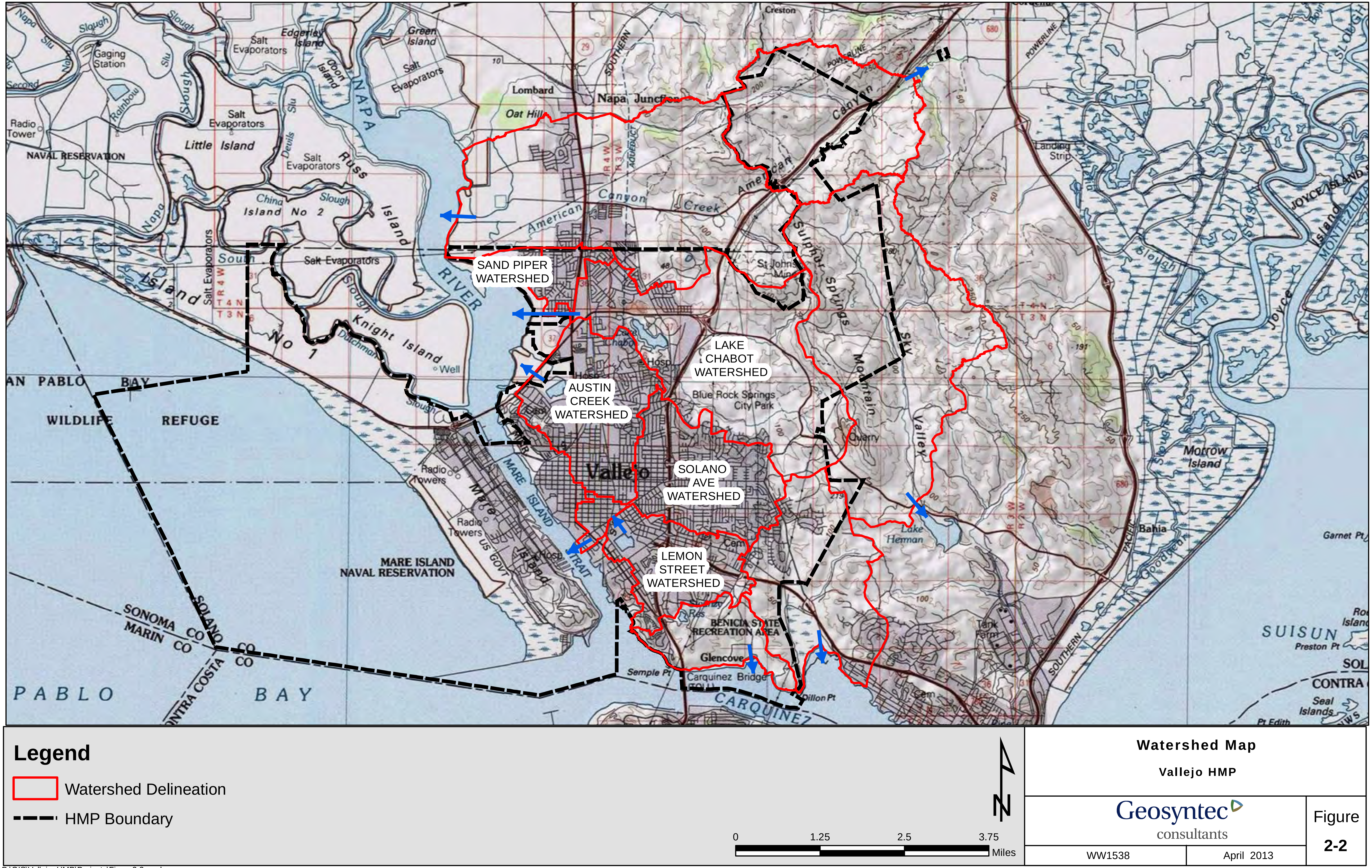

Watershed Map

Vallejo HMP

Geosyntec consultants

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Figure **2-2**

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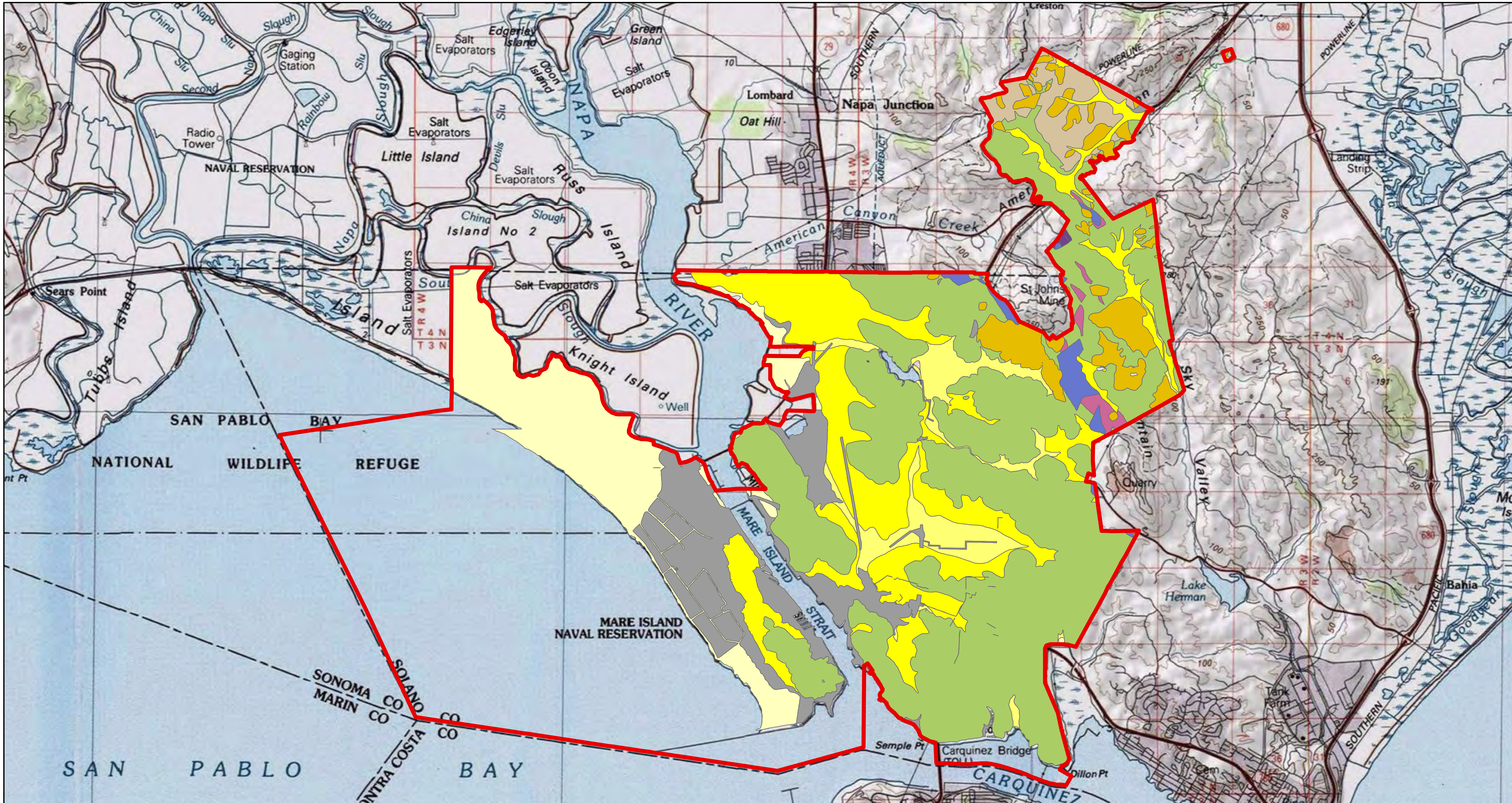


Legend

Geologic Units

- af Artificial Fill
- Jv Great Valley complex volcanic rock (Jurassic)
- Ji Great Valley complex plutonic rocks (Jurassic)
- Jsp Great Valley complex serpentinite (Jurassic)
- Ks Great Valley complex sedimentary rocks (Cretaceous)
- Qha Alluvium (Holocene)
- Qhym Med Deposits (late Holocene)
- Qpa Alluvium (Pleistocene)
- Qsl Hillslope Deposits (Quaternary)
- Tes Sedimentary Rocks (Eocene)
- HMP Boundary

Source: Geologic Map of the San Francisco Bay Region, Scientific Investigatory Map 2918 (USGS, 2006)

0 1.25 2.5 3.75 Miles

N

Geology Map

Vallejo HMP

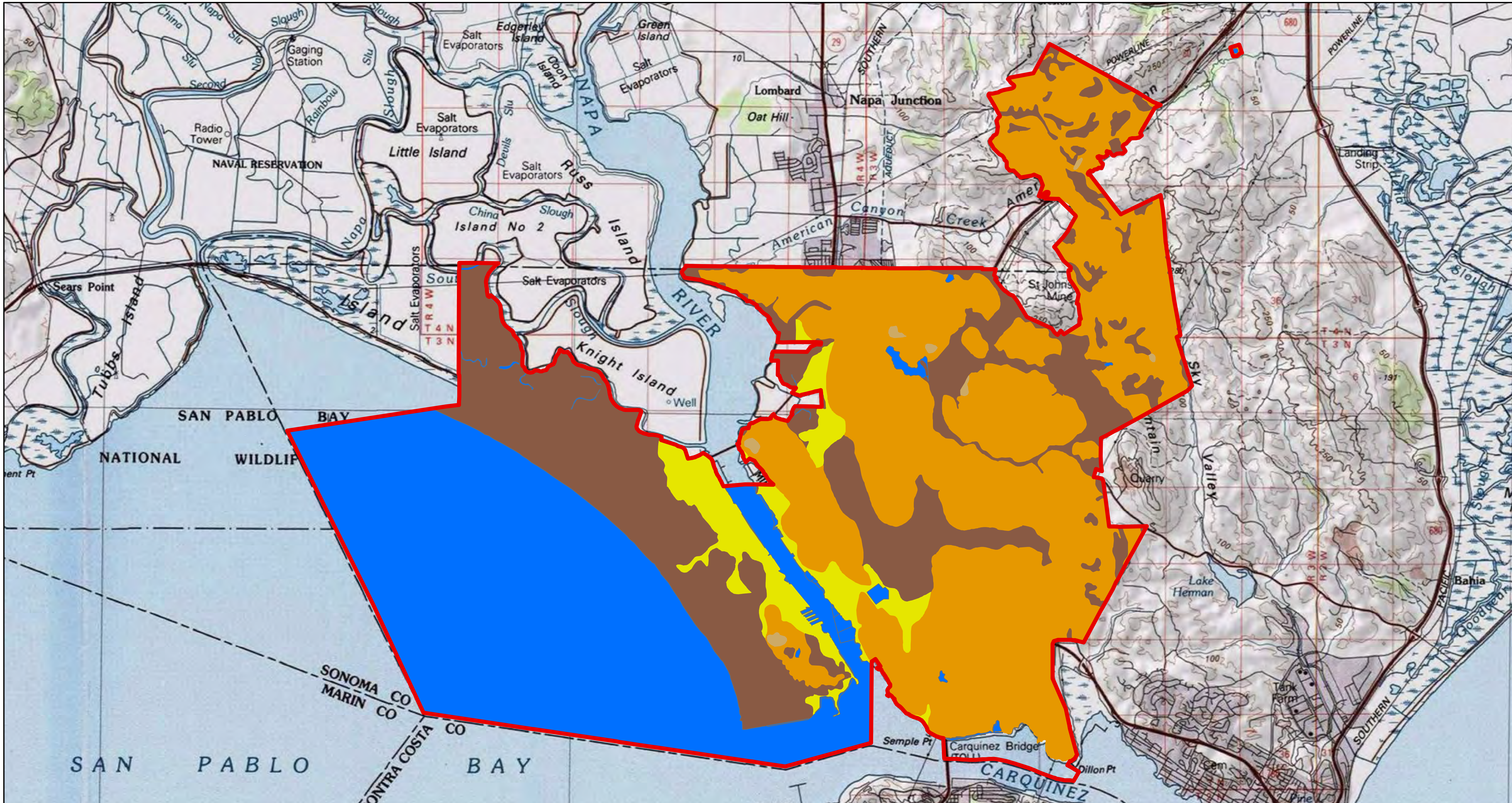
Geosyntec consultants

Figure 2-3

WW1538

April 2013

P:\GIS\Vallejo_HMP\Projects\Figure 2-3.mxd



Legend

Hydrologic Soil Group or Classification — HMP Boundary

- Borrow Pits
- C
- D
- Made Land
- Water

0 1.25 2.5 3.75 Miles

N

Soils Map

Vallejo HMP

Geosyntec consultants

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Figure 2-4

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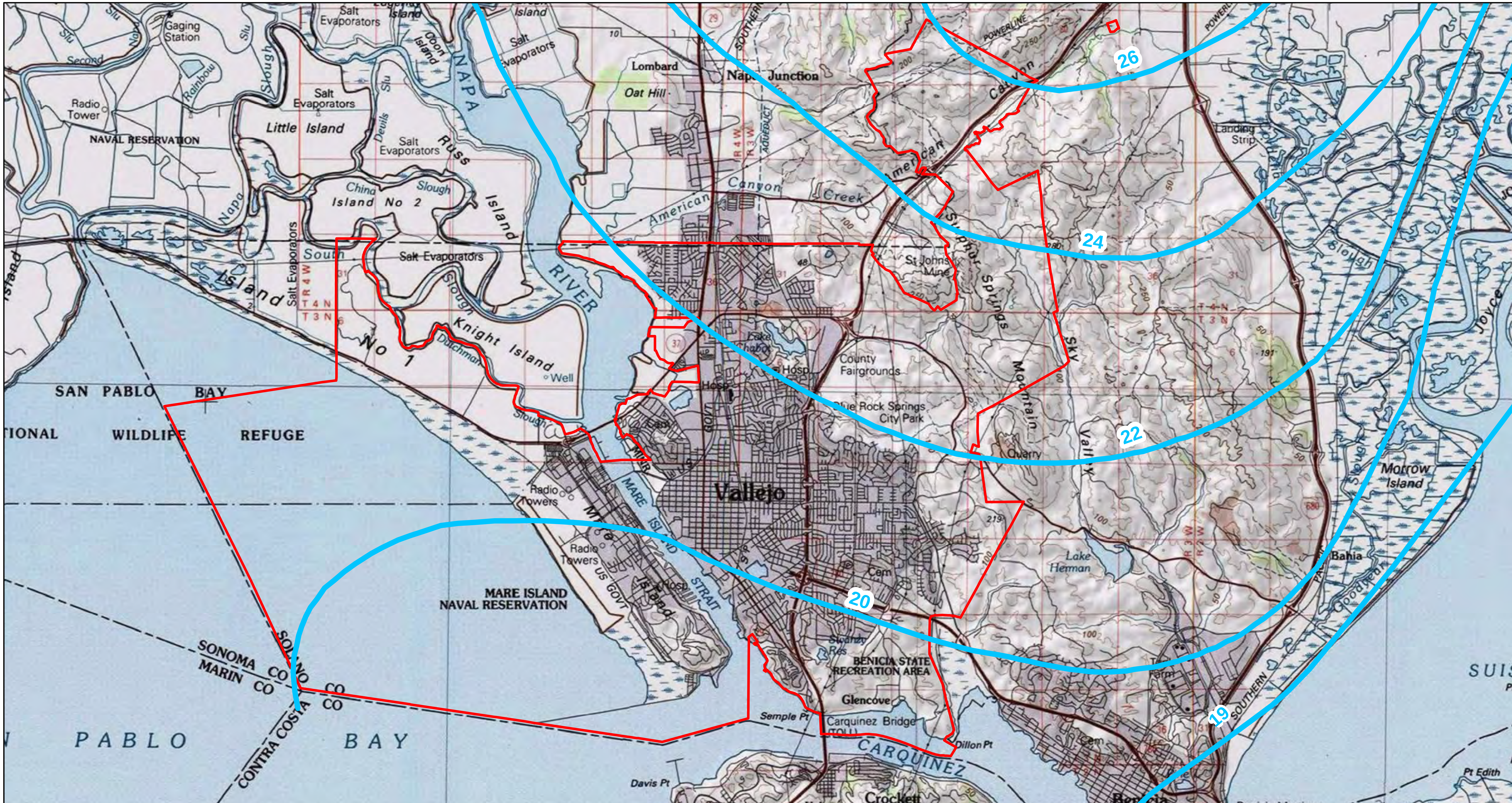

Legend

Isohyetal Lines

HMP Boundary

Note: Isohyetal lines from 1999 Solano County Design Rainfall Study by West Yost & Associates

0 1.25 2.5 3.75 Miles

N

Isohyetal Map

Vallejo HMP

Geosyntec consultants

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Figure 2-5

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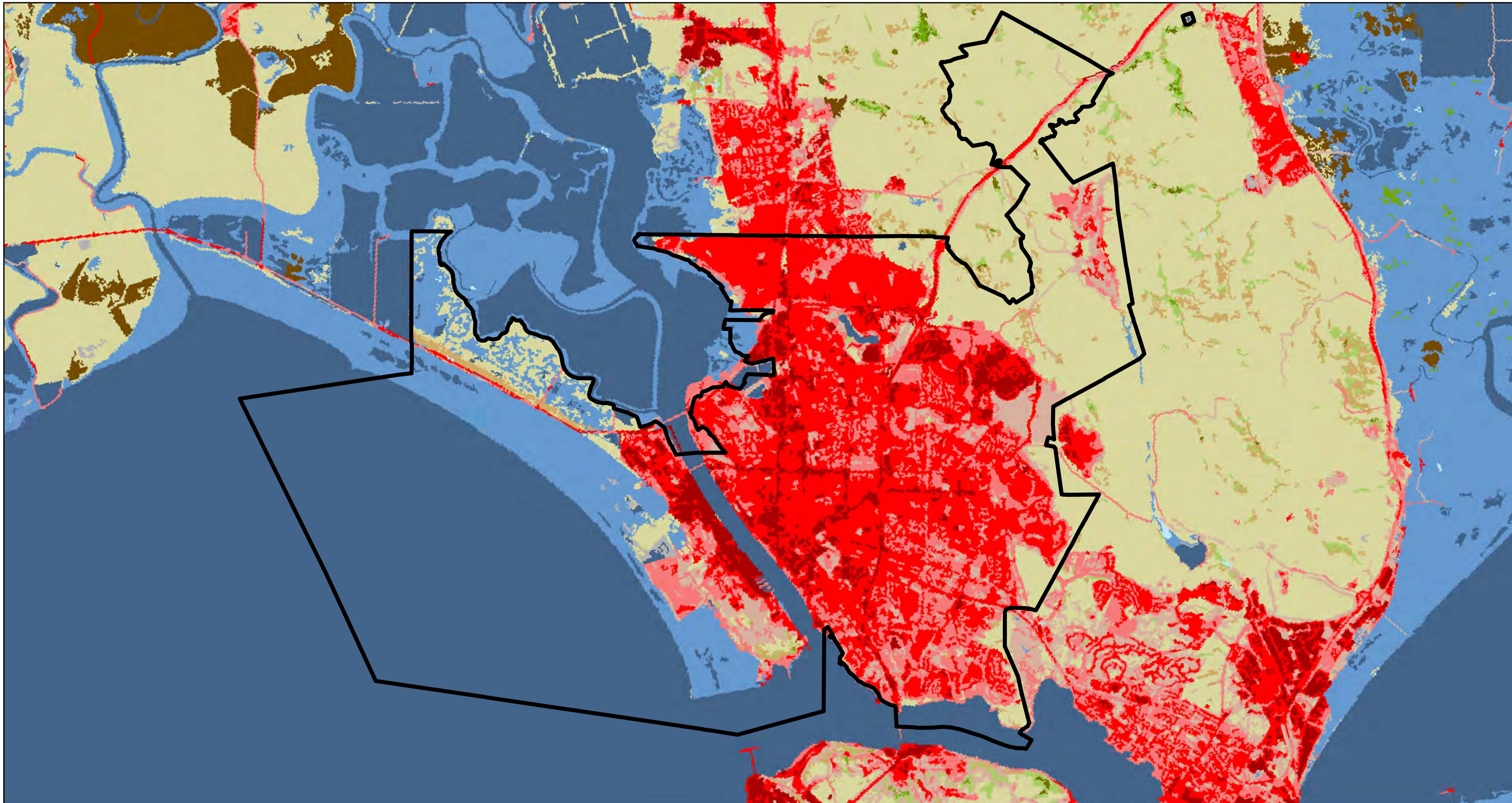

Legend

HMP Boundary

2001 NLCD Classification

- Open Water
- Developed, Open Space
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, High Intensity
- Barren Land
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Scrub/Shrub
- Grassland/Herbaceous
- Pasture/Hay
- Cultivated Crops
- Woody Wetlands
- Emergent Herbaceous Wetland

0 1.25 2.5 3.75 Miles

N

Land Cover Map

Vallejo HMP

Geosyntec consultants

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Figure 2-6

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Figure 2-7

City of Vallejo Zoning (West)

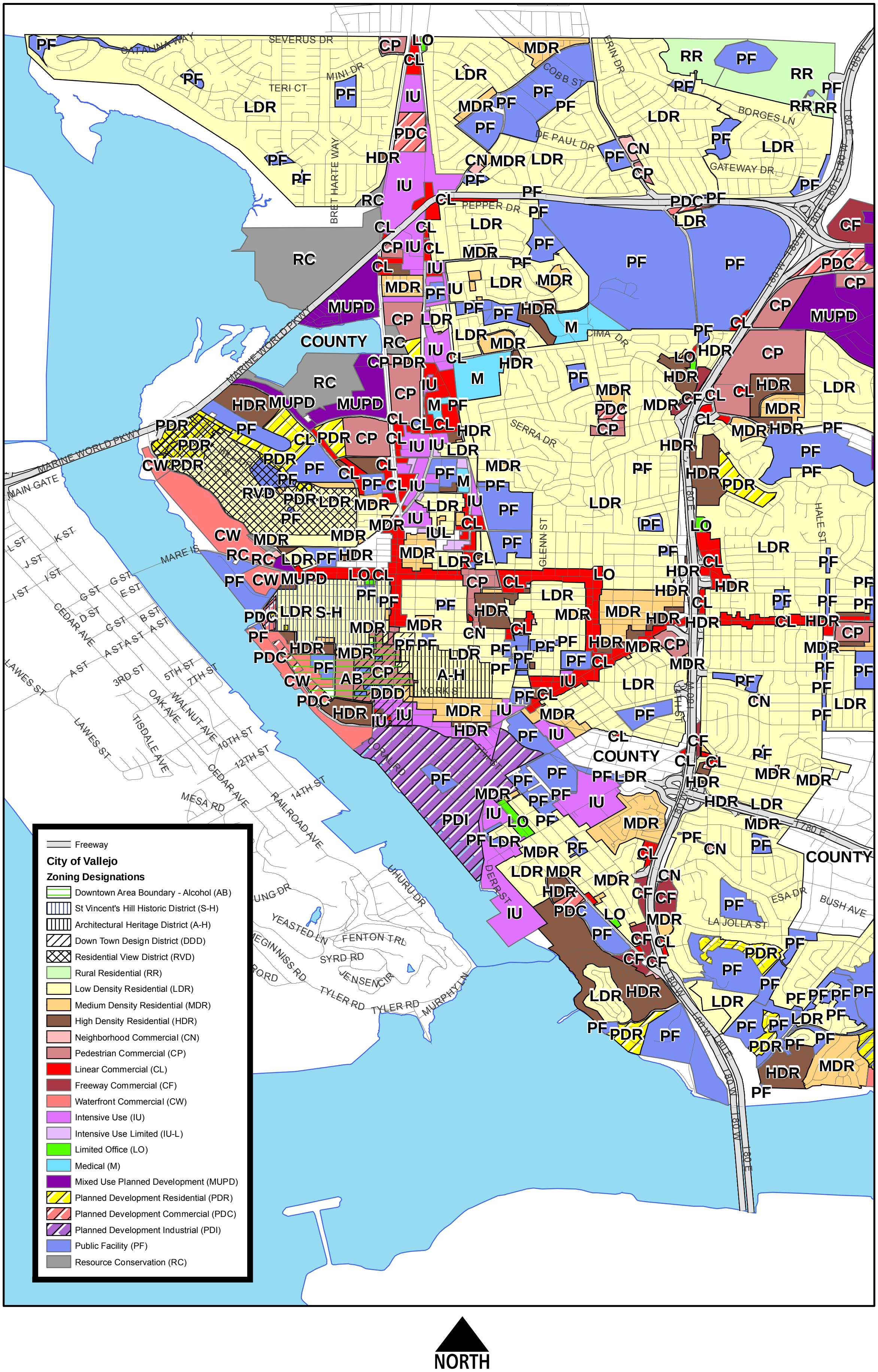
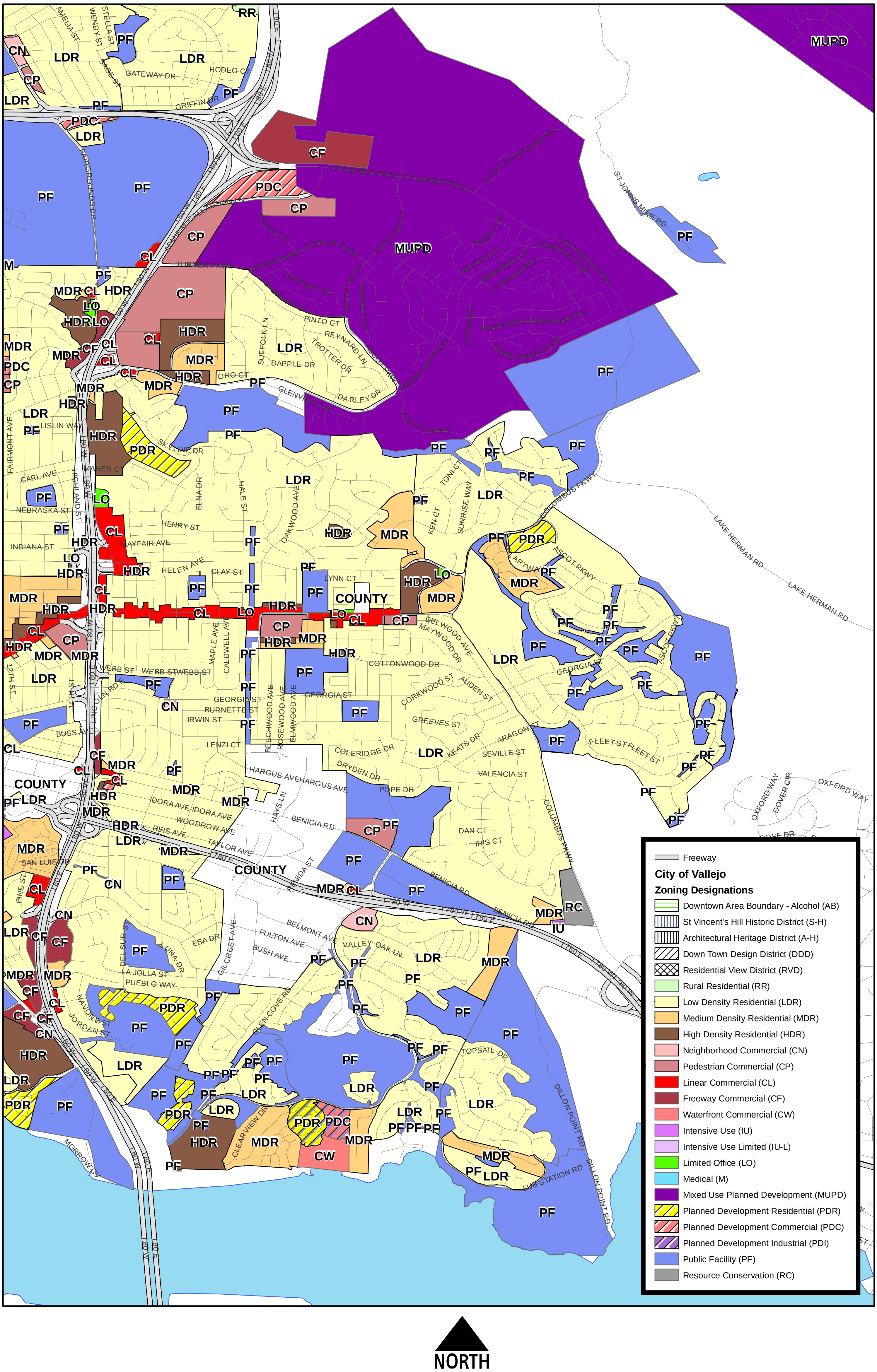
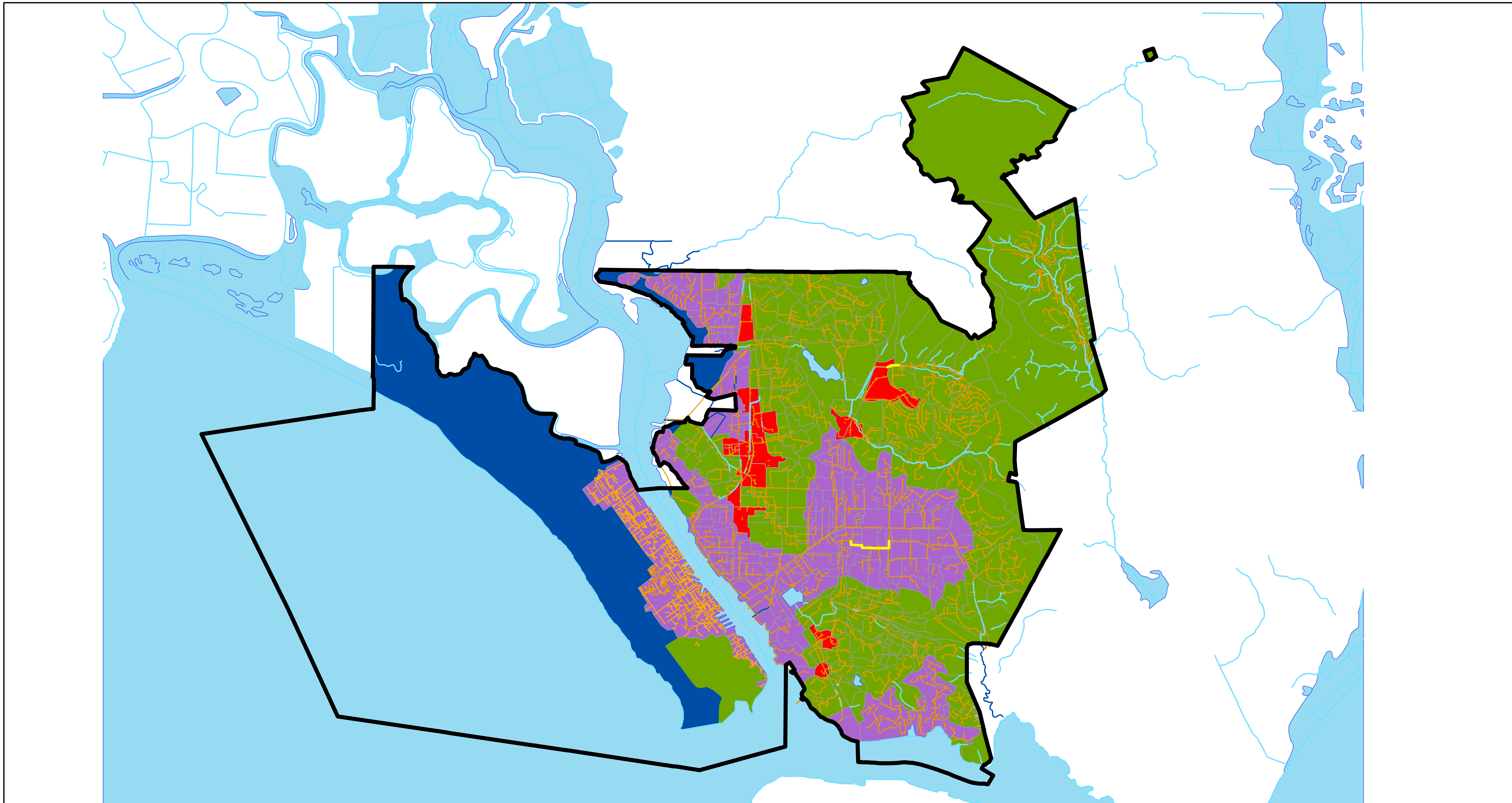


Figure 2-8

City of Vallejo Zoning (East)





Legend

- HMP Boundary
- Fully Hardened Channels
- Non-Hardened Channels (Non-Tidal)
- Non-Hardened Channels (Tidal)
- Storm Drain System
- Open Water
- Areas Draining to Continuously Hardened Conveyances to the Bay
- HMP Applicable Areas
- Subcatchments with greater than or equal to 65% Impervious
- Baylands

N

0 1.25 2.5 3.75 Miles

HMP Applicability Map

Vallejo HMP

Geosyntec consultants

WW1538 | April 2013

Figure 3-1

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Figure 6-1: City of Vallejo
Development Entitlement Process Incorporating HMP Requirements

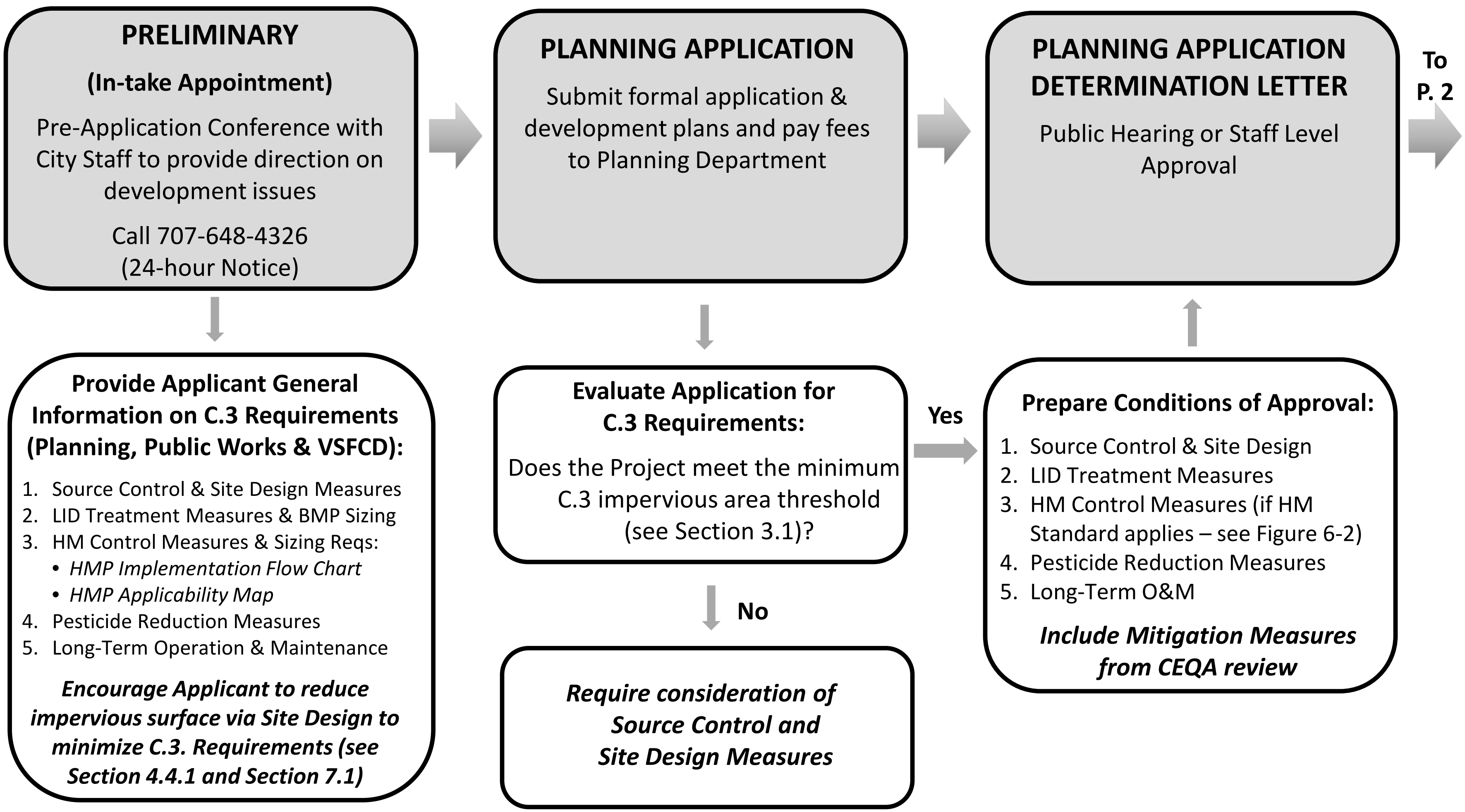


Figure 6-1: City of Vallejo
Development Entitlement Process Incorporating HMP Requirements

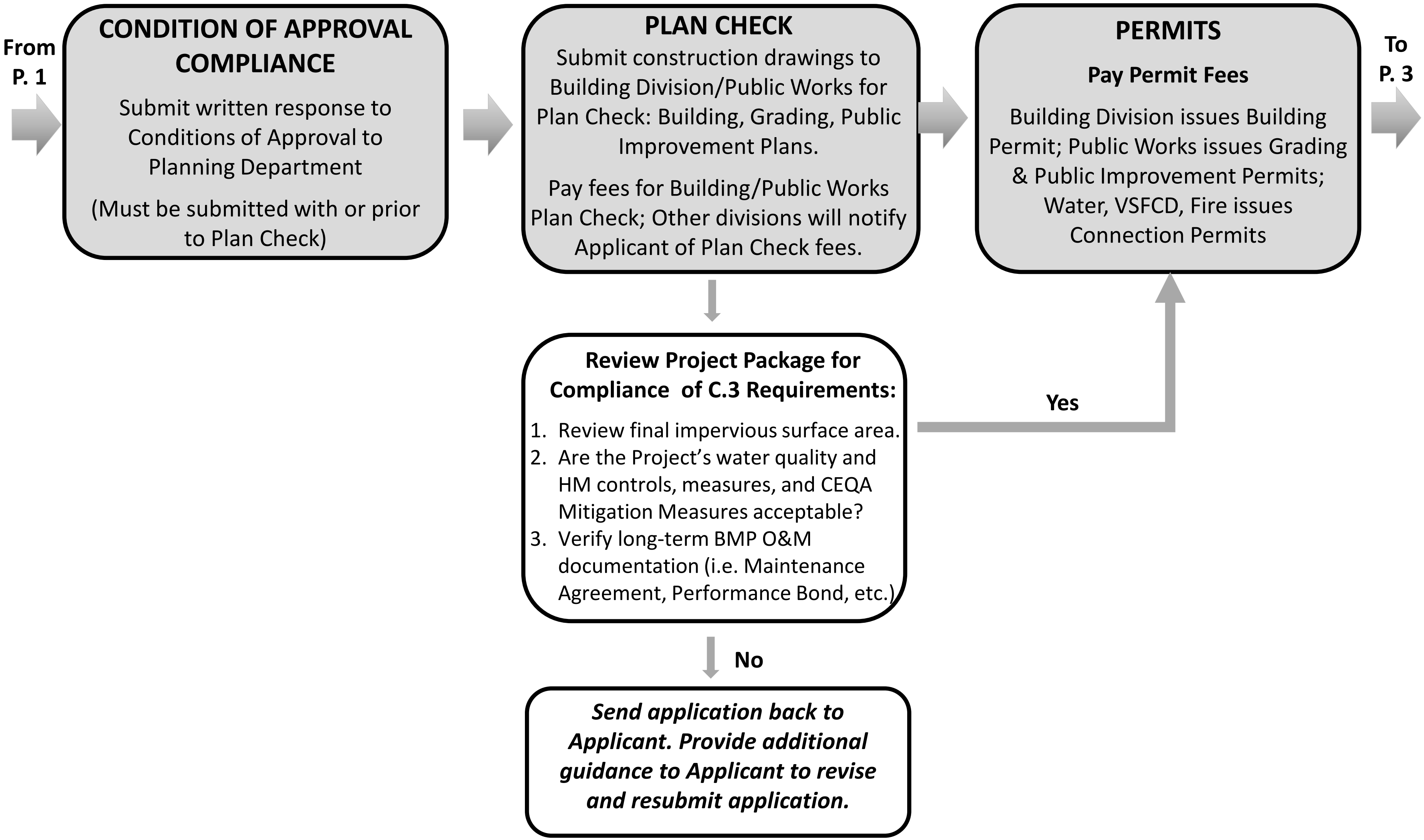


Figure 6-1: City of Vallejo
Development Entitlement Process Incorporating HMP Requirements

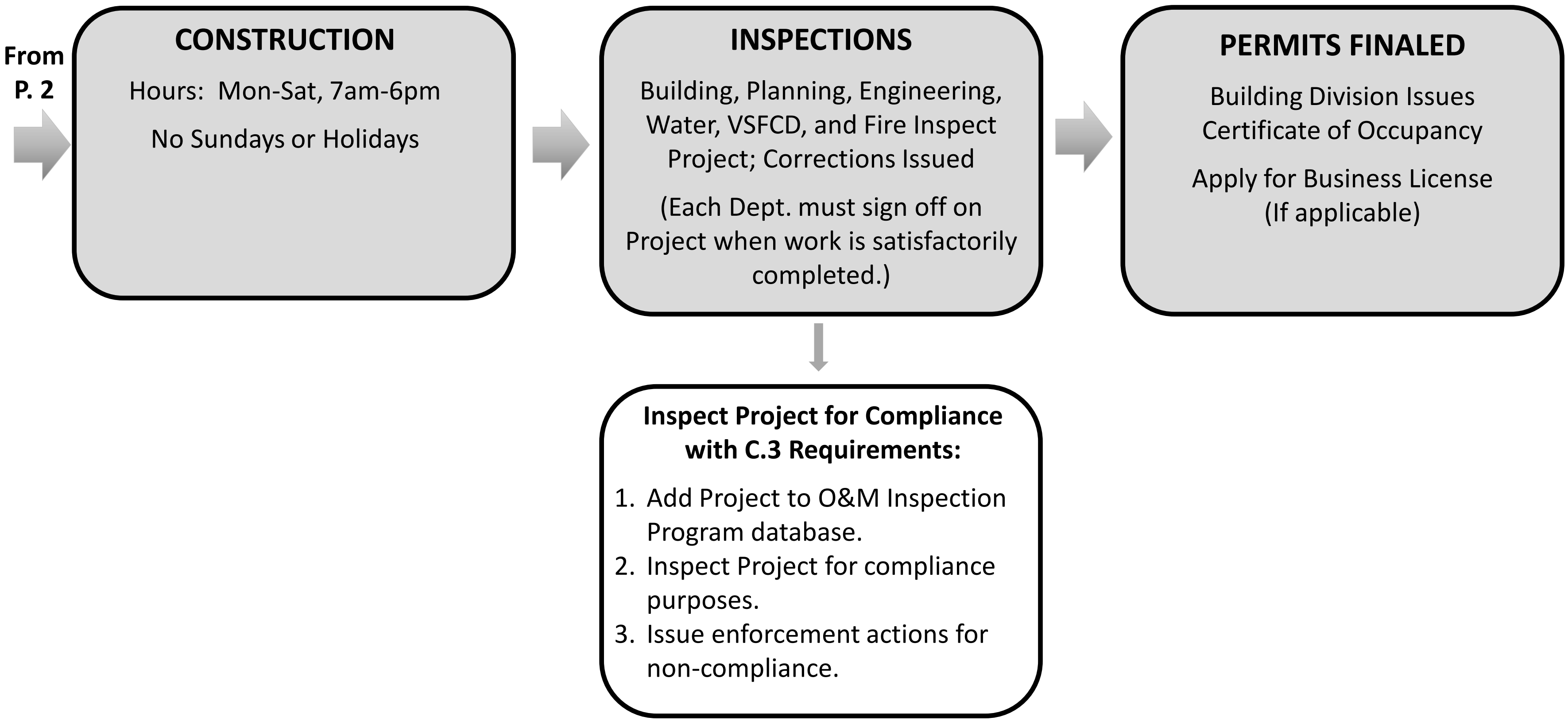
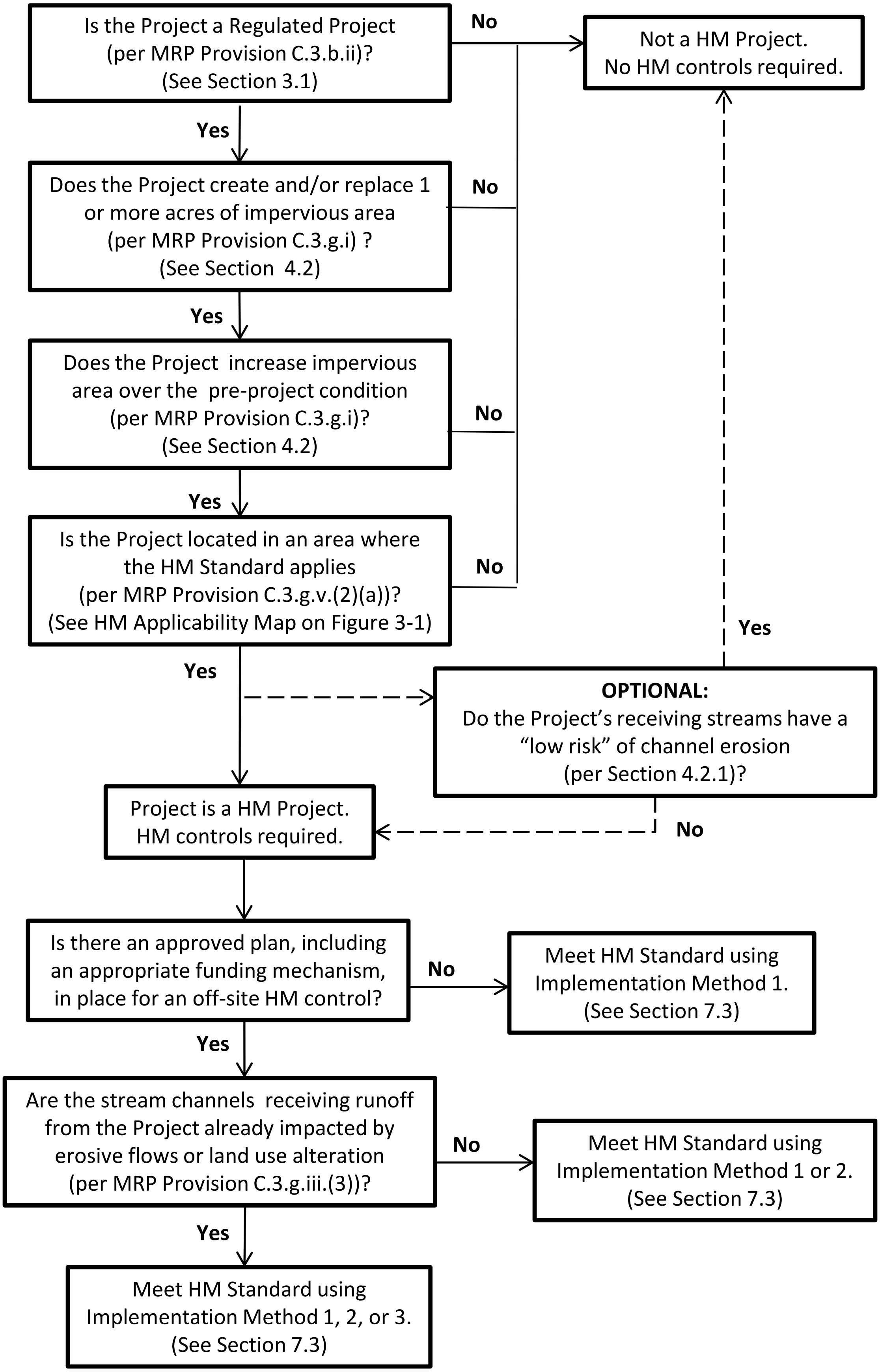


Figure 6-2: HMP Implementation Flow Chart



APPENDIX A

Municipal Regional Stormwater NPDES Permit Provision C.3.g

Stormwater Quality Association (CASQA), or the equivalent, may be considered qualifying training.

iii. **Reporting –** Projects reviewed by third parties shall be noted in reporting tables for Provision C.3.b.

C.3.g. Hydromodification Management

i. **Hydromodification Management (HM) Projects** are Regulated Projects that create and/or replace one acre or more of impervious surface and are not specifically excluded within the requirements of Attachments B–F. A project that does not increase impervious surface area over the pre-project condition is not an HM Project. All HM Projects shall meet the Hydromodification Management Standard of Provision C.3.g.ii.

ii. **HM Standard**

Stormwater discharges from HM Projects shall not cause an increase in the erosion potential of the receiving stream over the pre-project (existing) condition. Increases 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 on beneficial uses due to increased erosive force. The demonstration that post-project stormwater runoff does not exceed estimated pre-project runoff rates and durations shall include the following:

(1) **Range of Flows to Control:** For Alameda, Contra Costa, San Mateo, and Santa Clara Permittees, HM controls shall be designed such that post-project stormwater discharge rates and durations match pre-project discharge rates and durations from 10 % of the pre-project 2-year peak flow[7] up to the pre-project 10-year peak flow. For Fairfield-Suisun Permittees, HM controls shall be designed such that post-project stormwater discharge rates and durations shall match from 20 percent of the 2-year peak flow up to the pre-project 10-year peak flow. Contra Costa Permittees, when using pre-sized and pre-designed Integrated Management Practices (IMPs) per Attachment C of this Order, are not required to meet the low-flow criterion of 10% of the 2-year peak flow. These IMPs are designed to control 20% of the 2-year peak flow. After the Contra Costa Permittees conduct the required monitoring specified in Attachment C, the design of these IMPs will be reviewed.

(2) **Goodness of Fit Criteria:** The post-project flow duration curve shall not deviate above the pre-project flow duration curve by more than 10 percent

[7] 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 peak flow statistically expected to occur at a 2-year recurrence interval. In this analysis, the appropriate record of hourly rainfall data (e.g., 35-50 years of data) is run through a continuous simulation hydrologic model, the annual peak flows are identified, rank ordered, and the 2-year peak flow is estimated. Such models include USEPA's Hydrologic Simulation Program—Fortran (HSPF), U.S. Army Corps of Engineers' Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS), and USEPA's Storm Water Management Model (SWMM).

over more than 10 percent of the length of the curve corresponding to the range of flows to control.

(3) **Precipitation Data:** Precipitation data used in the modeling of HM controls shall, at a minimum, be 30 years of hourly rainfall data representative of the area being modeled. Where a longer rainfall record is available, the longer record shall be used.

(4) **Calculating Post-Project Runoff:** Retention and detention basins shall be considered impervious surfaces for purposes of calculating post-project runoff. Pre- and post-project runoff shall be calculated and compared for the entire site, without separating or excluding areas that may be considered self-retaining.

(5) **Existing HM Control Requirements:** The Water Board has adopted HM control requirements for all Permittees (except for the Vallejo Permittees), and these adopted requirements are attached to this Order as listed below. The Permittees shall comply with all requirements in their own Permittee-specific Attachment, unless otherwise specified by this Order. In all cases, the HM Standard shall be achieved.

- Attachment B for Alameda Permittees
- Attachment C for Contra Costa Permittees
- Attachment D for Fairfield-Suisun Permittees
- Attachment E for San Mateo Permittees
- Attachment F for Santa Clara Permittees

iii. Types of HM Controls

Projects shall meet the HM Standard using any of the following HM controls or a combination thereof.

(1) **Onsite HM controls** are flow duration control structures and hydrologic source controls that collectively result in the HM Standard being met at the point(s) where stormwater runoff discharges from the project site.

(2) **Regional HM controls** are flow duration control structures that collect stormwater runoff discharge from multiple projects (each of which shall 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.

(3) **In-stream measures** shall be an option only where the stream, which receives runoff from the project, 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 long-term 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 onsite 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 or to achieve an equivalent degree of flow control mitigation (based on amount of impervious surface mitigated) as part of an in-stream project located in the same watershed. Designing in-stream controls requires a hydrologic and geomorphic evaluation (including a longitudinal profile) of the stream system downstream and upstream of the project. As with all in-stream activities, other regulatory permits must be obtained by the project proponent.[8]

iv. Reporting

For each HM Project approved during the reporting period, the following information shall be reported electronically in tabular form. This information shall be added to the required reporting information specified in Provision C.3.b.v.

(1) Device(s) or method(s) used to meet the HM Standard, such as detention basin(s), biodetention unit(s), regional detention basin, or in-stream control;

(2) Method used by the project proponent to design and size the device or method used to meet the HM Standard; and

(3) Other information as required in the Permittee’s existing HM requirements, as shown in Attachments B–F.

v. Vallejo Permittees shall complete the following tasks in lieu of complying with Provisions C.3.g.i-iv.

(1) Develop a Hydrograph Modification Management Plan (HMP) for meeting the requirements of Provisions C.3.g.i–iv. The Vallejo Permittees’ HMP shall be subject to approval by the Water Board.

(2) Vallejo Permittees shall include the following in their HMP:

(a) A map of the City of Vallejo, delineating areas where the HM Standard applies. The HM Standard shall apply in all areas except where a project:

- discharges stormwater runoff into creeks or storm drains that are concrete-lined or significantly hardened (e.g., with rip-rap, sackrete) downstream to their outfall in San Francisco Bay;
- discharges to an underground storm drain discharging to the Bay; or
- is located in a highly developed watershed.[9]

---

8 In-stream control projects require a Stream Alteration Agreement from the California Department of Fish & Game, a CWA section 404 permit from the U.S. Army Corps of Engineers, and a section 401 certification from the Water Board. Early discussions with these agencies on the acceptability of an in-stream modification are necessary to avoid project delays or redesign.

9 Within the context of Provision C.3.g., “highly developed watersheds” refers to catchments or subcatchments that are 65% impervious or more.

However, plans to restore a creek reach may reintroduce the applicability of HM controls, and would need to be addressed in the HMP;

(b) A thorough technical description of the methods project proponents may use to meet the HM Standard. Vallejo Permittees shall use the same methodologies, or similar methodologies, to those already in use in the Bay Area to meet the HM Standard. Contra Costa sizing charts may be used on projects up to ten acres after any necessary modifications are made to the sizes to control runoff rates and durations from ten percent of the pre-project 2-year peak flow to the pre-project 10-year peak flow, and adjustments are made for local rainfall and soil types;

(c) A description of any land use planning measures the City of Vallejo will take (e.g., stream buffers and stream restoration activities, including restoration-in-advance of floodplains, revegetation, and use of less-impacting facilities at points of discharge) to allow expected changes in stream channel cross sections, stream vegetation, and discharge rates, velocities, and/or durations without adverse impacts on stream beneficial uses;

(d) A description of how the Vallejo Permittees will incorporate these requirements into their local approval processes, and a schedule for doing so; and

(e) Guidance for City of Vallejo project proponents explaining how to meet the HM Standard.

(3) Vallejo Permittees shall complete the HMP according to the schedule below. All required documents shall be submitted acceptable to the Executive Officer, except the HMP, which shall be submitted to the Water Board for approval. Vallejo Permittees shall report on the status of HMP development and implementation in each Annual Report and shall also provide a summary of projects incorporating measures to address Provision C.3.g and the measures used.

- By April 1, 2011, submit a detailed workplan and schedule for completion of the information required in Provision C.3.g.v.(2).
- By December 1, 2011, submit the map required in Provision C.3.g.v.(2)(a).
- By April 1, 2012, submit a draft HMP.
- By December 1, 2012, provide responses to Water Board comments on the draft HMP so that the final HMP is submitted for Water Board approval by July 1, 2013.
- Upon adoption by the Water Board, implement the HMP, which shall include the requirements of this measure. Before approval of the HMP by the Water Board, Vallejo Permittees shall encourage early implementation of measures likely to be included in the HMP.

APPENDIX B

HMP Applicability Map Documentation

APPENDIX B

HMP APPLICABILITY MAP DOCUMENTATION

1. INTRODUCTION

This appendix describes the development of the Vallejo Hydromodification Management Plan (HMP) applicability map required by Provision C.3.g.v.2.a of the San Francisco Bay Region Municipal Regional Stormwater NPDES Permit (MRP) (SFRWQCB, 2009). This provision states that the Vallejo Permittees[1] shall include in their HMP:

> *A map of the City of Vallejo, delineating areas where the HM Standard applies. The HM Standard shall apply in all areas except where a project:*
>
> *• discharges stormwater runoff into creeks or storm drains that are concrete-lined or significantly hardened (e.g., with rip-rap, sackrete) downstream to their outfall in San Francisco Bay;*
>
> *• discharges to an underground storm drain discharging to the Bay; or*
>
> *• is located in a highly developed watershed.*[2]

This technical memorandum describes the methodology used to develop the map and is organized as follows:

- Section 2 describes how the HMP boundary was developed.
- Section 3 describes how exempt areas draining to continuously hardened conveyances (channels and pipes) that extend to the Bay were identified.
- Section 4 describes how exempt areas that are located in highly developed watersheds were identified.
- Section 5 describes the Vallejo HMP applicability map.

The spatial datasets referenced in this memorandum are summarized in Table B-1.

2. HMP BOUNDARY

Provision C.3.g.v.2.a stipulates that the City jurisdiction be used to delineate areas where the HM Standard applies. The City wished to include additional Spheres of Influence (SOIs) of interest in the HMP boundary because these areas could potentially be annexed by the City in the future.

---

[1] Per page 1 of the MRP, Vallejo Permittees are the City of Vallejo (the City) and the Vallejo Sanitation and Flood Control District (VSFCD).
[2] Provision C.3.g. defines "highly developed watersheds" as catchments or subcatchments that are 65% impervious or higher.

The recently annexed Bordoni Ranch was also included in the HMP boundary. Figure B-1 shows the extent of the City boundary (cov_boundary5-05.dwg), the Bordoni Ranch annexed boundary (2011-11-07_Waterstone-Bndy.dwg) as well as the SOIs of interest (a subset of citysoi.shp) which together make up the HMP boundary.

3. AREAS DRAINING TO CONTINUOUSLY HARDENED CONVEYANCES THAT EXTEND TO THE BAY

GIS was used to overlay the stormdrain system network provided by VSFCD (Master-VStorm.dwg and MI_STORM.dwg) with the subcatchment layer (VSFCD_stormshed.shp) for the system. If a drainage system is continuously hardened and extends to the Bay, then the developed areas tributary to that conveyance system were identified as exempt. In some cases subcatchments were further subdivided if only a portion of the subcatchment was exempt. Geosyntec used aerial imagery (Bing Maps) and topography (x-vsfcd-topoall-northern.dwg and x-vsfcd-topoall-southern.dwg) to make these more detailed delineations.

In assessing whether a conveyance system is continuously hardened to the Bay, Geosyntec assumed that if one segment of channel is both non-hardened and non-tidal[3], then the exemption for hardened conveyances does not apply to the area tributary to that channel. VSFCD staff assisted in identifying non-hardened, non-tidal channels by providing an existing map of these channels (natural creeks.dwg) and reviewing Geosyntec's assumptions of channel condition. Geosyntec supplemented the natural creeks.dwg layer by manually adding non-hardened channels found from aerial imagery (Bing Maps) and identifying National Hydrography Dataset (NHD) blue lines (NHDFlowline.shp) subject to runoff from areas within the HMP boundary. Additionally, Geosyntec, VSFCD, and the City conducted a field assessment on November 16th, 2011 to verify the condition of key channels mapped as non-hardened and non-tidal.

4. AREAS LOCATED IN HIGHLY DEVELOPED SUBCATCHMENTS

Geosyntec calculated the percent imperviousness of subcatchments within the HMP boundary by overlaying the latest available Association of Bay Area Governments (ABAG) land use file (Existing_Land_Use_2005_SL.shp) with VSFCD's subcatchment layer (VSFCD_stormshed.shp) and area weighting the imperviousness. The percent impervious values applied to the ABAG land uses were based on those used for San Mateo County's HMP applicability map (STOPPP, 2005). The land use/impervious table is provided in Table B-2. Best professional judgment was used to assign percent impervious values for ABAG land use categories that were not included in the San Mateo mapping effort.

A second step in the analysis was conducted to ensure consistency with the most recent land use map available in the City (Landuse.dwg), and a land use/impervious table (Table B-3) based on

---

[3] Tidal channels were distinguished from non-tidal ones because tidal channels are considered to be a part of the Bay, and thus areas draining directly to them are exempt from the HM Standard.

VSFCD's Storm Drain Master Plan (West Yost, 2002). In this step, subcatchments that were identified as having greater than 65% imperviousness based on ABAG land use were compared to subcatchment imperviousness from the City land use map. If the weighted results, based on the City land use map, indicated that the imperviousness for the given subcatchment was less than 65%, that subcatchment imperviousness was changed to less than 65%[4].

VSFCD's subcatchment layer did not cover the entire area within the HMP boundary. For areas which were not included within a formal subcatchment, Geosyntec confirmed that these areas are not highly developed using recent aerial imagery (Bing Maps).

5. HMP APPLICABILITY MAP

Based on the steps described above, the HMP applicability map was developed as shown on Figure B-2. Areas within the HMP boundary have been designated with one of five colors, according to the following:

- Purple areas drain to continuously hardened conveyances (channels and pipes) that extend to the San Francisco Bay. The HM standard does not apply to projects in these areas.

- Red areas represent subcatchments that are currently highly developed to a level of 65% imperviousness or greater and that do not drain to continuously hardened conveyances extending to the Bay. The HM Standard does not apply to projects in these areas.

- Light Blue areas represent open water. A majority of this area is the Bay, but open water reservoirs are included as well. The HM Standard does not apply to these areas.

- Dark Blue areas represent bayland areas which are considered tidally connected to the Bay, but are not classified as open water. These areas have a ground elevation generally less than the mean high tide elevation[5] and are considered a part of the Bay. The HM Standard does not apply to projects in these areas.

- Green areas represent those areas within the HMP boundary that are not purple, red, light blue, or dark blue. The HM Standard applies to projects in these areas[6].

---

[4] There are two sources of uncertainty in estimating subcatchment imperviousness, land use and the relationship between imperviousness and land use. With respect to the latter, the conversion table used for the ABAG land use (Table B-2) and that for the Master Plan (Table B-3) are generally consistent.

[5] The mean high tide elevation is 5.56-ft NAVD 88 according to NOAA tide gage station 9415218 at Mare Island. Some areas within the HMP Boundary are less than this elevation, but are not considered tidal if they are hydraulically disconnected from the Bay (i.e. areas behind coastal levees and/or drained by a low lying pump station).

[6] Further exemptions to the HM Standard can be granted in these applicable areas if one of the exemption criteria listed in Section 4.2 of the HMP applies to the project.

6. ACKNOWLEDGEMENTS

The project team would like to acknowledge West Yost and Associates for sharing GIS shapefiles, documents, and data used to support the applicability mapping effort.

7. REFERENCES

San Francisco Regional Water Quality Control Board (SFRWQCB). 2009. Municipal Regional Stormwater NPDES Permit. Order R2-2009-0074. NPDES Permit No. CAS612008.

San Mateo Countywide Stormwater Pollution Prevention Program. 2005. Hydromodification Management Plan.

West Yost and Associates. 2002. Vallejo Sanitation and Flood Control District Storm Drain Master Plan. Volume 2. Drainage Models.

TABLES

Table B-1. Spatial Datasets Used to Create the Vallejo HMP Applicability Map

Description	Dataset Name	Source	Feature
City Of Vallejo jurisdictional boundary	cov_boundary5-05.dwg	City of Vallejo	polyline
Bordoni Ranch annexation boundary	2011-11-07_Waterstone-Bndy.dwg	MacKay & Somps	polyline
Spheres of Influence (SOIs) for cities in Solano County	citysoi.shp	Solano Regional GIS Consortium	polygon
VSFCD stormdrain network	Master-VStorm.dwg	VSFCD	polyline
Mare Island stromdrain network	MI_STORM.dwg	VSFCD	polyline
Subcatchment delineations of VSFCD's stormdrain network	VSFCD_stormshed.shp	West Yost and VSFCD	polygon
2009 aerial imagery	Bing Maps - Aerial	Microsoft Corporation and ESRI, Inc.	raster
Contour map of the northern portions of Vallejo	x-vsfcd-topoall-northern.dwg	West Yost and VSFCD	polyline
Contour map of the southern portions of Vallejo	x-vsfcd-topoall-southern.dwg	West Yost and VSFCD	polyline
Non-hardened channels throughout VSFCD stormdrain system	natural creeks.dwg	VSFCD	polyline
NHD flowlines	NHDFlowline.shp	National Hydrography Dataset	polyline
2005 ABAG land use for Solano County	Existing_Land_Use_2005_SL.shp	Association of Bay Area Governments	polygon
Land use map for the City of Vallejo	Landuse.dwg	VSFCD	polyline

Table B-2. ABAG 2005 Land Uses and Percent Impervious Surface

Land Use Code	Land Use Description	% Impervious Surface	Source
5	Unclassified Water	100	B
52	Lakes	100	B
53	Reservoirs	100	B
54	Bays & Estuaries	100	B
121	Retail And Wholesale	96	A
129	Hotels And Motels	96	A
13	Industrial	91	A
131	Heavy Industrial	91	A
132	Light Industrial	91	A
1418	Local Roads And Streets	90	A
114	Mobile Homes And Mobile Home Parks	82	A
1262	Churches, Synagogues, And Mosques	82	A
126	Local Government And Other Public Facilities	75	A
1253	Military - General Use	75	B
1259	Closed Military Facilities	75	B
1265	City Halls & Co., State, Fed. Govt. Facility	75	A
124	Hospitals, Rehab, Health, & State Prison Facility	74	A
1242	Community Hospitals	74	A
1254	Military Hospital	74	A
1231	Elementary & Secondary Schools	67	A
122	Commercial Intensive Outdoor Recreation	66	A
1233	Stadiums	66	A
1411	Highways And Interchanges	66	A
115	High Density: >= 8 Du/ Acre	64	A
113	Medium Density: >= 3 Du/ Acre And <8 Du/ Acre	47	A
119	Commonly Owned Residential, No Du	47	B
172	Cemeteries	28	A
112	Low Density: >= 1 Du/Acre And <3 Du/ Acre	21	B
17	Other Urban And Built-Up Land	20	A
51	Streams & Canals	20	A
171	Extensive Recreation	20	A
173	Urban Parks	20	A
111	Very Low Density: < 1 & >= 0.2 Du Per Acre	10	A
1711	Golf Courses	3	A

Land Use Code	Land Use Description	% Impervious Surface	Source
21	Cropland & Pasture	2	A
22	Orchards, Groves, Vineyards, And Nurseries	2	A
62	Nonforested Wetlands	2	A
212	Pasture	2	A
752	Earth Works Not Part Of Commercial Extraction	2	A
1751	Residential Vacant	2	A
1752	Commercial Or Services Vacant	2	B
1753	Industrial Vacant	2	B
2111	Row Crops	2	B
31	Herbaceous Rangeland	1	A
32	Shrub And Brush Rangeland	1	A
41	Deciduous Forest	1	A
42	Evergreen Forest	1	A
43	Mixed Forest	1	A
61	Forested Wetlands	1	A
311	Herbaceous Rangeland - Protected As Park	1	A
321	Shrubland - Protected As Park	1	A
411	Deciduous Forest - Protected As Park	1	A
421	Evergreen Forest - Protected As Park	1	A
431	Mixed Forest - Protected As Park	1	A

Sources: (A) San Mateo County HMP [STOPPP, 2005]; (B) current study using best professional judgment.

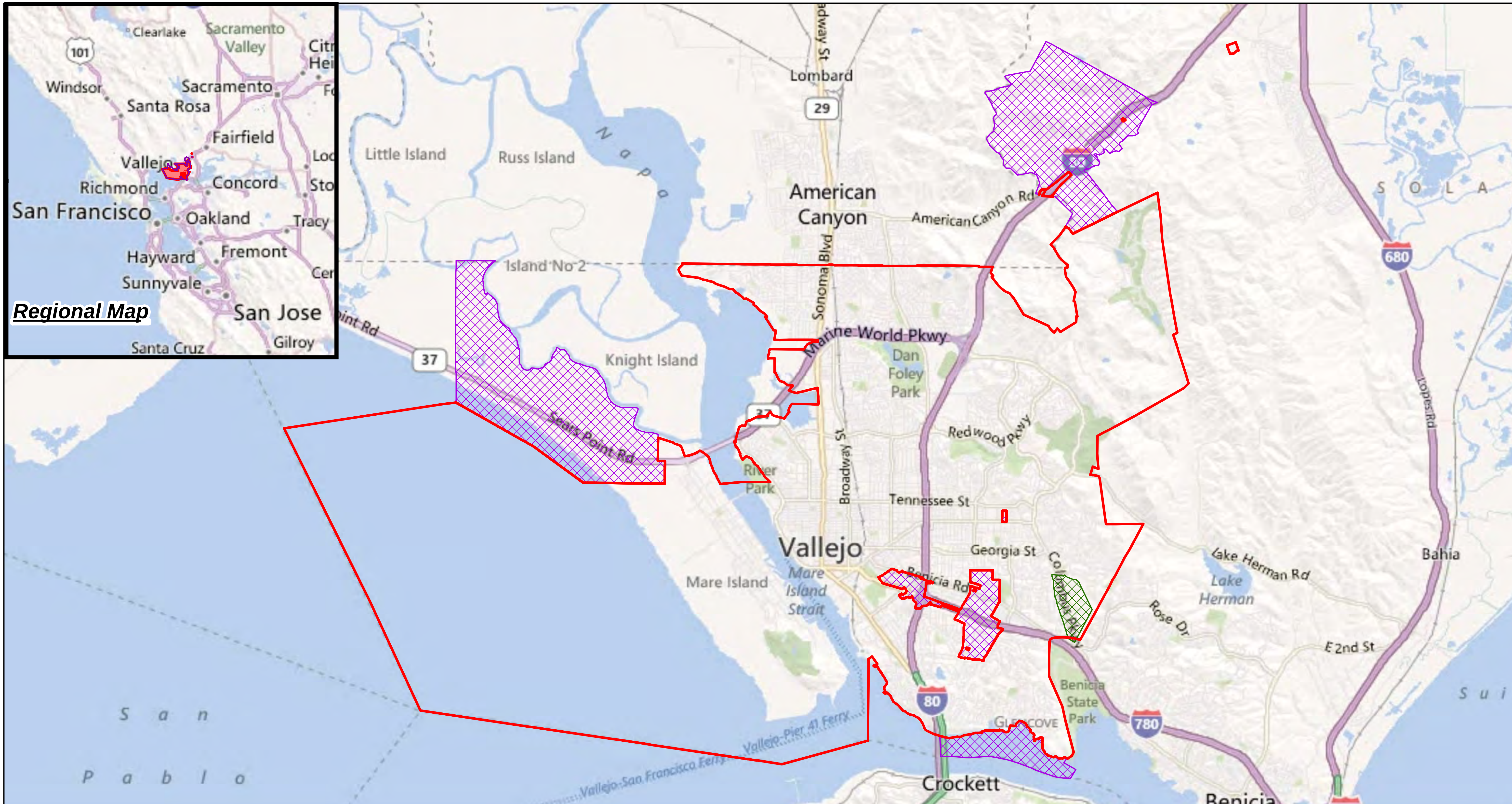
Note: Percent impervious surface values used in the San Mateo County HMP are provided in Attachment B-1.

Table B-3. Percent Imperviousness for Zoning Map Land Uses

Land Use Description	% Impervious Surface	Source
Commercial	90	A
Intensive	90	A
Resdiential High Density	70	A
Residential - Medium Density	60	A
Residential - Low Density	50	A
Intensive/Open	40	A
Open Space	10	A
Golf Course	10	B
Open Water	0	B

Sources: (A) VSFCD Strom Drain Master Plan [West Yost 2002]; (B) current study using best professional judgment.

FIGURES



Legend

City of Vallejo, Boundary

City of Vallejo, Sphere Of Influence of Interest

Bordoni Ranch Annexation Boundary

Basemap: Bing Maps, 2009

0 1.25 2.5 3.75 Miles

N

Vallejo HMP Boundary Map

Vallejo HMP

Geosyntec consultants

Figure **B-1**

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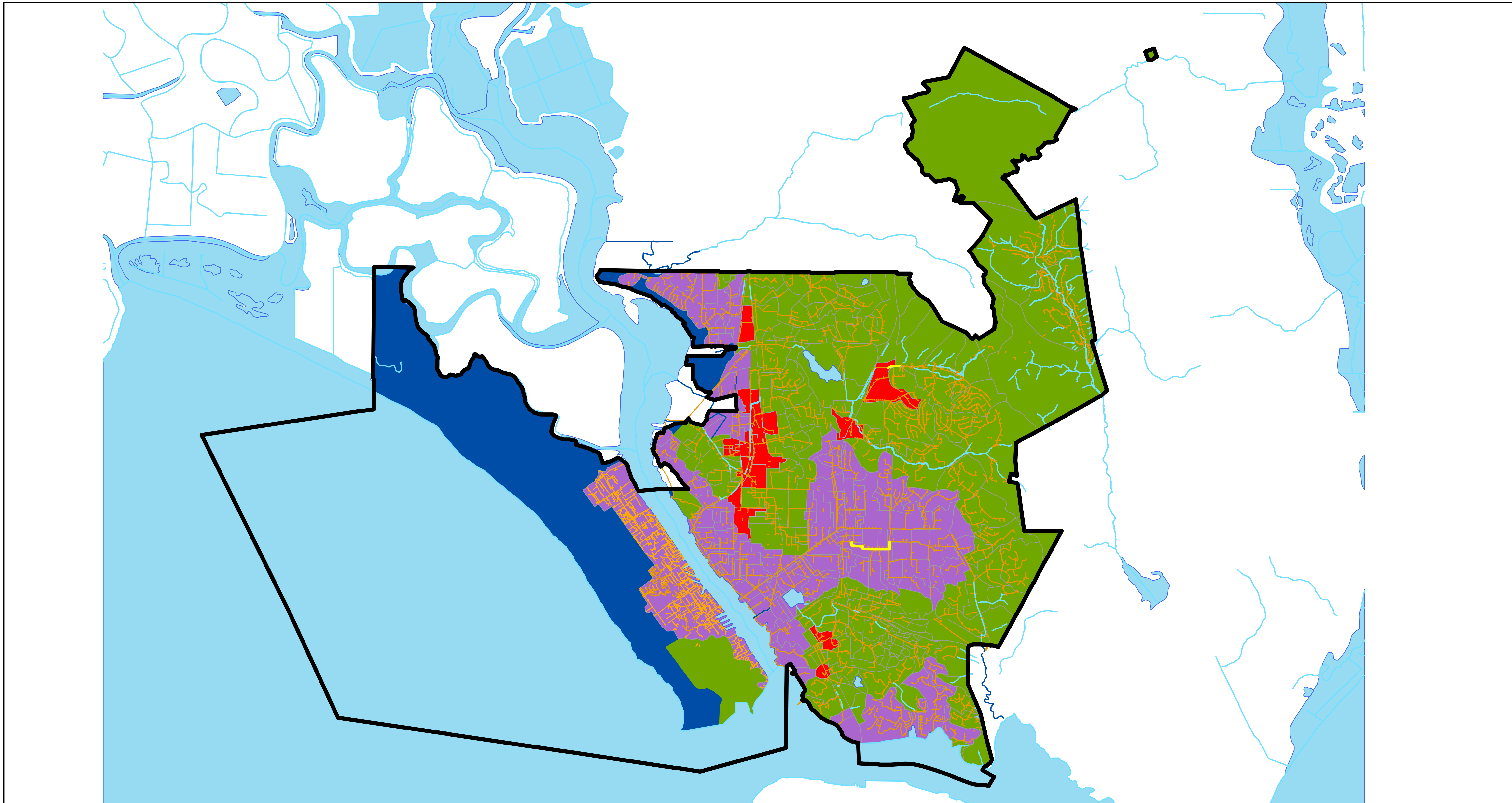

Legend

- HMP Boundary
- Fully Hardened Channels
- Non-Hardened Channels (Non-Tidal)
- Non-Hardened Channels (Tidal)
- Storm Drain System
- Open Water
- Areas Draining to Continuously Hardened Conveyances to the Bay
- HMP Applicable Areas
- Subcatchments with greater than or equal to 65% Impervious
- Baylands

0 1.25 2.5 3.75 Miles

N

HMP Applicability Map

Vallejo HMP

Geosyntec consultants

Figure **B-2**

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Attachment B-1

As was described in the previous section, subwatershed boundaries for bayside watersheds were delineated along major roadways that represented significant changes in land use patterns (i.e., impervious surfaces) and/or the upper end of the channel that are continuously hardened downstream to their outfalls to the low gradient areas near the Bay. The street or highway used to delineate each subwatershed is identified in Table 3-5.

All of the lower subwatershed areas draining into the Bay ranged from 66-81% impervious surface area and were fully developed (98-99%) and therefore, met the infill and highly developed area criterion for exemption. The only exception was Colma Creek watershed, which did not meet the criteria due to lower impervious surfaces from cemeteries and open space areas on San Bruno Mountain. Colma Creek watershed (excluding San Bruno Mountain), however,

Table 3-2.
ABAG 2000 Land uses Occurring in San Mateo County That Are Designated As Developed Land Use Types Using Best Professional Judgment.
Percent impervious surface area for ABAG land uses based on following: (A) Bredehorst (1981); (B) EOA (2002); and (C) current study using best professional judgment.

Land Use Classification Category	Total Area (Acres)	Percent Impervious Surface	Source
Commercial airport runway	819.0	99	C
Commercial airport air cargo facilities	97.0	96	C
Commercial airport airline maintenance	410.2	96	C
Commercial airport passenger terminal	210.2	96	C
Commercial port - other	2.3	96	C
Food Processing	54.2	96	A
Hotels and Motels	228.5	96	A
Retail and Wholesale	2483.9	96	B
Electric Substation	19.2	95	B
Mixed Commercial and Industrial	1550.6	95	B
Rail Passenger Stations	21.9	95	B
Rail Yards	168.3	95	B
Mixed Residential and Commercial Use	145.5	93	B
Heavy Industry	476.5	91	B
Industry	16.6	91	B
Light Industry	1248.3	91	B
Offices	1970.0	91	B
Transitional (Mixed land use)	24.7	91	C
Warehousing	1861.3	91	A
Local Streets and Roads	18135.7	90	C
Marine Transportation Facilities	2.7	90	C
Parking Garages	462.5	90	B
Recreation and Common Facilities Assoc with Multifamily residential	3.1	90	B
Road Transportation Facilities	3419.6	90	C
Transportation, Communication and Utilities	290.9	90	C
Truck or Bus Maintenance Yard	0.5	90	C
>Twenty DUs per Hectare	9019.5	86	B
Churches	426.7	82	B

Land Use Classification Category	**Total Area (Acres)**	**Percent Impervious Surface**	**Source**
Mobile Home Parks	304.7	82	B
General Military Use	35.2	75	B
County Government Center	22.4	75	B
Fire Station	0.3	75	B
Jails and Rehabilitation Centers	7.8	75	B
Other Public Institutions and Facilities	12.9	75	B
Police Station	5.2	75	B
Psychiatric Facility	22.8	75	B
Research Centers	0.7	75	B
Waste Pumping Station	7.0	75	B
Wastewater Treatment Plant	87.7	75	B
Community Hospital	0.8	74	B
Hospital Trauma Center	18.7	74	B
Hospitals, Rehabilitation, Health, and State Prison Facilities	91.6	74	B
Military Hospital	83.2	74	A
Municipal Water Supply Facilities	82.8	70	C
Medical Long-Term Care Facility	0.4	68	A
Education	34.3	67	B
Elementary/Secondary Schools	2445.5	67	B
Airports	386.1	66	B
Commercial Intensive Outdoor Recreation	222.4	66	B
Commercial airport - other	1435.8	66	C
Commercial airport utilities	61.8	66	C
Highways and Interchanges	479.7	66	B
Public Airports	10.4	66	B
Racetracks	189.8	66	B
Stadium (not college or university)	56.4	66	A
Marina	601.5	66	C
Nine and Over DUs per Hectare	13791.9	64	B
Colleges and Universities	1491.5	47	B
Electric - Other	102.3	47	B
Greenhouses and Floriculture	150.7	47	B
Two to Eight DUs per Hectare	7411.7	47	B
Cemeteries	1003.5	28	B
Extensive Recreation	10.4	20	B
Other Urban and Built-Up Land	208.2	20	B
Parks	1163.7	20	B
Streams and Canals	426.3	20	B
One and Under DUs per Hectare	23689.3	10	B
Golf Courses	2620.9	3	B
Camps and campgrounds	625.8	2	B
Sanitary Landfills	45.6	2	B
Strip Mines, Quarries and Gravel Pit	335.0	2	B
Total Area	102535.2		

Table 3-3.
ABAG 2000 Land uses Occurring in San Mateo County That Are Designated As Undeveloped Land Use Types Using Best Professional Judgment.
Percent impervious surface area for ABAG land uses based on following: (A) Bredehorst (1981); (B) EOA (2002); and (C) current study using best professional judgment.

Land Use Classification Category	Total Area (Acres)	Percent Impervious Surface	Source
Bare Exposed Rock	46.0	95	B
Earthworks not associated with commercial operation	27.2	2	
Farmsteads and Other Agriculture	493.9	2	B
Irrigated Cropland	3403.0	2	B
Nonforested Wetlands	1834.6	2	B
Open Space - Urban	44.6	2	B
Orchards	21.0	2	B
Orchards, groves, vineyards etc	450.9	2	C
Other Transitional	430.8	2	B
Pasture	8692.4	2	B
Transitional Areas	39.4	2	B
Urban Vacant Land	101.4	2	B
Vacant commercial or services	1.0	2	A
Vacant residential	1506.8	2	A
Beaches	1459.2	1	B
Chaparral	15260.2	1	B
Deciduous Forest	476.2	1	B
Evergreen Forest	13158.6	1	B
Forested Wetlands	69.8	1	B
Herbaceous Rangeland	14556.0	1	B
Mixed Forest	7984.4	1	B
Mixed Rangeland	2553.6	1	B
Mixed Sparsely Vegetated Land	1.8	1	C
Non-Irrigated Cropland	374.2	1	B
Protected as Parkland	37181.6	1	C
Redwood and Douglas Fir	60976.2	1	B
Reservoirs	311.8	1	B
Sand Other than Beaches	98.0	1	C
Shrub and Brush Rangeland	7410.9	1	B
Water on USGS Base Maps, not on assessors maps	46.9	1	B
Bays and Estuaries	957.2	0	B
Lakes	623.1	0	B
Salt Evaporation Ponds	4852.7	0	B
Water	4109.0	0	B
Total Area	189554.3		

APPENDIX C

Design Guidance for System Specific Flow Duration Control

APPENDIX C

DESIGN GUIDANCE FOR SYSTEM SPECIFIC FLOW DURATION CONTROL

This section describes suggested steps for sizing flow duration control facilities using a site- or region-specific system-based approach. The system-based approach relies on continuous hydrologic simulations of the actual drainage system and control measures tributary to the point of compliance, which allows for customization, instead of using sizing relationships based on generic modeling, as was done for the Contra Costa County IMP sizing calculator. For on-site HM controls, the point of compliance is where stormwater runoff discharges from the project site. For regional HM controls, the point of compliance is where the regional control measure discharges to the existing drainage system.

The steps for performing the system-based approach are to:

1. Characterize site specific hydrologic conditions,
2. Locate structural control measures,
3. Establish hydrologic modeling parameters,
4. Define the flow range of interest,
5. Establish structural control measure configurations,
6. Iteratively size control measure footprints to meet the flow duration control criteria,
7. Iterate control measure location (step 2) and configuration (step 5) to best meet proposed layout, and
8. Document the proposed control measure plan and analysis

1. STEP 1: CHARACTERIZE SYSTEM SPECIFIC HYDROLOGIC CONDITIONS

The first step is to characterize the pre- and post-project hydrologic conditions in order to qualitatively understand the land use changes associated with the project. This characterization also forms the basis for input parameters used in continuous simulations (Step 3). At a minimum, the characterization should identify the following hydrologic factors: drainage catchments, soil types, vegetation cover, pre-development impervious cover, and overland slope. A discussion of each of these hydrologic factors is provided below.

Drainage catchments should be delineated into areas tributary to each point of compliance (also called "drainage management areas") for the project site. Delineations used for the flood control analyses, which take into account existing and proposed storm drain systems, can be used here. If different portions of the project site discharge to different receiving creeks downstream, then a separate flow duration control analysis is needed for each associated outlet and tributary area on-site. If, however, two or more outlets from the project discharge to the identical receiving creeks, then flow duration control analysis can be applied to the combined tributary areas.

Soil type or Hydrologic Soil Group (i.e., Type A, B, C, and D) associated with the pre- and post-project conditions should be summarized by acreage and percentage for the site. While the Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) Database (http://soils.usda.gov/) can be used for this summary, site-specific data based on infiltration testing or boring logs is preferred and takes precedence for characterizing soil type. It is important to evaluate potential changes in soil conditions from pre- to post-project conditions. Changes may occur due to compaction, importation and fill with non-native soils, and grading that will alter the surface soil type and properties.

Vegetation type should be characterized for pervious areas associated with the pre- and post-project conditions. Aerial imagery, geospatial data, and field observations can be used to characterize vegetation type in the pre-project condition. Proposed vegetation will depend on the landscaping plan.

Impervious cover should be summarized by area and by percentage of the site for the pre- and post-project conditions.

The range of **overland slope** for the site should be characterized for the pre- and post-project conditions. The slopes should be based on topographic maps and grading plans. Slope may decrease from the pre- to post-project condition if the site is graded into a flatter pad for development.

2. STEP 2: LOCATE STRUCTURAL CONTROL MEASURE(S)

Structural control measures should be situated for the developed condition based on the specific spatial constraints of the system being analyzed. Impervious areas in the post-project condition should be routed to at least one control measure location and catchment delineations should be refined from step 1 such that each control measure location has at least one sub-catchment tributary to it. Locating control measures may be an iterative process as site layouts change in the planning process. While locating control measures consideration of the type of facility should be taken into account.

3. STEP 3: ESTABLISH HYDROLOGIC MODELING PARAMETERS

Continuous hydrologic simulation is needed to construct a continuous record of pre- and post-project runoff conditions from which flow duration curves are developed. Before these simulations can be run, however, input parameters for the model must be established.

The site information collected in Step 1 should be used to establish appropriate input parameters for the continuous hydrologic simulations of each catchment area. These parameters will differ depending on the modeling program used, but the most essential input assumptions, described in subsequent paragraphs, include: (1) precipitation record, (2) catchment area, (3) soil and vegetation parameters that affect the infiltration properties, and (4) connectivity of impervious cover. No one hydrologic modeling software program is preferred, however, the program used must be capable of simulating continuous hourly runoff over a period of several decades. Publicly available software programs commonly used to perform continuous hydrologic simulations include USEPA's Storm Water Management Model (SWMM), USGS's Hydrological Simulation Program – Fortran (HSPF), and the US Army Corps of Engineers' Hydrologic Modeling System (HMS).

As a practical matter, the longer the **precipitation record** the better, but at a minimum, a record of at least 30 years with an hourly time interval of rainfall readings should be used. Quality assurance of the precipitation record is of utmost importance to ensure that excessive data gaps or errors in the record are rectified. The Martinez gauge record, as constructed for the Contra Costa County HMP modeling effort, has been identified as the nearest appropriate precipitation record for hydromodification analysis in Vallejo, as shown in Figure C-1. Although the Martinez gauge is 7 miles southeast of the HMP area, it has a similar mean annual precipitation (MAP), 20.2 inches, as that for Vallejo, 20 to 26 inches, as shown by the isohyetal map of Vallejo (Solano County Water Agency, 1999) provided in Figure C-2. The Fairfield precipitation gage is also in relative proximity to Vallejo, compared to other gages, but: has a shorter period of record than the Martinez gauge; a lower MAP than Vallejo, 18.7 inches; and is east of a hill range, which distinguishes its precipitation characteristics from Vallejo.

Sub-catchment areas should be delineated in a logical fashion based on anticipated control measure locations, the points of compliance, and the proposed storm drain system. At minimum, there should be a distinct sub-catchment area associated with the outlet of each control measure and point of compliance. Assumed catchment shape and flow path is also a key input parameter which is parameterized differently according to the modeling software program used.

The assumed **soil infiltration** parameters (e.g., hydraulic conductivity) should be provided for each soil type associated with the site and justified in a logical fashion for the natural and proposed conditions. If the proposed condition includes compacted fill, then a reduction in hydraulic conductivity should be assumed (e.g., 75% of natural). In order to represent the infiltration and storage properties associated with **vegetative cover**, assumed depression storage and overland roughness parameters should be provided for natural and proposed conditions. The parameterization of vegetation effects will differ according to the software program used.

The **connectivity of impervious cover** will affect how the proposed condition hydrologic simulations are modeled. Impervious cover can be defined as either connected, meaning it is routed directly to the storm drain system, or disconnected, meaning it is routed through a pervious area prior to entering the storm drain system. Disconnecting an impervious area is a non-structural approach for reducing the footprint and storage requirements of structural control measures.

4. STEP 4: DEFINE THE FLOW RANGE OF INTEREST (Q_{CP} AND Q_{10})

In order to establish the flow range of interest the 2-year (Q_2) and 10-year (Q_{10}) return period discharges for the pre-project condition must be calculated at the points of compliance. This should be done by constructing a partial-duration series from the pre-project condition simulation output as follows:

- The entire runoff time series generated by the pre-project hydrologic simulation is divided into a set of discrete events based on independence criteria.
- Unless other independence criteria are shown to be more appropriate for the project site, the independence criteria described in the Contra Costa County Hydromodification Management Plan shall be used to separate discrete events as follows:
    - Flow events should be considered separate when the flow rate drops below a threshold value of 0.05 cfs/acre for a period of at least 24 hours.
- The peak flows from each discrete event are ranked and the return intervals are computed using plotting position methods to establish the Q_2 and Q_{10}. The low flow discharge is simply 10 percent of the computed Q_2 ($0.1Q_2$), unless a stream specific incipient motion analysis is conducted. See Section 4.1 below to evaluate an alternative fraction of Q_2 using such an approach.

4.1 Selecting a Low Flow Discharge Rate (Qcp) Other than $0.1Q_2$

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 also varies depending on the density of vegetation.

Qc is an in-stream, low-flow criteria that cannot be exceeded when all sub-areas (including all individual projects or portions of projects) are contributing flow to the stream, if the stream is to be protected from response to hydromodification. Qcp is the portion of Qc from each project and undeveloped areas within the watershed. It is important to note that Qc and Qcp represent the local conditions (i.e., the resilience of the receiving stream). Selecting a value for Qcp that is too high could concentrate cumulative stormwater discharges just above the critical flow for bed mobility and exacerbate erosion problems. In order to calculate Qc for a creek and Qcp for the areas tributary to it, both a hydrologic and geomorphic evaluation of the creek system downstream of the project is needed.

4.1.1 Hydrologic Evaluation

The hydrologic evaluation requires calculating the pre-project 2-year peak flow (Q_2) at the channel sections of interest. In computing Q_2, the original condition of the watershed tributary to the stream, before development, shall be considered. This does not imply that the developer is being required to provide flow controls to match pre-development conditions; rather, 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 Q_2 can be computed using a standard engineering method for calculating the peak flow for a 2-year return period storm event (e.g., per Solano County Water Agency Hydrology Manual (1999) or the Rantz Method (1971)). It is preferred that Q_2 be estimated based on a flow gage record in the receiving stream or a continuous hydrologic model, if available. Partial duration series analysis, as described in Section 4 above, should be utilized to evaluate Q_2 from continuous flow data.

4.1.2 Geomorphic Evaluation

The geomorphic evaluation requires surveying the cross-section and longitudinal profile geometry of the active channel, estimating the hydraulic roughness of the creek, and evaluating the critical shear stress (pounds per square foot) of the most sensitive bed and bank material. Using normal flow hydraulics or a one-dimensional hydraulic model (i.e., HEC-RAS) for the central portion, or active bed, of the channel, Qc can be evaluated as the discharge needed to generate the critical shear stress. To account for the effects of vegetation density and channel irregularities, a method for partitioning the applied shear stress into form and bed/bank roughness components is provided in the Fairfield-Suisun HMP (2009), Appendix C, Section 1.5.4.

4.1.3 Normalizing Qc

For management purposes and ease of implementation, the Qc is normalized by dividing it by the Q_2 so that Qc can be expressed as a fraction of Q_2. This allows developers and their engineers to determine the low-flow discharge from a project area, Qcp, where the effects of hydromodification for flows greater than this become important and must be managed. An example of a selection of Qcp is provided in the Fairfield-Suisun HMP Appendix D, section 2.1.3.

5. STEP 5: ESTABLISH A STRUCTURAL CONTROL MEASURE CONFIGURATION

For each structural control measure, a hydraulic outlet configuration, infiltration rate, and geometric configuration must be assumed so that each control measure can be modeled as a storage unit with a specific stage-storage, stage-discharge, and stage-infiltration relationship. A simple generic model setup is represented in Figure C-3. The approach is that if the basic configuration is held constant, only the footprint needs to be iteratively adjusted (Step 6) to achieve flow duration control. The **hydraulic outlet configuration** dictates the stage-discharge relationship entered into the proposed scenario models for the control measure and can be iteratively designed to size the most space efficient control measure. One simple outlet configuration is to have a low flow orifice at the bottom of the control measure and an overflow weir at the top, as shown in Figure C-4. While the orifice would be sized to discharge the Qcp at the pressure head associated with the overflow weir crest, the weir itself would be designed to convey the peak discharge, per the Solano County Water Agency Hydrology Manual, with sufficient freeboard.

Discharge from an orifice can be calculated using the equation $Q = 3.78\ D^2\ H^{1/2}$,where: Q = discharge (cfs); D = diameter (ft); and H = head above the orifice center (ft). Discharge from a rectangular weir can be calculated using the equation $Q = 3.33\ L\ H^{1.5}$ if the weir is suppressed and $Q = 3.33\,(L - 0.2H)\ H^{1.5}$ if the weir is contracted, where: Q = discharge (cfs); L = crest length (ft); and H = head above weir crest (ft). Other weir equations are provided in the Contra Costa HMP (2005), Attachment 2 Appendix B.

If infiltration is great enough, a low flow orifice may not be necessary. Additional intermediate orifices or more complicated compound weirs can be part of the hydraulic control as well. For the example model shown in Figure C-3, the stage-discharge relationship has been split into two components, one for low flow control and one for overflow so that the runoff volume routed through each component can be quantified.

The **infiltration rate** can be assumed to be constant or increase as the stage and resulting pressure head increases. Ideally, the assumed infiltration rate should relate to site-specific infiltration testing data. Infiltrating runoff through the bottom of a control measure may not be feasible if the subsoil has low permeability, the groundwater table is too high, a contaminated groundwater plume is nearby, a drinking water well is nearby, or if the site is in a designated liquefaction or landslide zone.

The **geometric configuration** dictates the stage-storage relationship entered into the proposed scenario models. It also affects the stage-infiltration curve, since a shallower, wider control measure will infiltrate runoff at a greater rate than a deeper control measure with a smaller footprint. The simplest control measure geometry to model is one with a rectangular footprint and vertical side walls. If media such as sand or gravel will be placed in the control measure, then the stage-storage curve should account for only the storage capacity within the media and not include the volume of the grains.

6. STEP 6: ITERATIVELY SIZE THE CONTROL MEASURE FOOTPRINT

Once the control measure configurations are established, the control measure footprint area can be iteratively adjusted such that the simulated discharge record at the point of compliance meets the flow duration control goodness of fit criteria with a minimum footprint. The resulting control measure footprint[1] and capture volume[2] should be summarized in a table.

To demonstrate that the goodness of fit criteria is met, a graphical comparison should be made of the baseline (pre-project) flow duration curve to that of the proposed condition (see Figure C-5). In order to plot a flow duration curve, a table of flow rates and corresponding cumulative

[1] Control measure footprint area is defined as the area, in square feet, of the control measure at the overflow weir crest.

[2] Control measure capture volume is the storage capacity, in cubic feet, of the control measure below the overflow weir crest.

durations (hours), at which the specified flow rate is equaled or exceeded in the simulation record, is required. Comparing these flow duration tables (see Table C-1) can be helpful in confirming that the goodness of fit criteria is met, per MRP Provision C.3.g.ii.(2) (see Appendix A) (SFRWQCB, 2009):

> *The post-project flow duration curve shall not deviate above the pre-project flow duration curve by more than 10 percent over more than 10 percent of the length of the curve corresponding to the range of flows to control.*

There are a number of ways of establishing the flow bin values used in the flow duration table[3]. The method used should be documented and should provide a relatively smooth flow duration curve, without too many steps, indicating that the distribution of flows is well represented.

7. STEP 7: ITERATE CONTROL MEASURE LOCATION, TYPE, CONFIGURATION, AND SIZE TO BEST MEET PROPOSED LAYOUT

Once the control measures are sized, the modeled control measure locations, configurations, and sizes should be evaluated as to whether they best meet the physical constraints of the system. If it is determined that relocating control measures will more effectively meet the proposed layout than the previous iteration, then the designer should return to step 2. If it is desired for the control measures to have a smaller size, then adjustments to the control measure configurations should be made and the designer should return to Step 5. Suggested procedures for iteratively designing the hydraulic outlet configuration for a single control measure are provided in the San Mateo HMP (2005) on page 4-6, the Santa Clara HMP (2005) in Appendix F, and in the Fairfield-Suisun HMP (2009) in Appendix E Exhibit B.

8. STEP 8: DOCUMENT THE PROPOSED CONTROL MEASURE PLAN AND ANALYSIS

The final control measure plan should be documented with: (1) a map or maps showing control measure locations, catchments, soil boundaries, and impervious surfaces for the project; (2) a summary of modeling inputs (e.g., soil type, % imperviousness, and catchment area) and outputs (e.g., capture volume and footprint area); (3) a graph and table of the final flow duration curves at the points of compliance; (4) a demonstration that the proposed control measure locations can accommodate the calculated sizing; (5) a summary of the hydraulic outlet control dimensions for each control measure; and (6) the final pre- and post-project modeling files used to design the flow duration control facilities.

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[3] One method is to create a flow bin for every output flow generated from the simulation. Another method is to set up generic channel geometry and increment the flow bins according to increments of flow stage using the normal depth equation. Using the same flow bins for both land use conditions allows for a clear comparison of the flow durations

9. REFERENCES

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San Mateo Countywide Stormwater Pollution Prevention Program. 2005. Hydromodification Management Plan. May 12, 2005.

Santa Clara Valley Urban Runoff Pollution Prevention Program. 2005. Hydromodification Management Plan. April 21, 2005.

Solano County Water Agency. 1999. Hydrology Manual. June 1999.

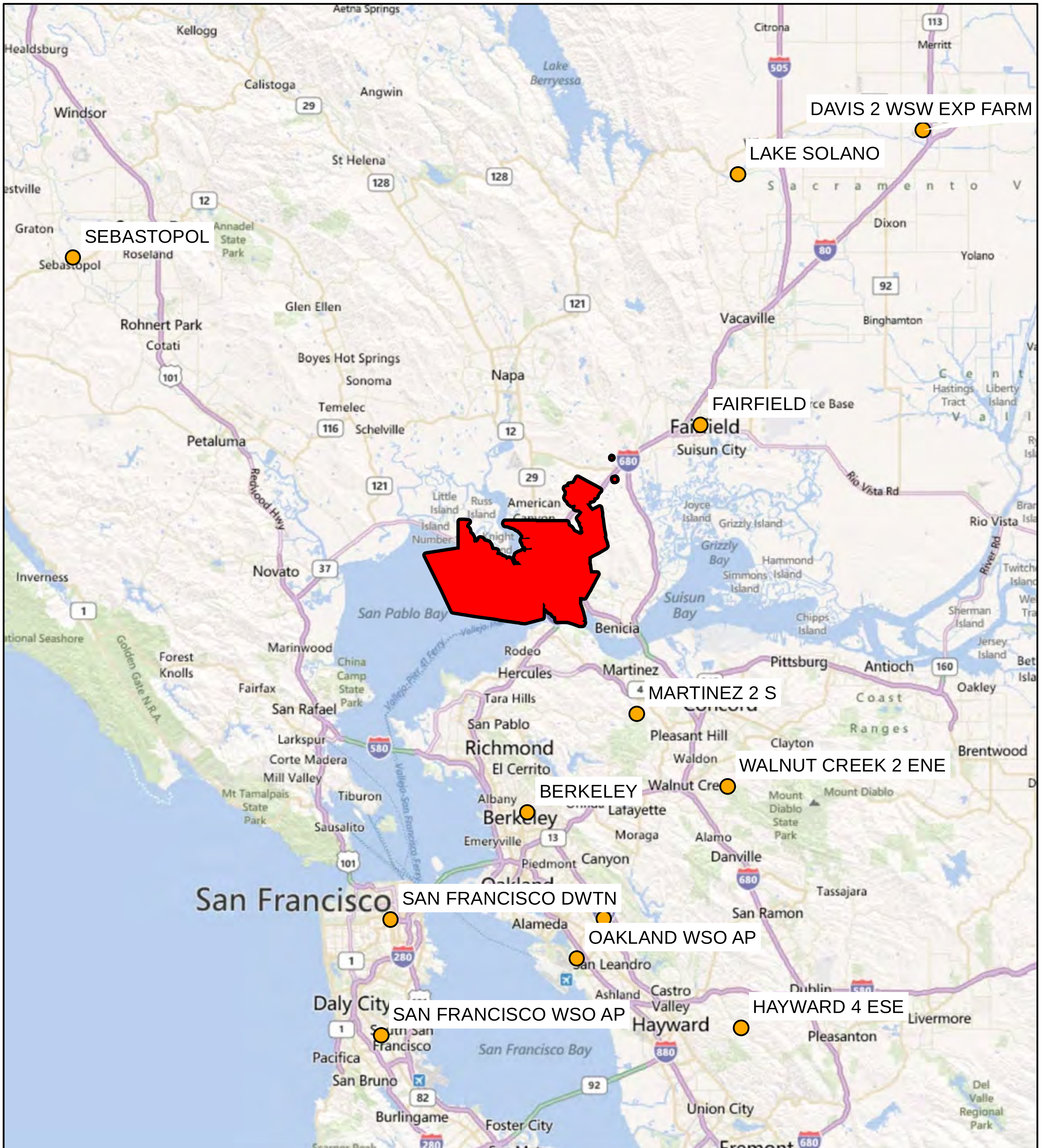
TABLES

Table C-1. Example Flow Duration Table

Flow (cfs)	Cumulative Duration at which the specified flow rate is equaled or exceeded (hrs)	
	Pre-Development	Post-Project with HM Control
0.01	1242	24264
0.02	839	16654
0.03	669	425
0.04	543	372
0.05	458	323
0.06	390	281
0.07	338	246
0.08	300	216
0.09	266	187
0.10	228	155
0.11	204	134
0.12	181	125
0.13	159	114
0.14	143	104
0.15	129	92
0.16	119	81
0.17	112	79
0.18	101	75
0.19	90	70
0.20	83	65
0.21	72	57
0.22	67	56
0.23	59	53
0.24	57	46
0.25	51	45
0.26	48	42
0.27	43	36
0.28	39	32
0.29	35	30
0.30	29	23
0.31	26	19
0.32	24	18
0.33	24	15
0.34	21	13

Flow (cfs)	Cumulative Duration at which the specified flow rate is equaled or exceeded (hrs)	
	Pre-Development	Post-Project with HM Control
0.35	18	12
0.36	15	10
0.37	12	8
0.38	10	8
0.39	9	7
0.40	8	6
0.41	6	6
0.42	6	6
0.43	5	4
0.44	4	4
0.45	3	3
0.46	2	3
0.47	1	2
0.48	1	2
0.49	1	2
0.50	1	2
0.51	1	2
0.52	1	2
0.53	1	2
0.54	1	2
0.55	1	2
0.56	1	2
0.57	1	2
0.58	1	2
0.59	1	2
0.60	1	2
0.61	1	1
0.62	1	1
0.63	1	1
0.64	1	1
0.65	1	1
0.66	0	1
0.67	0	1
0.68	0	1
0.69	0	1
0.70	0	1

FIGURES



Legend

- Hourly Precipitation Gages
- Project Location

Note: Basemap from Bing maps

Precipitation Gage Locations

Vallejo HMP

Geosyntec consultants

WW1538	April 2013	Figure **C-1**

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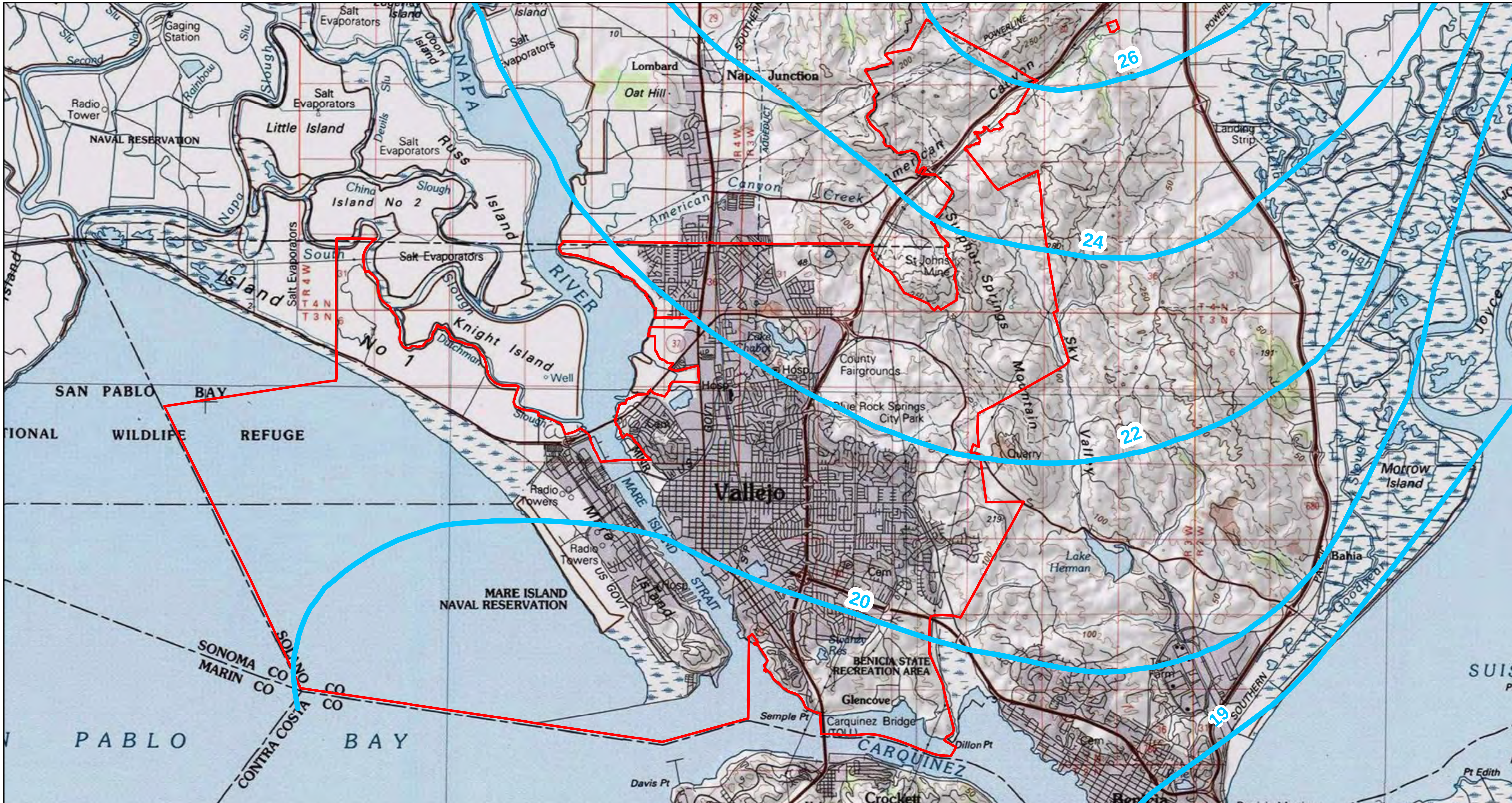

Legend

- Isohyetal Lines
- HMP Boundary

Note: Isohyetal lines from 1999 Solano County Design Rainfall Study
by West Yost & Associates

0 | 1.25 | 2.5 | 3.75 Miles

N

Isohyetal Map

Vallejo HMP

Geosyntec consultants

WW1538 | April 2013

Figure **C-2**

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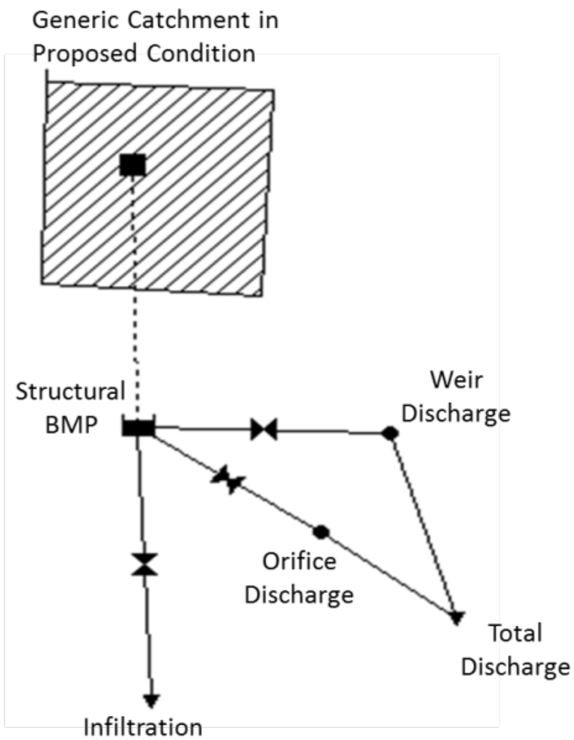

Figure C-3. Example Modeling Configuration for a Post-Project Hydrologic Simulation

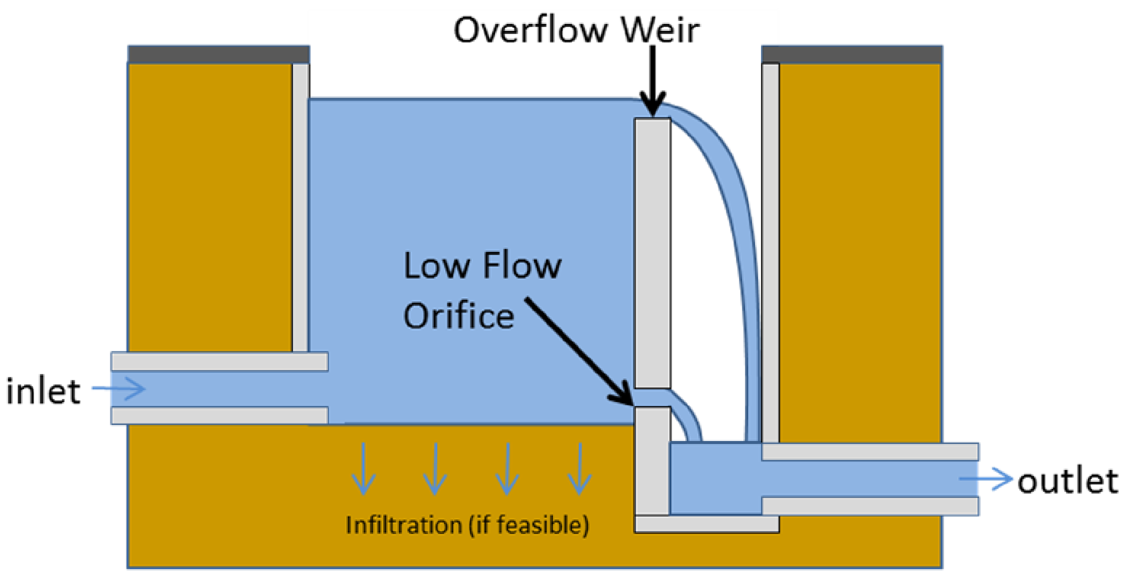

Figure C-4. Schematic of a Simple Hydraulic Outlet Configuration

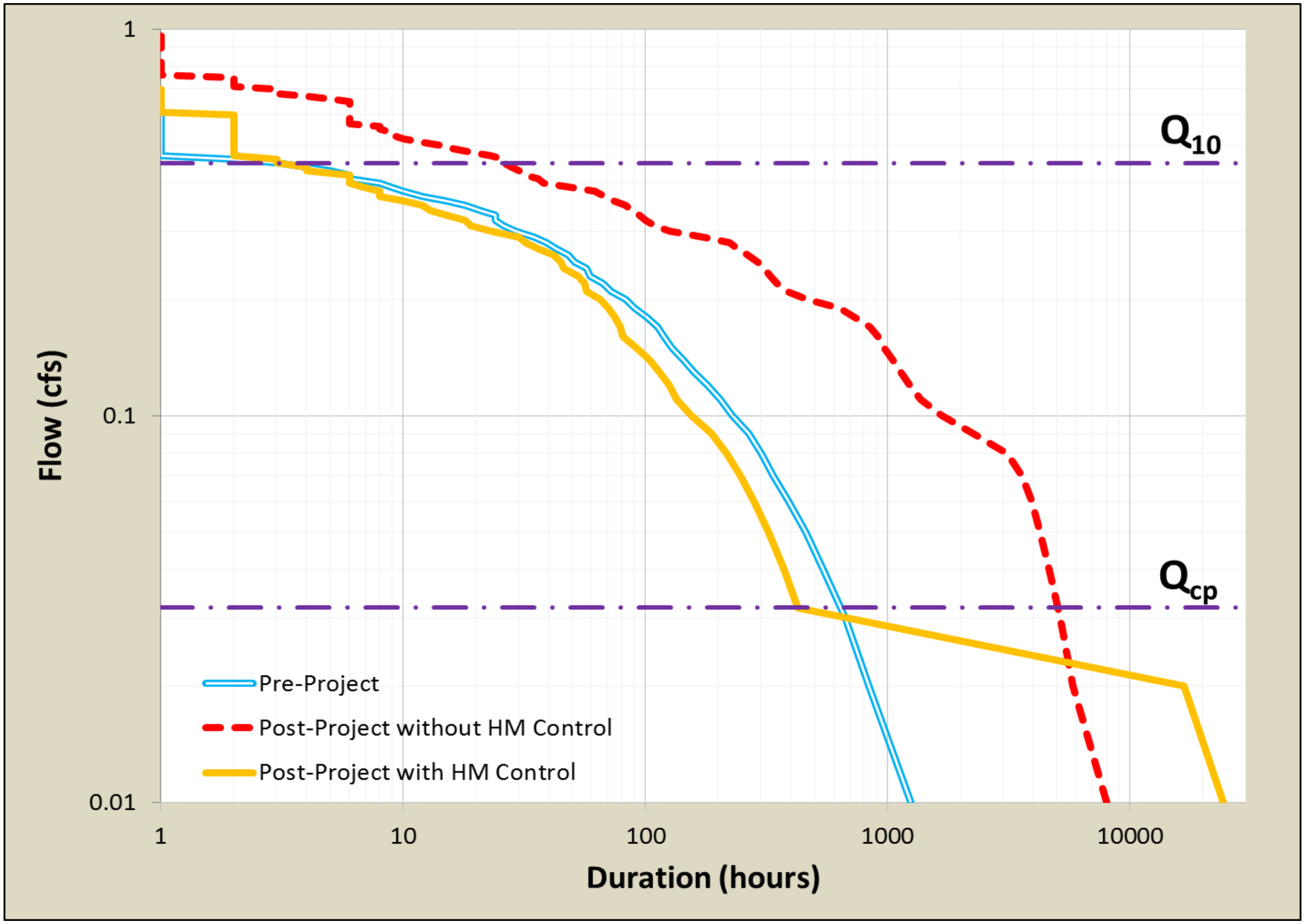

Figure C-5. Flow Duration Curve Comparison

APPENDIX D

Design Guidance for Erosion Potential Analysis

APPENDIX D

DESIGN GUIDANCE FOR EROSION POTENTIAL ANALYSIS

One method of quantifying hydromodification impacts to stream channels which takes into account changes in: (1) hydrology, (2) channel geometry, and (3) bed and bank material is to compare long-term changes in sediment transport capacity, or in-stream work, for the pre- and post-project conditions. The ratio of post/pre-project work is termed Erosion Potential (Ep). To calculate Ep, the three factors mentioned above should be characterized for the pre- and post-project scenarios. While evaluating changes in discharge is done primarily as a desktop analysis, a geomorphic field assessment is needed to characterize bed/bank material and channel geometry, as well as to ground truth assumptions for the desktop analyses. Suggested steps for performing an Ep analysis are provided in Figure D-1. The following describes each analysis step shown in Figure D-1, including the inputs and outputs of each step.

1. STEP 1: CONTINUOUS HYDROLOGIC ANALYSIS

Hydrologic models are applied to simulate the hydrologic response of catchments under pre- and post-developed conditions for a continuous period of record. Steps 1 through 5 in Appendix C can be used for guidance in setting up such continuous simulations. Modeling software appropriate for this type of simulation includes USEPA's Storm Water Management Model (SWMM), USGS's Hydrological Simulation Program – Fortran (HSPF), and the US Army Corps of Engineers' Hydrologic Modeling System (HMS). Input parameters for these continuous simulations are hourly precipitation data for a long-term (>30 years) record, sub-catchment delineation, impervious cover, soil type, vegetative cover, terrain steepness, lag time or flow path length, and monthly evapotranspiration rate. The primary output is a discharge record associated with the stream location of concern.

Traditionally, a hydrograph (Figure D-2) is the primary means for graphically comparing discharge records; however, a hydrograph is not ideal because long-term flow records span several decades. Instead, a more effective means for comparing long-term continuous discharge records is to create a flow histogram, which differentiates the simulated flowrates into distinct "flow bins" so that the duration of flow for each bin can be tabulated. One method for establishing the distribution of flow bins is to increment the flow bins according to increments of flow stage using a hydraulic analysis, such as the normal depth equation. In this way, the hydraulic analysis step (Step 2) can be considered an input to the hydrologic analysis step. While there is no established rule of thumb for how many flow bins are necessary, it is suggested that no less than 20 be used for an Ep analysis.

An example of a flow histogram is provided on Figure D-3. Flow duration curves are another commonly used method for graphically interpreting long-term flow records. A flow duration curve is simply a plot of flowrate (y-axis) versus the cumulative duration, or percentage of time, that a flowrate is exceeded in the simulation record (x-axis). Figure D-4 provides an example flow duration curve.

2. STEP 2: HYDRAULIC ANALYSIS

Hydraulic parameters, such as stage, effective shear stress[1], and flow velocity, are computed for each designated flow bin using channel geometry and roughness data. Hydraulic calculations can be as simple as using the normal flow equation[2] and obtaining results for the central channel or as complicated as using hydraulic models which account for backwater effects, such as HEC-RAS. Additional guidance on stream channel hydraulics calculations is provided in the Fairfield-Suisun HMP (2009), Appendix C, Section 1.5.2.

Channel geometry inputs should be characterized by surveying cross-sections and longitudinal profiles of the active channel at strategic locations. Methods of collecting topographic survey data can range from simply using an auto level, cloth tape, and survey rod to conducting a detailed ground-based LiDAR survey. There are several sources that provide lists of roughness coefficients for use in the hydraulic analysis (Chow, 1959).

3. STEP 3: WORK ANALYSIS

Hydraulic results for each flow bin along with the critical bed/bank material strength parameters are input into a work or sediment transport function in order to produce a work rating curve. An example of such a rating curve is provided on Figure D-3. The work equations used can be simplistic indices[3], material specific sediment transport equations, or more complex functions based on site-calibrated sediment transport rating curves. More discussion of a simplified work index is provided in the Fairfield-Suisun HMP (2009), Appendix C, Section 1.5.1. In addition to a work rating curve, the critical flow rate (Qc) is also evaluated in this step. Qc is the flowrate that results in an effective shear stress equal to the estimated critical shear stress. Qc is often expressed as a fraction of the pre-urban 2-year peak flow.

Bed and bank material should be characterized during a geomorphic field assessment, at the same time that channel geometry and roughness data is obtained. For each stream location analyzed, a measure of critical shear stress should be obtained for the weakest bed or bank material prevalent in the channel. For non-cohesive material, a Wolman pebble count or sieve

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[1] Using the formula for unit tractive force (Chow 1959), effective shear stress is expressed as: $\tau = \gamma R S$, Where: τ = Effective Shear Stress [lb/ft^2]; γ = Unit Weight of Water [lb/ft^3]; R = Hydraulic Radius [ft]; S = Energy Gradient Assumed Equal to Longitudinal Slope [ft/ft].

[2] Manning's normal flow equation is expressed as: $Q = \frac{1.49AR^{0.67}S^{0.5}}{n}$ or $V = \frac{1.49R^{0.67}S^{0.5}}{n}$

Where: Q = Peak Flowrate [cfs]; V = Average Flow Velocity [ft/s]; A = Cross-Section Flow Area [ft^2]; R = Hydraulic Radius [ft] = A/P; P = Wetted Perimeter [ft]; S = Energy Gradient Assumed Equal to Longitudinal Slope [ft/ft]; n = Manning Roughness [unitless]

[3] An example of a simplified effective work equation (Palhegyi 2004) is expressed as: $W = (\tau - \tau_c)^{1.5} V$, Where: W = Work [dimensionless]; τ = Effective Shear Stress [lb/ft^2]; τ_c = Critical Shear Stress [lb/ft^2]; V = Flow Velocity [ft/s]

analysis is used to obtain a grain size distribution, which can be converted to a critical shear stress using an empirical relationship[4] or reference tables in the literature. For cohesive material, an in-situ jet test or reference tables are used. For banks reinforced with vegetation, reference tables are generally used. Appropriate references for critical shear stress values are provided in ASCE No.77 (1992) and Fischenich (2001). To account for the effects of vegetation density and channel irregularities, a method for partitioning the applied shear stress into form and bed/bank roughness components is provided in the Fairfield-Suisun HMP (2009), Appendix C, Section 1.5.4.

4. STEP 4: CUMULATIVE WORK ANALYSIS

Cumulative work is a measure of the long-term total work or sediment transport capacity performed at a creek location. It incorporates the distribution of both discharge magnitude and duration for the full range of flowrates simulated. To calculate cumulative work, first the work and duration associated with each flow bin is multiplied. Then the cumulative work for all flow bins is summed to obtain total work. This analysis can be expressed as:

$$W_t = \sum_{i=1}^{n} W_i \, \Delta t_i$$

Where:

W_t = Total Work [dimensionless]

W_i = Work per flow bin [dimensionless]

Δt = Duration per flow bin [hours]

n = number of flow bins

The distribution of cumulative work, also referred to as a work curve, is helpful in understanding which flowrates are doing the most work in the channel of interest. An example work curve is provided in Figure D-3.

5. STEP 5: EROSION POTENTIAL ANALYSIS

Ep is calculated by simply dividing the total work of the post-project condition by that of the pre-project condition. Ep is expressed as:

$$E_p = W_{t,post} / W_{t,pre}$$

Where:

[4] One such empirical equation for estimating critical shear stress is: $\tau_c = \tau_c^* (\gamma_s - \gamma_w) D_{50}$, where: τ_c is critical shear stress; τ_c^* is the dimensionless critical shear stress (generally ranging from 0.03 to 0.06, 0.047 for gravel); γ_s is the unit weight of sediment; γ_w is the unit weight of water; D_{50} is the median grain size.

E_p = Erosion Potential [unitless]

$W_{t,post}$ = Total Work associated with the post-project condition [unitless]

$W_{t,pre}$ = Total Work associated with the pre-project condition [unitless]

6. STEP 6: IMPLEMENTATION OF HM CONTROLS TO MEET THE HM STANDARD

As stated in the HM Performance Standard, an Ep of up to 1.0 shall be maintained for creek segments downstream of the project discharge point. Without HM controls, the calculated Ep can be well above 1.0, particularly in creek reaches just downstream of development. Generally, hydromodification impacts and Ep are expected to decrease as more undeveloped area contributes to the creek in the downstream direction, thus diluting the impact. Designing on-site, regional, and/or in-stream HM control measures to meet the Ep standard requires an iterative process. The following describes which steps in the Ep modeling framework (Figure D-1) need to be iterated for specific types of HM controls.

Out-of-stream BMPs, which include on-site and regional HM controls, effectively reduce the post-project work (W_t) and Ep by providing flow control mitigation. In other words, out-of-stream BMPs are incorporated in the Ep modeling framework at Step 1, the hydrologic analysis. Non-structural HM control measures which affect the post-project hydrology analysis include minimization of impervious areas / preservation of open spaces and prioritize soils for development and infiltration. Structural HM control measures associated with Step 1 include volume / flow management and detention / retention basins.

In-stream HM Controls do not affect the duration and magnitude of runoff entering the creek system. Instead they modify the receiving stream channel slope (i.e. drop structures, grade control structures, increased channel sinuosity), cross-section geometry (i.e., channel widening), and material strength (i.e., bed and bank reinforcement) so that the creek can convey a new urban flow regime while reducing the potential for erosion and damage to habitat. With regard to where in-stream HM controls are incorporated in the Ep modeling framework, modifications to channel geometry (in plan, cross-section, and profile) affect Step 2, hydraulic analysis, while modifications to the bed and bank material affect Step 3, work analysis.

7. STEP 7: DOCUMENT THE PROPOSED HM CONTROLS AND ANALYSIS

The final stormwater management plan submittal should include: (1) a watershed-scale longitudinal profile (see Figure D-5 for example) indicating the extent of proposed in-stream HM controls, extent of exempt drainages, major confluences, Ep calculation points, and the point where project runoff enters the susceptible stream system; (2) a plan view map or maps indicating the flow path assumed for the watershed-scale longitudinal profile, HM control locations, the project location, Ep calculation points, delineated catchments, soil boundaries, and pre- and post-project impervious surfaces or land uses; (3) a summary of hydrologic, channel geometry, and bed/bank material modeling inputs and assumptions; (4) a flow duration curve, flow histogram, work rating curve, and work curve for each Ep calculation point comparing the pre- and post-project results; (5) a table for each Ep calculation including discharge, flow stage, mid channel velocity, effective shear stress, work, flow duration, and cumulative work for each flow bin in the pre- and post-project conditions (see Table D-1 for example); (6) a summary of total work and Ep results; (7) a demonstration that the proposed HM control locations can accommodate the proposed design; (8) a summary of the configuration of each HM control; and (9) the final pre- and post-project modeling files used to design the flow duration control facilities.

8. PARTICULARS OF IN-STREAM HM CONTROLS

8.1 Design Goals Beyond the HM Standard

In addition to meeting the HM Ep Standard, the design objective of in-stream HM controls is to modify a receiving channel such that it supports the beneficial uses and physical and ecological functions of the channel to the same extent or greater than it did prior to the proposed development. The stream modifications should maintain geomorphic dynamic equilibrium, sustainably support the flora and fauna that existed prior to the project, maintain the same degree of native wood and leaf debris input into the creek system, and maintain the hydrologic connectivity between streams and floodplains.

A key step in any in-stream project will be to define the design objectives in a clear manner. In particular, the project proponent and permittees will need to agree on whether a goal is to maintain the creek at pre-project conditions, as is the intention of the HM Standard, or to restore it to a previous, higher level function (San Diego County, 2009). Additionally, it should be determined whether in-stream HM controls should be designed with a level of conservatism to account for anticipated future buildout in the watershed.

8.2 Suggested Extent of In-stream HM Control

The upstream limit of in-stream HM controls is suggested to extend upstream of where project runoff discharges into the receiving creek, to an existing or proposed grade control. The suggested downstream limit is where: (1) Ep is consistently near 1.0 or less without in-stream controls; or (2) the stream connects to an exempt system. For the latter case at least one additional Ep calculation should be performed downstream of an exempt system if it drains to a creek segment that is susceptible to hydromodification impacts.

8.3 Permitting Requirements for In-stream Grading

It is likely that in-channel mitigation projects will have to be negotiated with permitting agencies on a case-by-case basis due to different site conditions. The HMP does not replace permit requirements for in-stream projects. In additional to meeting the HMP requirements, project proponents proposing an in-stream HM control will likely require the following permits (San Diego County, 2009):

- A CEQA/NEPA review and document
- California Department of Fish and Game – 1602 Streambed Alteration Agreement
- US Fish and Wildlife Service – Authorization Under the Endangered Species Act
- US Army Corps of Engineers – Nationwide 404 Permit
- Regional Water Quality Control Board – 401 Water Quality Certification
- Local Grading Permit

9. REFERENCES

American Society of Civil Engineers and Water Environment Federation. 1992. Design and Construction of Urban Stormwater Management Systems. ASCE Manual No. 77, WEF Manual No. 20, Alexandria, VA.

Chow, V.T. 1959. Open-Channel Hydraulics. McGraw-Hill Book Company.

County of San Diego. 2009. Final Hydromodification Management Plan. December 29, 2009.

Fairfield-Suisun Urban Runoff Management Program. 2009. Hydromodification Management Plan for the Fairfield-Suisun Urban Runoff Management Program. February 4, 2009.

Fischenich, C. 2001. "Stability Thresholds for Stream Restoration Materials." *EMRRP Technical Notes Collection* (ERDC TN-EMRRP-SR-29), U.S. Army Engineer Research and Development Center, Vicksburg, MS.

TABLES

Table D-1. Example Work Calculation

Stage	Flow (cfs)	Min Q (cfs)	Max Q (cfs)	Duration ***Δt*** (hr)	Cumulative Duration (hr)	Mid-Channel Velocity (ft/s)	Effective Shear (lb/ft^2)	Critical Shear (lb/ft^2)	Work ***W*** (unitless)	Cumulative Work ***W Δt*** (unitless)	Total Work ***Σ(W Δt)*** (unitless)
0	0	--	--	343973	355032	0.0	0.00	0.17	0.0	0.0	21198.3
0.1	1	0.5	2	1005	11059	1.1	0.13	0.17	0.0	0.0	
0.17	3	2	4.5	911	10054	1.5	0.16	0.17	0.0	0.0	
0.25	6	4.5	14	1327	9144	2.0	0.28	0.17	0.1	97.8	
0.5	22	14	35.5	2030	7817	2.9	0.45	0.17	0.4	857.2	
0.75	49	35.5	67.5	1242	5787	3.5	0.58	0.17	0.9	1138.2	
1	86	67.5	112	1389	4545	4.1	0.72	0.17	1.7	2312.0	
1.25	138	112	169.5	910	3156	4.6	0.84	0.17	2.5	2274.5	
1.5	201	169.5	238	627	2246	5.0	0.95	0.17	3.5	2171.7	
1.75	275	238	319.5	546	1619	5.5	1.07	0.17	4.7	2559.3	
2	364	319.5	407	410	1073	5.9	1.19	0.17	6.1	2501.9	
2.25	450	407	510	213	663	6.2	1.24	0.17	6.8	1455.2	
2.5	570	510	639.5	153	450	6.5	1.29	0.17	7.7	1169.6	
2.75	709	639.5	786.5	96	298	6.7	1.35	0.17	8.6	822.6	
3	864	786.5	949.5	61	202	7.1	1.46	0.17	10.4	636.3	
3.25	1035	949.5	1127.5	32	141	7.6	1.61	0.17	13.1	423.0	
3.5	1220	1127.5	1320	25	109	8.1	1.75	0.17	16.0	391.7	
3.75	1420	1320	1526.5	20	84	8.3	1.81	0.17	17.5	341.6	
4	1633	1526.5	1746	14	65	8.7	1.91	0.17	19.9	269.3	
4.25	1859	1746	1979	10	51	9.0	1.99	0.17	22.1	209.9	
4.5	2099	1979	2224.5	7	42	9.4	2.09	0.17	24.9	168.1	

Stage	Flow (cfs)	Min Q (cfs)	Max Q (cfs)	Duration Δt (hr)	Cumulative Duration (hr)	Mid-Channel Velocity (ft/s)	Effective Shear (lb/ft^2)	Critical Shear (lb/ft^2)	Work W (unitless)	Cumulative Work $W \Delta t$ (unitless)	Total Work $\Sigma(W \Delta t)$ (unitless)
4.75	2350	2224.5	2482.5	8	35	9.8	2.22	0.17	28.6	214.6	
5	2615	2482.5	2751	4	27	10.1	2.34	0.17	32.3	129.1	
5.25	2887	2751	3041	3	23	10.4	2.42	0.17	35.1	87.7	
5.5	3195	3041	3534	6	21	10.7	2.54	0.17	39.2	244.9	
6	3873	3534	4250.5	5	15	11.2	2.61	0.17	42.5	223.1	
6.5	4628	4250.5	5042.5	4	9	11.4	2.64	0.17	44.4	177.6	
7	5457	5042.5	5922	2	5	12.0	2.81	0.17	51.4	102.9	
7.5	6387	5922	6886.5	1	3	12.6	3.00	0.17	59.8	59.8	
8	7386	6886.5	7919.5	1	2	12.9	3.04	0.17	62.5	78.1	
8.5	8453	7919.5	9020	1	1	13.5	3.30	0.17	74.8	37.4	
9	9587	9020	10154	1	1	14.1	3.52	0.17	86.5	43.3	

FIGURES

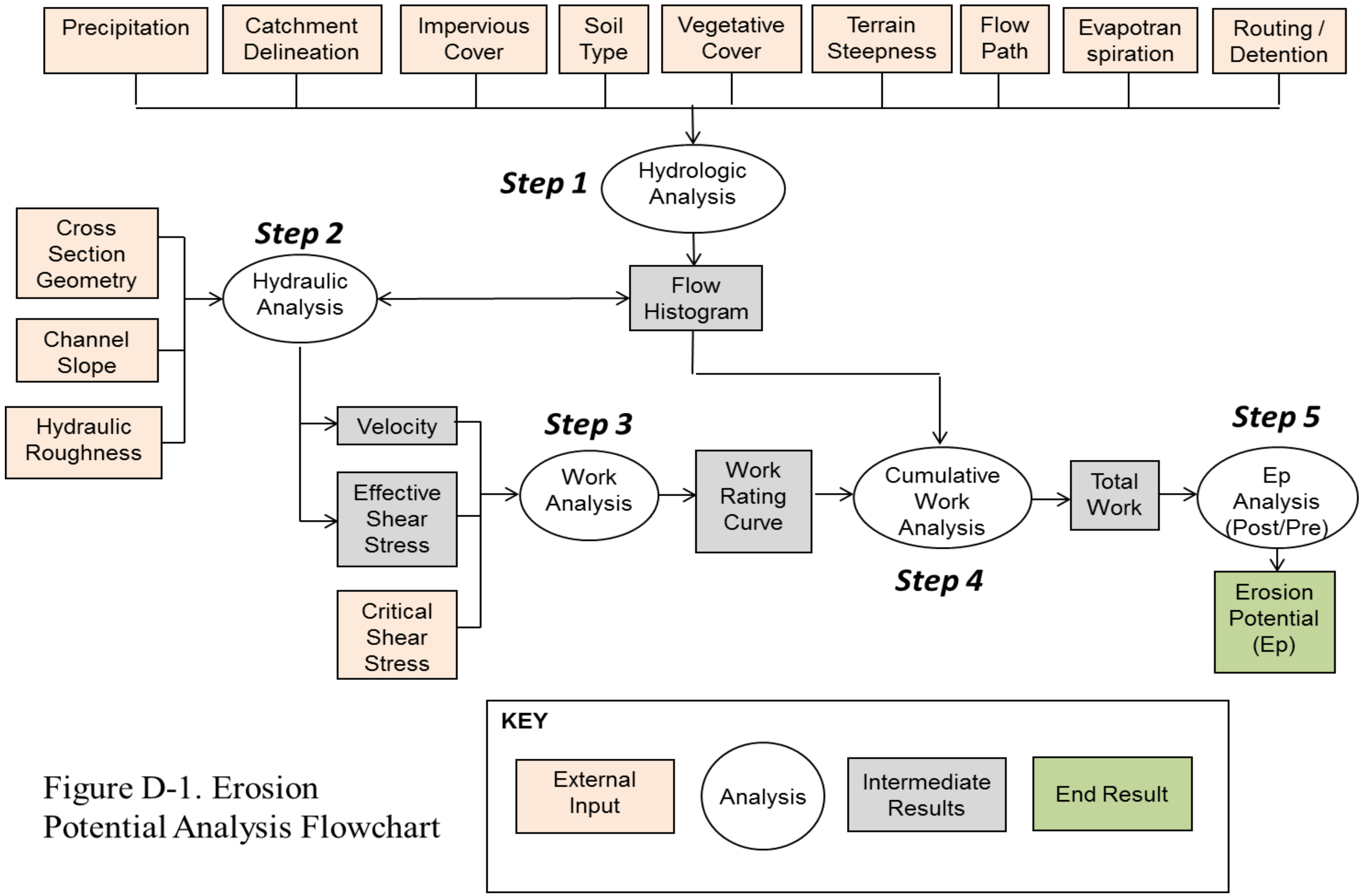

Figure D-1. Erosion Potential Analysis Flowchart

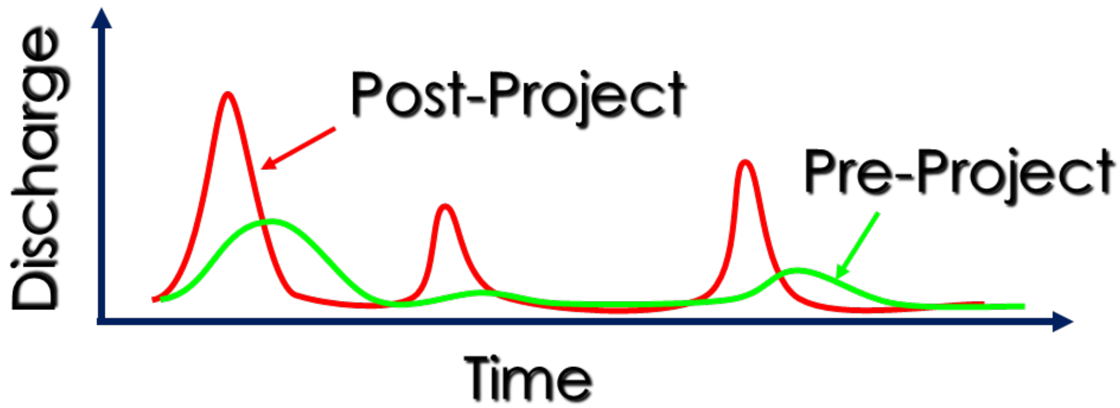

Figure D-2. Example Hydrograph Comparison

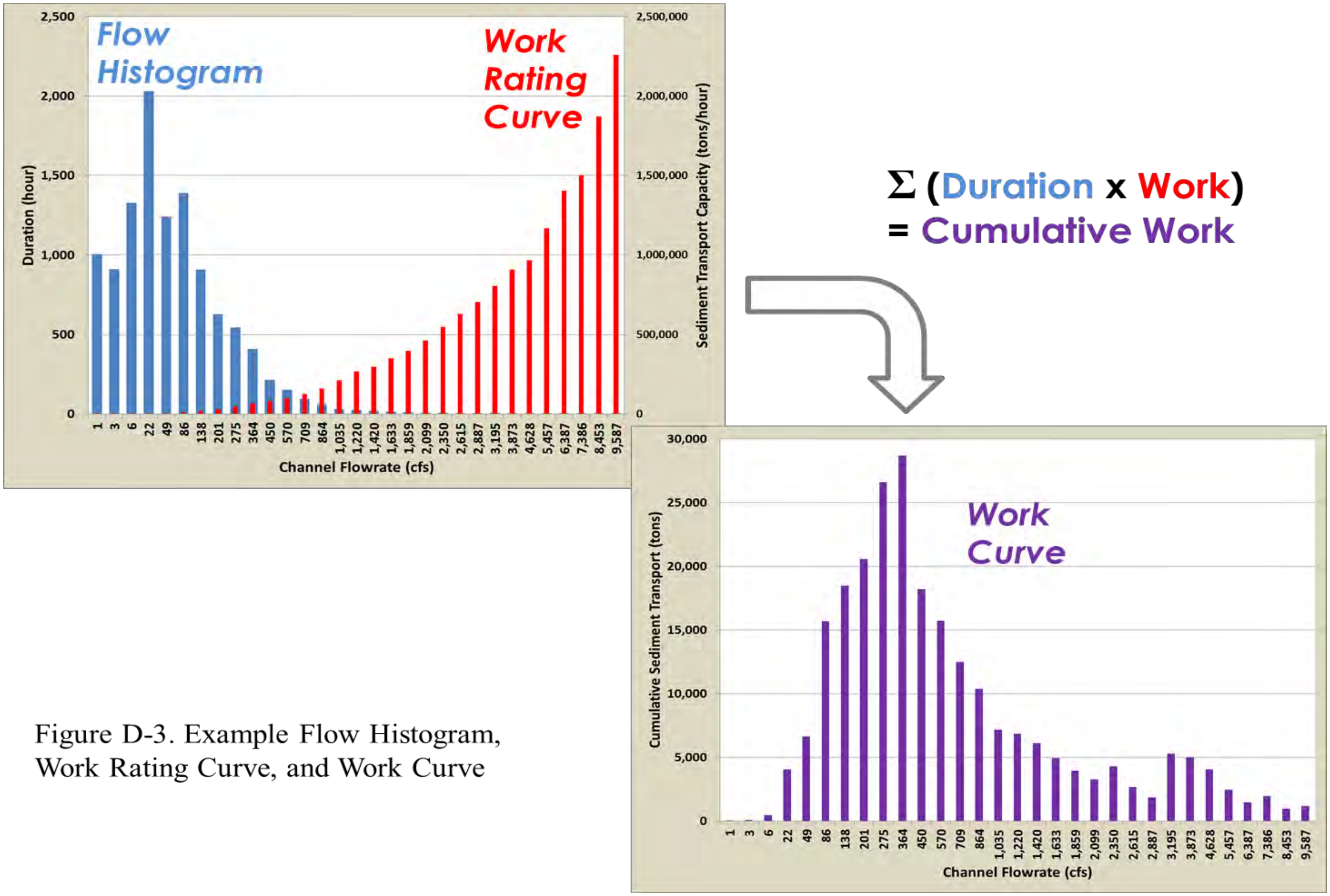

Figure D-3. Example Flow Histogram, Work Rating Curve, and Work Curve

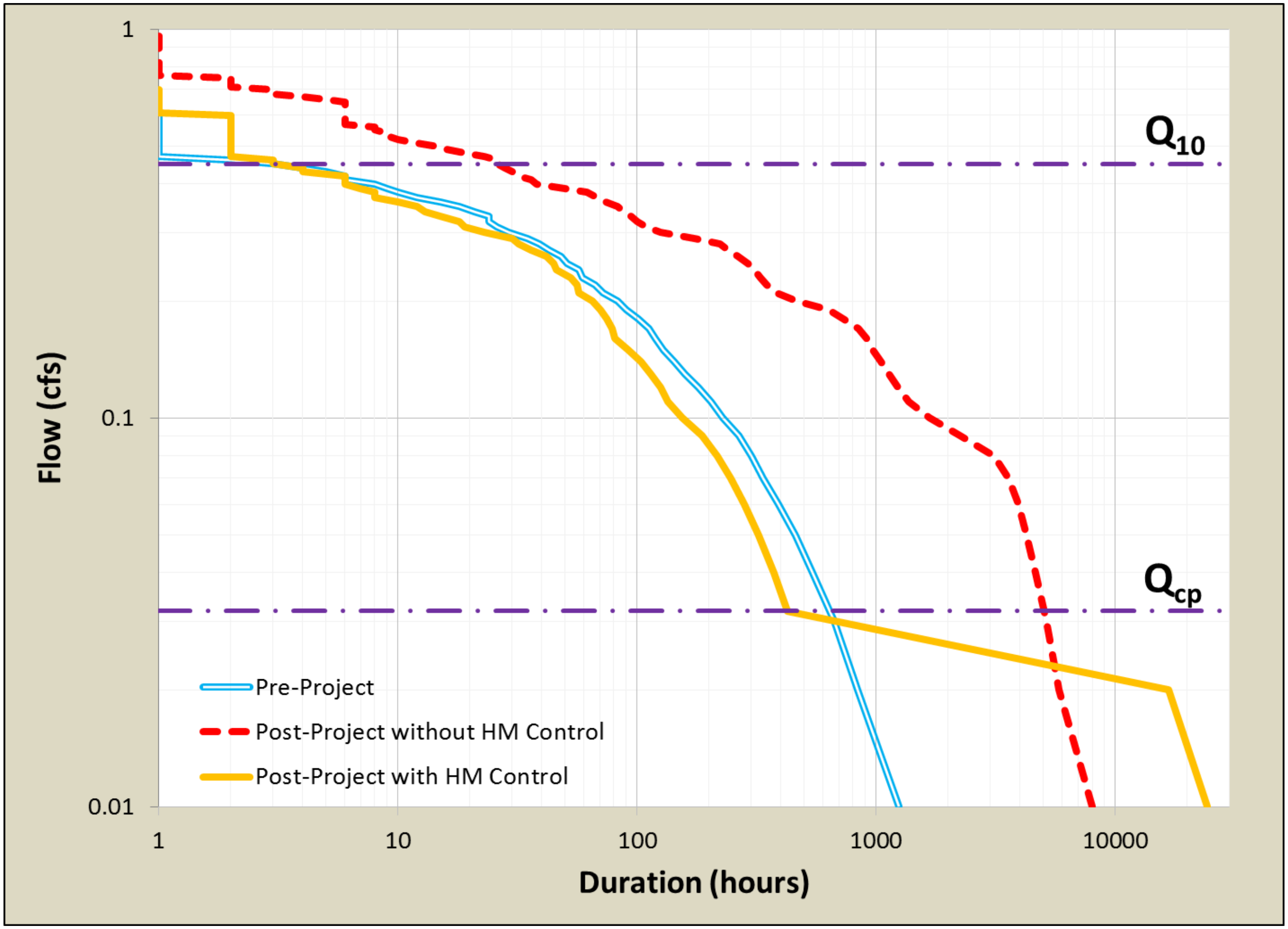

Figure D-4. Example Flow Duration Curve Comparison

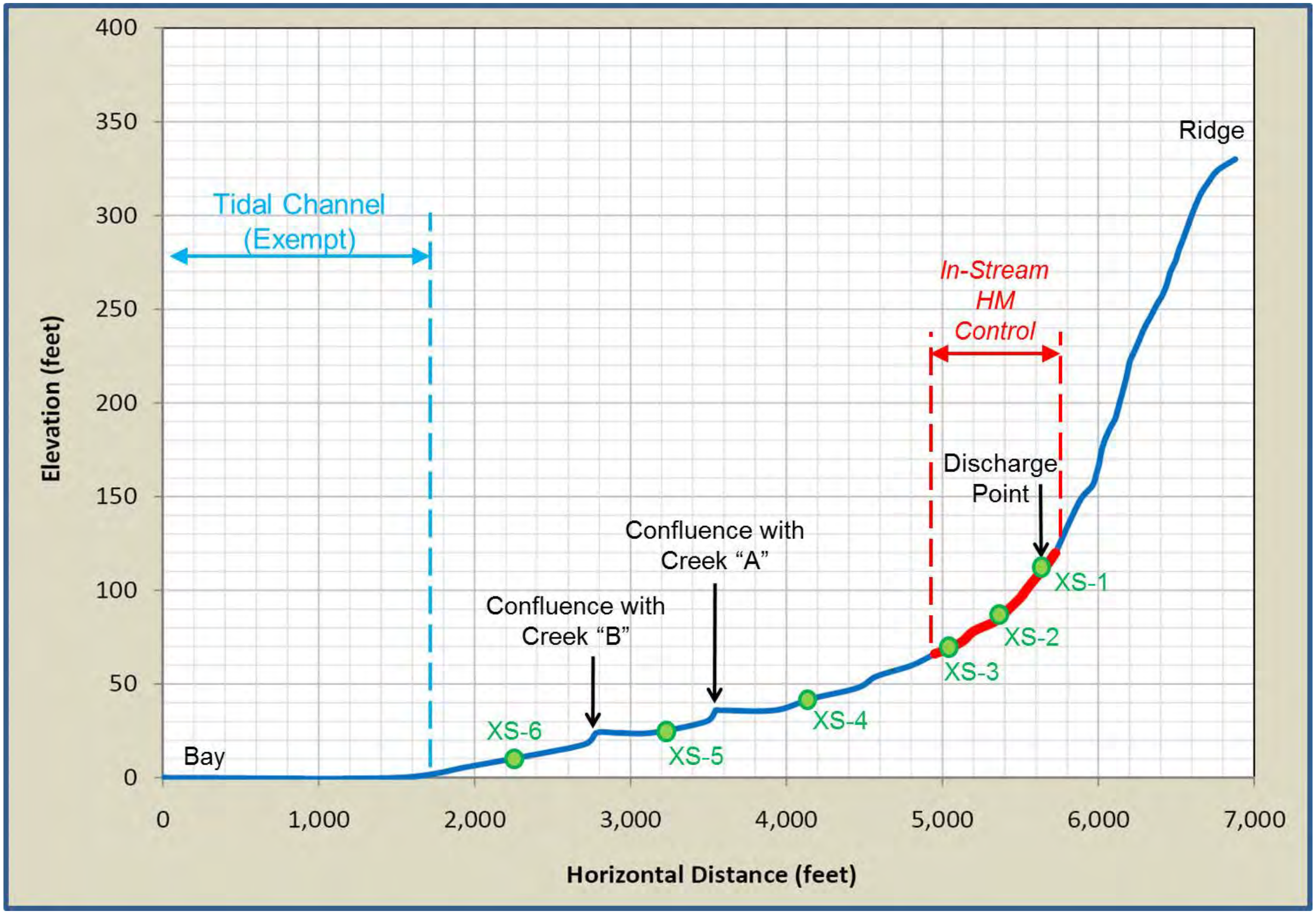

Figure D-5. Example Watershed Scale Longitudinal Profile

APPENDIX E

Modification to Contra Costa County IMP Sizing Calculator

APPENDIX E

MODIFICATION TO CONTRA COSTA COUNTY IMP SIZING CALCULATOR

1. OBJECTIVE/PURPOSE

This appendix documents the modeling exercise, conducted by Geosyntec Consultants, to support a method to size on-site HM controls using a similar approach as that used in Contra Costa County. This method relies on the Integrated Management Practices (IMP) Sizing Calculator, consistent with the 6th edition Contra Costa County stormwater C.3 guidebook, with adjustments made for conditions in Vallejo. In utilizing the Contra Costa County IMP Sizing Calculator, project proponents in Vallejo have an option to design on-site HM controls consistent with Implementation Method #1 (see Section 4.3 of the HMP) without the need of project-specific continuous hydrologic simulation to demonstrate flow duration control.

2. METHODOLOGY

Provision C.3.g.v.b in the Municipal Regional Stormwater Permit (MRP) (SFRWQCB, 2009) states that:

> *Contra Costa sizing charts may be used on projects up to ten acres after any necessary modifications are made to the sizes to control runoff rates and durations from ten percent of the pre-project 2-year peak flow to the pre-project 10-year peak flow, and adjustments are made for local rainfall and soil types.*

Below is the methodology used to adjust the IMP Sizing Tool to account for local soils, local precipitation, and the lower bound discharge ($0.1Q_2$ instead of $0.2Q_2$ as is used in Contra Costa County).

2.1 Adjustment for Local Soils

As shown on Figure E-1, only Hydrologic Soil Groups C and D are present within Vallejo; thus only C and D type soils should be used in the IMP Sizing Calculator when applying it to Vallejo projects. In comparing the distribution of saturated hydraulic conductivity (Ksat) for C and D soils in Contra Costa County and Vallejo, the results are similar between the two (Table E-1). Given the similarity and the fact that there is little basis for changing the soil parameters assumed for the IMP Sizing Calculator, no adjustment for local soils in Vallejo was warranted.

2.2 Adjustment for Local Precipitation

Mean Annual Precipitation (MAP) is a direct input to the IMP Sizing Calculator. The Solano County Water Agency's isohyetal map (SCWA, 1999), provided on Figure E-2, shall be used to evaluate the MAP input for local Vallejo HM projects. Given that the nearest precipitation gage with 30 years of hourly rainfall data is the Martinez gauge (Figure E-3), located in Contra Costa County and used to create the IMP sizing relationships, no other adjustment to local rainfall is warranted. For comparison purposes, the Martinez gauge is approximately 7 miles southeast of the HMP boundary, and it has a similar MAP, (20.2 inches) as that for Vallejo (20 to 26 inches) (Figure E-2).

2.3 Adjustment for Low Flow Discharge

According to MRP provision C.3.g (SFRWQCB, 2009), the Contra Costa County IMPs are designed to meet the lower bound discharge (Qcp) of 20% of the 2-year peak flow ($0.2Q_2$), whereas projects in Vallejo are required to meet a Qcp of 10% of the 2-year peak flow ($0.1Q_2$). In order to adjust the IMP Sizing Calculator output to take into account this change in low flow discharge, the following modifications shall be made:

- The low flow orifice diameter must be divided by $\sqrt{2}$ (or 1.414) to account for the reduction in Qcp; and
- An additional multiplication factor shall be applied to the resulting footprint area and storage volumes obtained from the IMP Sizing Calculator.

To evaluate the appropriate multiplication factor to apply to the footprint area and storage volumes, a continuous hydrologic modeling exercise was conducted to size IMPs for Qcp of $0.2Q_2$ and $0.1Q_2$ in order to meet the flow duration control criteria described in the MRP. The ratio of resulting IMP footprint area (Area $0.1Q_2$/ Area $0.2Q_2$) was used as the basis for a table of recommended multiplication factors. In total, four multiplication factors were evaluated since two soil types (C and D) and two IMP infiltration conditions (infiltrating and non-infiltrating) were modeled. While Section 3 describes the inputs and assumptions used for this modeling exercise, Section 4 summarizes the results.

3. MODELING INPUT AND ASSUMPTIONS

Hydrologic Simulation Program—Fortran (HSPF) was used to model runoff patterns and compute flow duration statistics for the pre-project, post-project without mitigation, and post-project with mitigation conditions. The following sources were used as a basis for modeling inputs:

- The Contra Costa County HMP (CCCWP, 2005)
- Example HSPF input files for Contra Costa County, provided by Brown and Caldwell
- The recommended range of HSPF parameter values in the *EPA BASINs Technical Note 6 Estimating Hydrologic and Hydraulic Parameters for HSPF* (2000).

HSPF is capable of modeling hydrology processes on pervious and impervious land areas and within streams and impoundments. When used in conjunction with existing meteorological and hydrologic data, HSPF can be used as a continuous simulation model for hydrology in watersheds. Within HSPF, hydrologic processes are modeled as flows and storages, which are calculated based upon current storage levels and physical characteristics of the system. For pervious land segments, HSPF utilizes three paths and associated storage zones for the movement of water: overland flow, interflow, and groundwater flow. For impervious land segments, there is no infiltration, so just overland flow is simulated. The tool for modeling storage facilities, or IMPs, within HSPF is referred to as an F-Table and is discussed in further detail below.

3.1 Time Series Inputs

The two temporal data sets required as direct inputs to the HSPF model were precipitation and pan evaporation. The nearest precipitation gage with 30 years of hourly rainfall data is the Martinez gauge (Figure E-3), which has a mean annual precipitation value of 20.2 inches and a period of record from 1948 to 2004. As part of the HSPF modeling performed to create the IMP Sizing Tool, Brown and Caldwell made corrections to the Martinez gauge rainfall record. This corrected gauge record, obtained from the Contra Costa County Clean Water Program website (http://www.cccleanwater.org/c3-guidebook.html), was used for this modeling exercise.

The evaporation time series used for this modeling exercise was a combination of two datasets within the region. A higher quality evaporation dataset from Los Alamitos is available from 1960 to 1996, but does not cover the entire period of record established by the Martinez precipitation gage. As a result, the San Francisco Airport gage was used for the years between 1996 and 2004. This record was also used to develop the Contra Costa IMP Sizing Calculator.

3.2 Land Segment Inputs

Consistent with the Contra Costa HMP, a 1-acre generic catchment was modeled for all continuous simulation runs. While the pre-project catchment was modeled as pervious area using the pervious land segment modeling block (PERLND), post-project catchments were modeled as having impervious cover using the impervious segment modeling block (IMPLND). The majority of the input parameters within these blocks remained unchanged between those documented in the Contra Costa County HMP. The two input parameters that did not rely on the HMP were specific to Type C soil, including the mean infiltration rate (INFILT) and the fraction of infiltrating water lost to deep aquifers (DEEPFR). These parameter inputs were based on the input files received from Brown and Caldwell, which are consistent with *Technical Note 6* (EPA, 2000). A summary of the land segment inputs are provided in Tables E-2 and E-3.

3.3 F-Tables

HSPF has the capability of modeling storage facilities, or IMPs, with the FTABLE block, which designates the stage-storage-discharge relationship for that particular component. Two types of IMPs were modeled: one with infiltrating capacity and one without. In both cases, the storage facility was modeled using two F-Tables.

The first FTABLE represents the physical upper layer of a bioretention facility, which includes 18 inches of soil media and a 10-inch ponding layer. The soil water percolation out of the upper soil layer (FTABLE1) and into the lower gravel layer (FTABLE2) was the same as that provided in the input files received from Brown and Caldwell. These were originally computed using Darcy's Law and the van Genuchten relations, as described in the Contra Costa HMP. The outflow through the overflow pipe is modeled using a weir equation at a depth of 2.33-feet and a riser diameter of 1-foot. The effective porosity of the media was modeled as 0.40 consistent with the input files received from Brown and Caldwell.

The second FTABLE represents the 18-inch lower gravel layer and the underdrain. The percolation rate within this layer is controlled by the hydraulic conductivity of the surrounding soil at the bottom of the IMP or is designated as zero if the BMP does not infiltrate. The percolation rate used for Type C and D soil was 0.20 cm/s and 0.06 cm/s, respectively, consistent with the Contra Costa HMP. The outflow from the IMP through the underdrain is calculated using the orifice equation, and it is designed to match the low-flow discharge when the lower gravel layer is fully saturated. The distribution of this was the same as that provided in the input files received from Brown and Caldwell. The effective porosity of the gravel was modeled as 0.42, consistent with the input files received from Brown and Caldwell. The F-Tables used in the eight post-project IMP modeling scenarios are provided in Section 4.

3.4 Range of Flows to Control

In order to establish the flow range of interest for which flow duration control is required, the 2-year (Q_2) and 10-year (Q_{10}) return period discharges for the pre-project condition were calculated for C and D soils. This was done by constructing a partial-duration series from the pre-project condition simulation output as follows:

- The entire runoff time series generated by the pre-project hydrologic simulation is divided into a set of discrete events based on independence criteria.
- The independence criteria described in the Contra Costa HMP was used to separate discrete events as follows:
    - Flow events are considered separate when the flow rate drops below a threshold value of 0.05 cfs/acre for a period of at least 24 hours.
- The peak flows from each discrete event were ranked and the return intervals were computed using plotting position methods to establish the Q_2 and Q_{10}. The lower bound discharge (Qcp) is simply 10% or 20% of the computed Q_2 depending on what low flow criterion was being evaluated.

The partial duration series analysis was performed by placing the simulated pre-project flow output into EPA's Storm Water Management Model (SWMM) Version 5.0 and running the appropriate statistical analysis.

3.5 Goodness of Fit Criteria

According to MRP Provisions C.3.g.ii.(2) (SFRWQCB, 2009), the goodness of fit criteria for flow duration control is as follows:

> *The post-project flow duration curve shall not deviate above the pre-project flow duration curve by more than 10 percent over more than 10 percent of the length of the curve corresponding to the range of flows to control.*

For the purposes of this modeling exercise, it was assumed that the goodness of fit criteria applies to a 10% allowance for the cumulative durations rather than flowrate. With the IMP configuration established, as described in Section 3.3, the IMP footprint area was iteratively adjusted by 0.005 acre increments using the FTABLE input until the simulated discharge record met the goodness of fit criteria with the minimum footprint needed.

4. RESULTS

Based on the inputs and assumptions described in Section 3, the results of the modeling exercise are presented in Tables E-4 to E-14 and Figures E-4 and E-5. Table E-4 provides the partial duration series results needed to establish the range of flows to control. Table E-5 provides the minimum footprint needed to meet the goodness of fit criteria for each of the eight IMP scenarios modeled. Flow duration curves corresponding to the pre-development, post-development without mitigation, and post-development with mitigation (for the IMP footprints in Table E-5) are provided on Figure E-4 and E-5. Overlaid on these flow duration curves are lines representing the $0.1Q_2$ and $0.2Q_2$ lower bound discharges and the Q_{10} upper flow limit to show the range of flowrates that apply to the goodness of fit criteria. The results of greatest significance are the multiplication factors needed to adjust the low flow criteria, as summarized in Table E-6. IMPs sized for a low flow discharge of $0.1Q_2$ require 21% to 76% greater footprint and volume than those sized for $0.2Q_2$. The F-Tables used in the eight IMP scenarios modeled (corresponding to the footprints in Table E-5) are provided in Tables E-7 to E-14.

5. ACKNOWLEDGEMENTS

The project team would like to acknowledge the Contra Costa Clean Water Program and Brown and Caldwell for sharing HSPF input files and answering questions with regard to model assumptions.

6. REFERENCES

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TABLES

Table E-1. Distribution of Saturated Hydraulic Conductivity for C and D Soils in Contra Costa County and Vallejo

	C Soils		D Soils	
Ksat (in/hr)	Contra Costa County	Vallejo	Contra Costa County	Vallejo
0	0%	0%	0%	1%
0.13	0%	0%	63%	63%
0.38	82%	97%	10%	23%
1.28	18%	3%	23%	12%
3.97	0%	0%	1%	2%
13.04	0%	0%	3%	0%

Note: The Ksat listed is based on the NRCS SSURGO database, which is not a one-to-one comparison to the INFILT parameter in HSPF. Data used for this comparison is the same as that used in the *Harvest and Use, Infiltration and Evapotranspiration Feasibility/Infeasibility Criteria Report* (BASMAA, 2011).

Table E-2. Assumed HSPF PERLND Parameters

Parameter	Units	Value	Description
CSNO	N/A	0	Flag to determine if snow data is used
RTOP	N/A	1	Flag to identify overland routing method
UZFG	N/A	1	Flag to select upper zone inflow computation method
VCS	N/A	1	Flag to select constant or monthly interception storage capacity
VUZ	N/A	0	Flag to select constant or monthly upper zone nominal soil moisture storage
VNN	N/A	0	Flag to select constant or monthly Manning's n
VIFW	N/A	0	Flag to select constant or monthly interflow parameter
VIRC	N/A	0	Flag to select constant or monthly interflow recession parameter
VLE	N/A	1	Flag to select constant or monthly varied lower zone ET parameter
FOREST	N/A	0	Fraction of forest covered area that will transpire in winter
LZSN	Inch	7	Nominal lower zone soil moisture storage
INFILT	Inch/hour	Group C=0.075; Group D=0.03	Mean soil infiltration rate.
LSUR	Feet	660	Length of assumed overland flow plane
SLSUR	N/A	0.1	Average slope of overland flow path
KVARY	per inch	0	Groundwater recession flow parameter for non-linear GW recession rate
AGWRC	per day	0.95	Groundwater recession rate (when KVARY=0)
PETMAX	deg F	40	Temperature below which ET will reduce by 50% of input time series

Parameter	Units	Value	Description
PETMIN	deg F	35	Temperature threshold where plant transpiration is suspended
INFEXP	N/A	2	Exponent determining the extent deviation from nominal lower zone storage affects infiltration rate
INFILD	N/A	2	Ratio of maximum and mean soil infiltration capacities
DEEPFR	N/A	Group C=0.2; Group D=0.1	Fraction of infiltrating water lost to deep aquifers
AGWETP	N/A	0	Fraction of PERLND that is subject to direct evaporation from GW Storage (wetlands/marsh)
CEPSC	Inch	0.02	Amount of rainfall retained by vegetation and eventually evaporated (Type of vegetation=Range)
UZSN	Inch	0.5	Nominal upper zone soil moisture storage
NSUR	N/A	0.3	Manning’s friction coefficient, n, for overland flow
INTFW	N/A	0.4	Fraction of water in surface detention that becomes interflow
IRC	N/A	0.3	Interflow recession coefficient (ratio of current daily interflow discharge to previous day)
LZETP	N/A	0	Lower Zone ET coefficient for portion of ET that occurs in lower soil zone
CEPS	Inch	0	Interception storage initial value
SURS	Inch	0	Surface ponding storage initial value
UZS	Inch	0.15	Upper Zone Storage initial value
IFWS	Inch	0	Interflow storage initial value
LZSN	Inch	4	Lower Zone storage initial value
AGWS	Inch	0.05	Active groundwater storage initial value
GWVS	N/A	0	Initial groundwater storage slope

Table E-3. Assumed HSPF IMPLND Parameters

Parameter	Unit	Value	Description
CSNO	N/A	0	Flag to determine if snow data is used
RTOP	N/A	0	Flag to identify overland routing method
VRS	N/A	0	Flag to select constant or monthly retention storage capacity
VNN	N/A	0	Flag to select constant or monthly Manning's n
RTLI	N/A	1	Flag to select whether lateral surface inflow to IMPLND segment will be subject to retention storage
LSUR	N/A	100	Length of overland flow path
SLSUR	N/A	0.035	Average slope of overland flow path
NSUR	N/A	0.05	Manning's friction coefficient, n, for overland flow plane
RETSC	Inch	0.1	Retention storage of impervious surface
PETMAX	deg F	40	Temperature below which ET will reduce by 50% of input time series

Parameter	Unit	Value	Description
PETMIN	deg F	35	Temperature threshold where ET is set to zero
RETS	Inch	1.00E-03	Retention storage initial value
SURS	Inch	1.00E-03	Surface ponding storage initial value

Table E-4. Peak Flow Results for Pre-Project C and D Soils

Flow Event	Soils	
	C	**D**
Q_{10}	0.451	0.530
Q_2	0.319	0.424

Table E-5. Minimum IMP Footprint Areas Needed to Meet the Flow Duration Control Criteria

Soil	IMP Area (acres)			
	Infiltrating		**Non-Infiltrating**	
	$0.1Q_2$	**$0.2Q_2$**	**$0.1Q_2$**	**$0.2Q_2$**
C	0.145	0.120	0.215	0.125
D	0.110	0.080	0.150	0.085

Table E-6. Multiplication Factors to Adjust IMP Sizing Results from a Low Flow Discharge of $0.2Q_2$ to $0.1Q_2$

Soil	Infiltrating	Non-Infiltrating
C	1.21	1.72
D	1.38	1.76

Table E-7. FTABLES for an infiltrating IMP with 0.1Q2 low-flow discharge, C-Soils, and a footprint area of 0.145 acres

Depth (ft)	Area (acres)	Volume (acre-ft)	QPerc (cfs)	QOver (cfs)
UPPER LAYER (PONDING AND MEDIA)				
0	0.145	0.0000	0.0000	0.0000
0.1	0.145	0.0058	0.0000	0.0000
0.2	0.145	0.0116	0.0000	0.0000
0.3	0.145	0.0174	0.0000	0.0000
0.4	0.145	0.0232	0.0000	0.0000
0.5	0.145	0.0290	0.0000	0.0000
0.6	0.145	0.0348	0.0000	0.0000
0.7	0.145	0.0406	0.0000	0.0000
0.8	0.145	0.0464	0.0001	0.0000
0.9	0.145	0.0522	0.0002	0.0000
1	0.145	0.0580	0.0003	0.0000
1.1	0.145	0.0638	0.0007	0.0000
1.2	0.145	0.0696	0.0015	0.0000
1.3	0.145	0.0754	0.0032	0.0000
1.4	0.145	0.0812	0.0069	0.0000
1.5	0.145	0.0870	0.0370	0.0000
1.6	0.145	0.1015	0.0398	0.0000
1.7	0.145	0.1160	0.0423	0.0000
1.8	0.145	0.1305	0.0435	0.0000
1.9	0.145	0.1450	0.0435	0.0000
2	0.145	0.1595	0.0435	0.0000
2.1	0.145	0.1740	0.0435	0.0000
2.2	0.145	0.1885	0.0435	0.0000
2.3	0.145	0.2030	0.0435	0.0000
2.4	0.145	0.2175	0.0435	0.2060
2.5	0.145	0.2320	0.0435	0.7930
2.6	0.145	0.2465	0.0435	1.4320
2.7	0.145	0.2610	0.0435	1.8903
2.8	0.145	0.2755	0.0435	2.1733
2.9	0.145	0.2900	0.0435	2.4524
3	0.145	0.3045	0.0435	2.6677
LOWER LAYER (GRAVEL)				
0	0.145	0.0000	0.0000	0.0000
0.1	0.145	0.0060	0.0002	0.0000
0.2	0.145	0.0121	0.0046	0.0004
0.3	0.145	0.0181	0.0116	0.0022
0.4	0.145	0.0242	0.0116	0.0071
0.5	0.145	0.0302	0.0116	0.0184

Depth (ft)	Area (acres)	Volume (acre-ft)	QPerc (cfs)	QOver (cfs)
0.6	0.145	0.0363	0.0116	0.0202
0.7	0.145	0.0423	0.0116	0.0218
0.8	0.145	0.0483	0.0116	0.0232
0.9	0.145	0.0544	0.0116	0.0248
1	0.145	0.0604	0.0116	0.0260
1.1	0.145	0.0665	0.0116	0.0273
1.2	0.145	0.0725	0.0116	0.0285
1.3	0.145	0.0785	0.0116	0.0297
1.4	0.145	0.0846	0.0116	0.0307
1.5	0.145	0.0906	0.0116	0.0319

Table E-8. FTABLES for an infiltrating IMP with 0.2Q2 low-flow discharge, C-Soils, and a footprint area of 0.120 acres

Depth (ft)	Area (acres)	Volume (acre-ft)	QPerc (cfs)	QOver (cfs)
UPPER LAYER (PONDING AND MEDIA)				
0	0.12	0.0000	0.0000	0.0000
0.1	0.12	0.0048	0.0000	0.0000
0.2	0.12	0.0096	0.0000	0.0000
0.3	0.12	0.0144	0.0000	0.0000
0.4	0.12	0.0192	0.0000	0.0000
0.5	0.12	0.0240	0.0000	0.0000
0.6	0.12	0.0288	0.0000	0.0000
0.7	0.12	0.0336	0.0000	0.0000
0.8	0.12	0.0384	0.0001	0.0000
0.9	0.12	0.0432	0.0003	0.0000
1	0.12	0.0480	0.0006	0.0000
1.1	0.12	0.0528	0.0012	0.0000
1.2	0.12	0.0576	0.0026	0.0000
1.3	0.12	0.0624	0.0054	0.0000
1.4	0.12	0.0672	0.0117	0.0000
1.5	0.12	0.0720	0.0625	0.0000
1.6	0.12	0.0840	0.0672	0.0000
1.7	0.12	0.0960	0.0714	0.0000
1.8	0.12	0.1080	0.0734	0.0000
1.9	0.12	0.1200	0.0734	0.0000
2	0.12	0.1320	0.0734	0.0000
2.1	0.12	0.1440	0.0734	0.0000
2.2	0.12	0.1560	0.0734	0.0000
2.3	0.12	0.1680	0.0734	0.0000
2.4	0.12	0.1800	0.0734	0.2060

Depth (ft)	Area (acres)	Volume (acre-ft)	QPerc (cfs)	QOver (cfs)
2.5	0.12	0.1920	0.0734	0.7930
2.6	0.12	0.2040	0.0734	1.4320
2.7	0.12	0.2160	0.0734	1.8903
2.8	0.12	0.2280	0.0734	2.1733
2.9	0.12	0.2400	0.0734	2.4524
3	0.12	0.2520	0.0734	2.6677
LOWER LAYER (GRAVEL)				
0	0.12	0.0000	0.0000	0.0000
0.1	0.12	0.0050	0.0002	0.0000
0.2	0.12	0.0100	0.0038	0.0008
0.3	0.12	0.0150	0.0096	0.0044
0.4	0.12	0.0200	0.0096	0.0143
0.5	0.12	0.0250	0.0096	0.0369
0.6	0.12	0.0300	0.0096	0.0404
0.7	0.12	0.0350	0.0096	0.0436
0.8	0.12	0.0400	0.0096	0.0464
0.9	0.12	0.0450	0.0096	0.0495
1	0.12	0.0500	0.0096	0.0519
1.1	0.12	0.0550	0.0096	0.0547
1.2	0.12	0.0600	0.0096	0.0571
1.3	0.12	0.0650	0.0096	0.0594
1.4	0.12	0.0700	0.0096	0.0614
1.5	0.12	0.0750	0.0096	0.0638

Table E-9. FTABLES for an infiltrating IMP with 0.1Q2 low-flow discharge, D-Soils, and a footprint area of 0.110 acres

Depth (ft)	Area (acres)	Volume (acre-ft)	QPerc (cfs)	QOver (cfs)
UPPER LAYER (PONDING AND MEDIA)				
0	0.11	0.0000	0.0000	0.0000
0.1	0.11	0.0044	0.0000	0.0000
0.2	0.11	0.0088	0.0000	0.0000
0.3	0.11	0.0132	0.0000	0.0000
0.4	0.11	0.0176	0.0000	0.0000
0.5	0.11	0.0220	0.0000	0.0000
0.6	0.11	0.0264	0.0000	0.0000
0.7	0.11	0.0308	0.0000	0.0000
0.8	0.11	0.0352	0.0001	0.0000
0.9	0.11	0.0396	0.0002	0.0000
1	0.11	0.0440	0.0004	0.0000

Depth (ft)	Area (acres)	Volume (acre-ft)	QPerc (cfs)	QOver (cfs)
1.1	0.11	0.0484	0.0009	0.0000
1.2	0.11	0.0528	0.0019	0.0000
1.3	0.11	0.0572	0.0038	0.0000
1.4	0.11	0.0616	0.0084	0.0000
1.5	0.11	0.0660	0.0451	0.0000
1.6	0.11	0.0770	0.0451	0.0000
1.7	0.11	0.0880	0.0451	0.0000
1.8	0.11	0.0990	0.0451	0.0000
1.9	0.11	0.1100	0.0451	0.0000
2	0.11	0.1210	0.0451	0.0000
2.1	0.11	0.1320	0.0451	0.0000
2.2	0.11	0.1430	0.0451	0.0000
2.3	0.11	0.1540	0.0451	0.0000
2.4	0.11	0.1650	0.0451	0.2060
2.5	0.11	0.1760	0.0451	0.7930
2.6	0.11	0.1870	0.0451	1.4320
2.7	0.11	0.1980	0.0451	1.8903
2.8	0.11	0.2090	0.0451	2.1733
2.9	0.11	0.2200	0.0451	2.4524
3	0.11	0.2310	0.0451	2.6677
LOWER LAYER (GRAVEL)				
0	0.11	0.0000	0.0000	0.0000
0.1	0.11	0.0046	0.0002	0.0000
0.2	0.11	0.0092	0.0027	0.0007
0.3	0.11	0.0138	0.0027	0.0033
0.4	0.11	0.0183	0.0027	0.0109
0.5	0.11	0.0229	0.0027	0.0246
0.6	0.11	0.0275	0.0027	0.0268
0.7	0.11	0.0321	0.0027	0.0290
0.8	0.11	0.0367	0.0027	0.0312
0.9	0.11	0.0413	0.0027	0.0330
1	0.11	0.0458	0.0027	0.0348
1.1	0.11	0.0504	0.0027	0.0366
1.2	0.11	0.0550	0.0027	0.0381
1.3	0.11	0.0596	0.0027	0.0395
1.4	0.11	0.0642	0.0027	0.0410
1.5	0.11	0.0688	0.0027	0.0424

Table E-10. FTABLES for an infiltrating IMP with 0.2Q2 low-flow discharge, D-Soils, and a footprint area of 0.080 acres

Depth (ft)	Area (acres)	Volume (acre-ft)	QPerc (cfs)	QOver (cfs)
UPPER LAYER (PONDING AND MEDIA)				
0	0.08	0.0000	0.0000	0.0000
0.1	0.08	0.0032	0.0000	0.0000
0.2	0.08	0.0064	0.0000	0.0000
0.3	0.08	0.0096	0.0000	0.0000
0.4	0.08	0.0128	0.0000	0.0000
0.5	0.08	0.0160	0.0000	0.0000
0.6	0.08	0.0192	0.0000	0.0000
0.7	0.08	0.0224	0.0000	0.0000
0.8	0.08	0.0256	0.0001	0.0000
0.9	0.08	0.0288	0.0004	0.0000
1	0.08	0.0320	0.0008	0.0000
1.1	0.08	0.0352	0.0017	0.0000
1.2	0.08	0.0384	0.0036	0.0000
1.3	0.08	0.0416	0.0073	0.0000
1.4	0.08	0.0448	0.0161	0.0000
1.5	0.08	0.0480	0.0867	0.0000
1.6	0.08	0.0560	0.0867	0.0000
1.7	0.08	0.0640	0.0867	0.0000
1.8	0.08	0.0720	0.0867	0.0000
1.9	0.08	0.0800	0.0867	0.0000
2	0.08	0.0880	0.0867	0.0000
2.1	0.08	0.0960	0.0867	0.0000
2.2	0.08	0.1040	0.0867	0.0000
2.3	0.08	0.1120	0.0867	0.0000
2.4	0.08	0.1200	0.0867	0.2060
2.5	0.08	0.1280	0.0867	0.7930
2.6	0.08	0.1360	0.0867	1.4320
2.7	0.08	0.1440	0.0867	1.8903
2.8	0.08	0.1520	0.0867	2.1733
2.9	0.08	0.1600	0.0867	2.4524
3	0.08	0.1680	0.0867	2.6677
LOWER LAYER (GRAVEL)				
0	0.08	0.0000	0.0000	0.0000
0.1	0.08	0.0033	0.0002	0.0000
0.2	0.08	0.0067	0.0019	0.0014
0.3	0.08	0.0100	0.0019	0.0065

Depth (ft)	Area (acres)	Volume (acre-ft)	QPerc (cfs)	QOver (cfs)
0.4	0.08	0.0133	0.0019	0.0217
0.5	0.08	0.0167	0.0019	0.0493
0.6	0.08	0.0200	0.0019	0.0536
0.7	0.08	0.0233	0.0019	0.0580
0.8	0.08	0.0267	0.0019	0.0623
0.9	0.08	0.0300	0.0019	0.0660
1	0.08	0.0333	0.0019	0.0696
1.1	0.08	0.0367	0.0019	0.0732
1.2	0.08	0.0400	0.0019	0.0761
1.3	0.08	0.0433	0.0019	0.0790
1.4	0.08	0.0467	0.0019	0.0819
1.5	0.08	0.0500	0.0019	0.0848

Table E-11. FTABLES for a non-infiltrating IMP with 0.1Q2 low-flow discharge, C-Soils, and a footprint area of 0.215 acres

Depth (ft)	Area (acres)	Volume (acre-ft)	QPerc (cfs)	QOver (cfs)
UPPER LAYER (PONDING AND MEDIA)				
0	0.215	0.0000	0.0000	0.0000
0.1	0.215	0.0086	0.0000	0.0000
0.2	0.215	0.0172	0.0000	0.0000
0.3	0.215	0.0258	0.0000	0.0000
0.4	0.215	0.0344	0.0000	0.0000
0.5	0.215	0.0430	0.0000	0.0000
0.6	0.215	0.0516	0.0000	0.0000
0.7	0.215	0.0602	0.0000	0.0000
0.8	0.215	0.0688	0.0000	0.0000
0.9	0.215	0.0774	0.0001	0.0000
1	0.215	0.0860	0.0003	0.0000
1.1	0.215	0.0946	0.0005	0.0000
1.2	0.215	0.1032	0.0011	0.0000
1.3	0.215	0.1118	0.0023	0.0000
1.4	0.215	0.1204	0.0051	0.0000
1.5	0.215	0.1290	0.0272	0.0000
1.6	0.215	0.1505	0.0292	0.0000
1.7	0.215	0.1720	0.0311	0.0000
1.8	0.215	0.1935	0.0319	0.0000
1.9	0.215	0.2150	0.0319	0.0000
2	0.215	0.2365	0.0319	0.0000
2.1	0.215	0.2580	0.0319	0.0000
2.2	0.215	0.2795	0.0319	0.0000

Depth (ft)	Area (acres)	Volume (acre-ft)	QPerc (cfs)	QOver (cfs)
2.3	0.215	0.3010	0.0319	0.0000
2.4	0.215	0.3225	0.0319	0.2060
2.5	0.215	0.3440	0.0319	0.7930
2.6	0.215	0.3655	0.0319	1.4320
2.7	0.215	0.3870	0.0319	1.8903
2.8	0.215	0.4085	0.0319	2.1733
2.9	0.215	0.4300	0.0319	2.4524
3	0.215	0.4515	0.0319	2.6677
LOWER LAYER (GRAVEL)				
0	0.215	0.0000	0.0000	0.0000
0.1	0.215	0.0090	0.0000	0.0000
0.2	0.215	0.0179	0.0000	0.0004
0.3	0.215	0.0269	0.0000	0.0022
0.4	0.215	0.0358	0.0000	0.0071
0.5	0.215	0.0448	0.0000	0.0184
0.6	0.215	0.0538	0.0000	0.0202
0.7	0.215	0.0627	0.0000	0.0218
0.8	0.215	0.0717	0.0000	0.0232
0.9	0.215	0.0806	0.0000	0.0248
1	0.215	0.0896	0.0000	0.0260
1.1	0.215	0.0985	0.0000	0.0273
1.2	0.215	0.1075	0.0000	0.0285
1.3	0.215	0.1165	0.0000	0.0297
1.4	0.215	0.1254	0.0000	0.0307
1.5	0.215	0.1344	0.0000	0.0319

Table E-12. FTABLES for a non-infiltrating IMP with 0.2Q2 low-flow discharge, C-Soils, and a footprint area of 0.125 acres

Depth (ft)	Area (acres)	Volume (acre-ft)	QPerc (cfs)	QOver (cfs)
UPPER LAYER (PONDING AND MEDIA)				
0	0.125	0.0000	0.0000	0.0000
0.1	0.125	0.0050	0.0000	0.0000
0.2	0.125	0.0100	0.0000	0.0000
0.3	0.125	0.0150	0.0000	0.0000
0.4	0.125	0.0200	0.0000	0.0000
0.5	0.125	0.0250	0.0000	0.0000
0.6	0.125	0.0300	0.0000	0.0000
0.7	0.125	0.0350	0.0000	0.0000
0.8	0.125	0.0400	0.0001	0.0000
0.9	0.125	0.0450	0.0002	0.0000

Depth (ft)	Area (acres)	Volume (acre-ft)	QPerc (cfs)	QOver (cfs)
1	0.125	0.0500	0.0005	0.0000
1.1	0.125	0.0550	0.0011	0.0000
1.2	0.125	0.0600	0.0022	0.0000
1.3	0.125	0.0650	0.0047	0.0000
1.4	0.125	0.0700	0.0102	0.0000
1.5	0.125	0.0750	0.0544	0.0000
1.6	0.125	0.0875	0.0585	0.0000
1.7	0.125	0.1000	0.0621	0.0000
1.8	0.125	0.1125	0.0638	0.0000
1.9	0.125	0.1250	0.0638	0.0000
2	0.125	0.1375	0.0638	0.0000
2.1	0.125	0.1500	0.0638	0.0000
2.2	0.125	0.1625	0.0638	0.0000
2.3	0.125	0.1750	0.0638	0.0000
2.4	0.125	0.1875	0.0638	0.2060
2.5	0.125	0.2000	0.0638	0.7930
2.6	0.125	0.2125	0.0638	1.4320
2.7	0.125	0.2250	0.0638	1.8903
2.8	0.125	0.2375	0.0638	2.1733
2.9	0.125	0.2500	0.0638	2.4524
3	0.125	0.2625	0.0638	2.6677
LOWER LAYER (GRAVEL)				
0	0.125	0.0000	0.0000	0.0000
0.1	0.125	0.0052	0.0000	0.0000
0.2	0.125	0.0104	0.0000	0.0008
0.3	0.125	0.0156	0.0000	0.0044
0.4	0.125	0.0208	0.0000	0.0143
0.5	0.125	0.0260	0.0000	0.0369
0.6	0.125	0.0313	0.0000	0.0404
0.7	0.125	0.0365	0.0000	0.0436
0.8	0.125	0.0417	0.0000	0.0464
0.9	0.125	0.0469	0.0000	0.0495
1	0.125	0.0521	0.0000	0.0519
1.1	0.125	0.0573	0.0000	0.0547
1.2	0.125	0.0625	0.0000	0.0571
1.3	0.125	0.0677	0.0000	0.0594
1.4	0.125	0.0729	0.0000	0.0614
1.5	0.125	0.0781	0.0000	0.0638

Table E-13. FTABLES for a non-infiltrating BMP with 0.1Q2 low-flow discharge, D-Soils, and a footprint area of 0.15 acres

Depth (ft)	Area (acres)	Volume (acre-ft)	QPerc (cfs)	QOver (cfs)
UPPER LAYER (PONDING AND MEDIA)				
0	0.15	0.0000	0.0000	0.0000
0.1	0.15	0.0060	0.0000	0.0000
0.2	0.15	0.0120	0.0000	0.0000
0.3	0.15	0.0180	0.0000	0.0000
0.4	0.15	0.0240	0.0000	0.0000
0.5	0.15	0.0300	0.0000	0.0000
0.6	0.15	0.0360	0.0000	0.0000
0.7	0.15	0.0420	0.0000	0.0000
0.8	0.15	0.0480	0.0001	0.0000
0.9	0.15	0.0540	0.0002	0.0000
1	0.15	0.0600	0.0004	0.0000
1.1	0.15	0.0660	0.0008	0.0000
1.2	0.15	0.0720	0.0018	0.0000
1.3	0.15	0.0780	0.0036	0.0000
1.4	0.15	0.0840	0.0079	0.0000
1.5	0.15	0.0900	0.0424	0.0000
1.6	0.15	0.1050	0.0424	0.0000
1.7	0.15	0.1200	0.0424	0.0000
1.8	0.15	0.1350	0.0424	0.0000
1.9	0.15	0.1500	0.0424	0.0000
2	0.15	0.1650	0.0424	0.0000
2.1	0.15	0.1800	0.0424	0.0000
2.2	0.15	0.1950	0.0424	0.0000
2.3	0.15	0.2100	0.0424	0.0000
2.4	0.15	0.2250	0.0424	0.2060
2.5	0.15	0.2400	0.0424	0.7930
2.6	0.15	0.2550	0.0424	1.4320
2.7	0.15	0.2700	0.0424	1.8903
2.8	0.15	0.2850	0.0424	2.1733
2.9	0.15	0.3000	0.0424	2.4524
3	0.15	0.3150	0.0424	2.6677
LOWER LAYER (GRAVEL)				
0	0.15	0.0000	0.0000	0.0000
0.1	0.15	0.0063	0.0000	0.0000
0.2	0.15	0.0125	0.0000	0.0007
0.3	0.15	0.0188	0.0000	0.0033
0.4	0.15	0.0250	0.0000	0.0109
0.5	0.15	0.0313	0.0000	0.0246

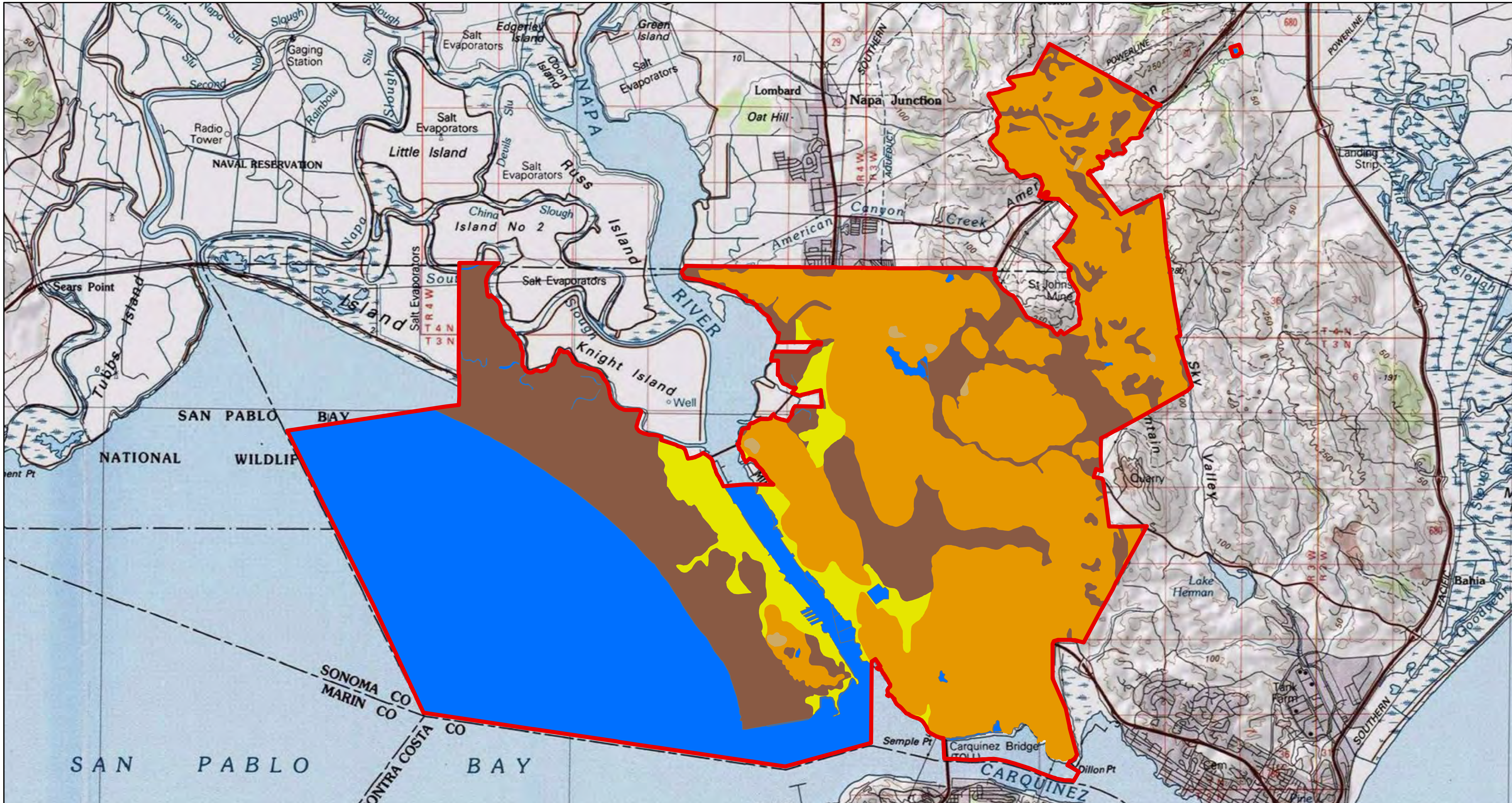
Depth (ft)	Area (acres)	Volume (acre-ft)	QPerc (cfs)	QOver (cfs)
0.6	0.15	0.0375	0.0000	0.0268
0.7	0.15	0.0438	0.0000	0.0290
0.8	0.15	0.0500	0.0000	0.0312
0.9	0.15	0.0563	0.0000	0.0330
1	0.15	0.0625	0.0000	0.0348
1.1	0.15	0.0688	0.0000	0.0366
1.2	0.15	0.0750	0.0000	0.0381
1.3	0.15	0.0813	0.0000	0.0395
1.4	0.15	0.0875	0.0000	0.0410
1.5	0.15	0.0938	0.0000	0.0424

Table E-14. FTABLES for a non-infiltrating BMP with 0.2Q2 low-flow discharge, D-Soils, and a footprint area of 0.085 acres

Depth (ft)	Area (acres)	Volume (acre-ft)	QPerc (cfs)	QOver (cfs)
UPPER LAYER (PONDING AND MEDIA)				
0	0.085	0.0000	0.0000	0.0000
0.1	0.085	0.0034	0.0000	0.0000
0.2	0.085	0.0068	0.0000	0.0000
0.3	0.085	0.0102	0.0000	0.0000
0.4	0.085	0.0136	0.0000	0.0000
0.5	0.085	0.0170	0.0000	0.0000
0.6	0.085	0.0204	0.0000	0.0000
0.7	0.085	0.0238	0.0000	0.0000
0.8	0.085	0.0272	0.0001	0.0000
0.9	0.085	0.0306	0.0004	0.0000
1	0.085	0.0340	0.0008	0.0000
1.1	0.085	0.0374	0.0017	0.0000
1.2	0.085	0.0408	0.0035	0.0000
1.3	0.085	0.0442	0.0072	0.0000
1.4	0.085	0.0476	0.0158	0.0000
1.5	0.085	0.0510	0.0848	0.0000
1.6	0.085	0.0595	0.0848	0.0000
1.7	0.085	0.0680	0.0848	0.0000
1.8	0.085	0.0765	0.0848	0.0000
1.9	0.085	0.0850	0.0848	0.0000
2	0.085	0.0935	0.0848	0.0000
2.1	0.085	0.1020	0.0848	0.0000
2.2	0.085	0.1105	0.0848	0.0000
2.3	0.085	0.1190	0.0848	0.0000

Depth (ft)	Area (acres)	Volume (acre-ft)	QPerc (cfs)	QOver (cfs)
2.4	0.085	0.1275	0.0848	0.2060
2.5	0.085	0.1360	0.0848	0.7930
2.6	0.085	0.1445	0.0848	1.4320
2.7	0.085	0.1530	0.0848	1.8903
2.8	0.085	0.1615	0.0848	2.1733
2.9	0.085	0.1700	0.0848	2.4524
3	0.085	0.1785	0.0848	2.6677
LOWER LAYER (GRAVEL)				
0	0.085	0.0000	0.0000	0.0000
0.1	0.085	0.0035	0.0000	0.0000
0.2	0.085	0.0071	0.0000	0.0014
0.3	0.085	0.0106	0.0000	0.0065
0.4	0.085	0.0142	0.0000	0.0217
0.5	0.085	0.0177	0.0000	0.0493
0.6	0.085	0.0213	0.0000	0.0536
0.7	0.085	0.0248	0.0000	0.0580
0.8	0.085	0.0283	0.0000	0.0623
0.9	0.085	0.0319	0.0000	0.0660
1	0.085	0.0354	0.0000	0.0696
1.1	0.085	0.0390	0.0000	0.0732
1.2	0.085	0.0425	0.0000	0.0761
1.3	0.085	0.0460	0.0000	0.0790
1.4	0.085	0.0496	0.0000	0.0819
1.5	0.085	0.0531	0.0000	0.0848

FIGURES



Legend

Hydrologic Soil Group or Classification

- HMP Boundary
- Borrow Pits
- C
- D
- Made Land
- Water

0 1.25 2.5 3.75 Miles

N

Soils Map

Vallejo HMP

Geosyntec consultants

WW1538	April 2013	Figure E-1

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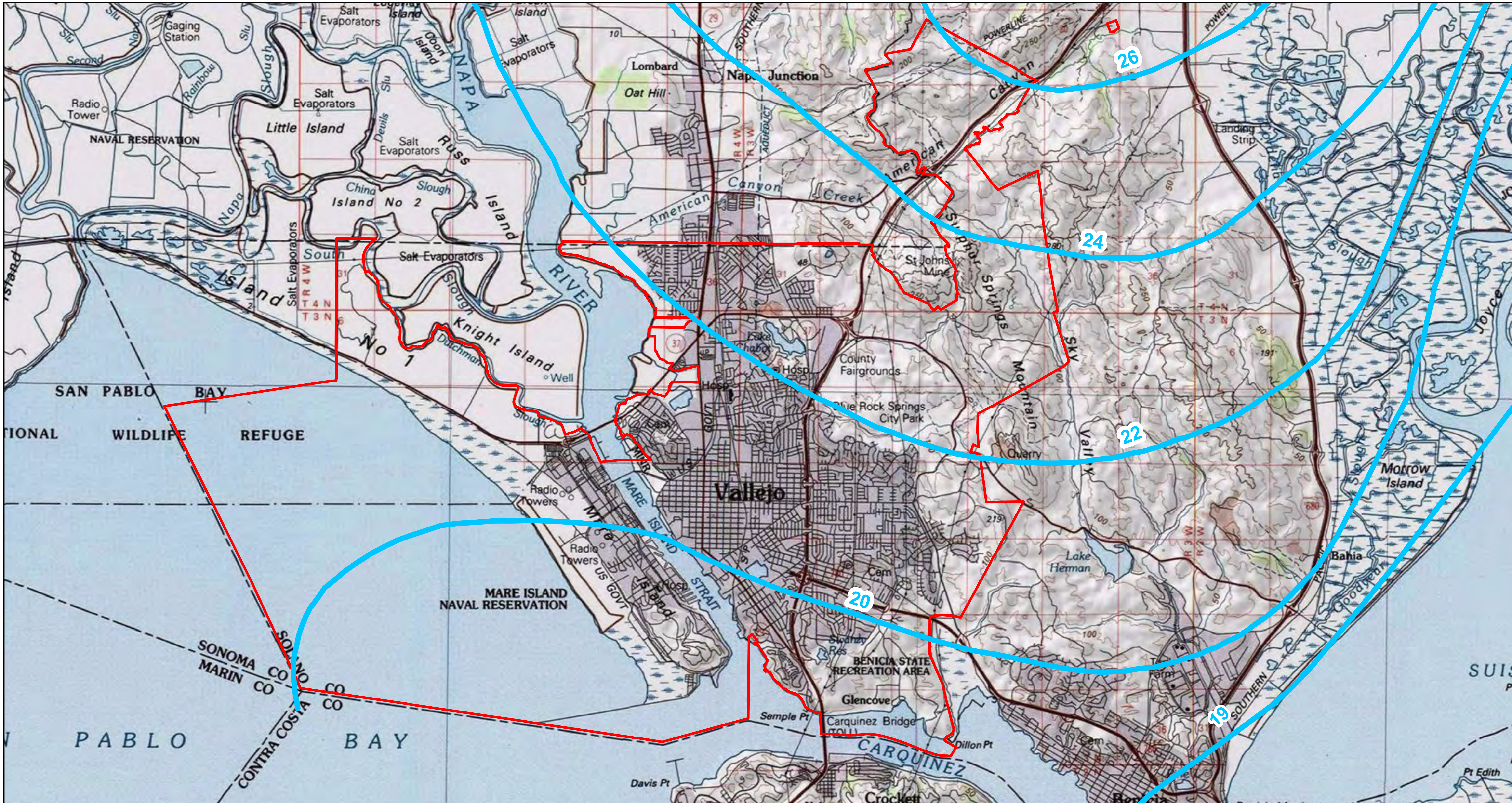

Legend

- Isohyetal Lines
- HMP Boundary

Note: Isohyetal lines from 1999 Solano County Design Rainfall Study
by West Yost & Associates

0 1.25 2.5 3.75 Miles

N

Isohyetal Map

Vallejo HMP

Geosyntec consultants

WW1538	April 2013	Figure E-2

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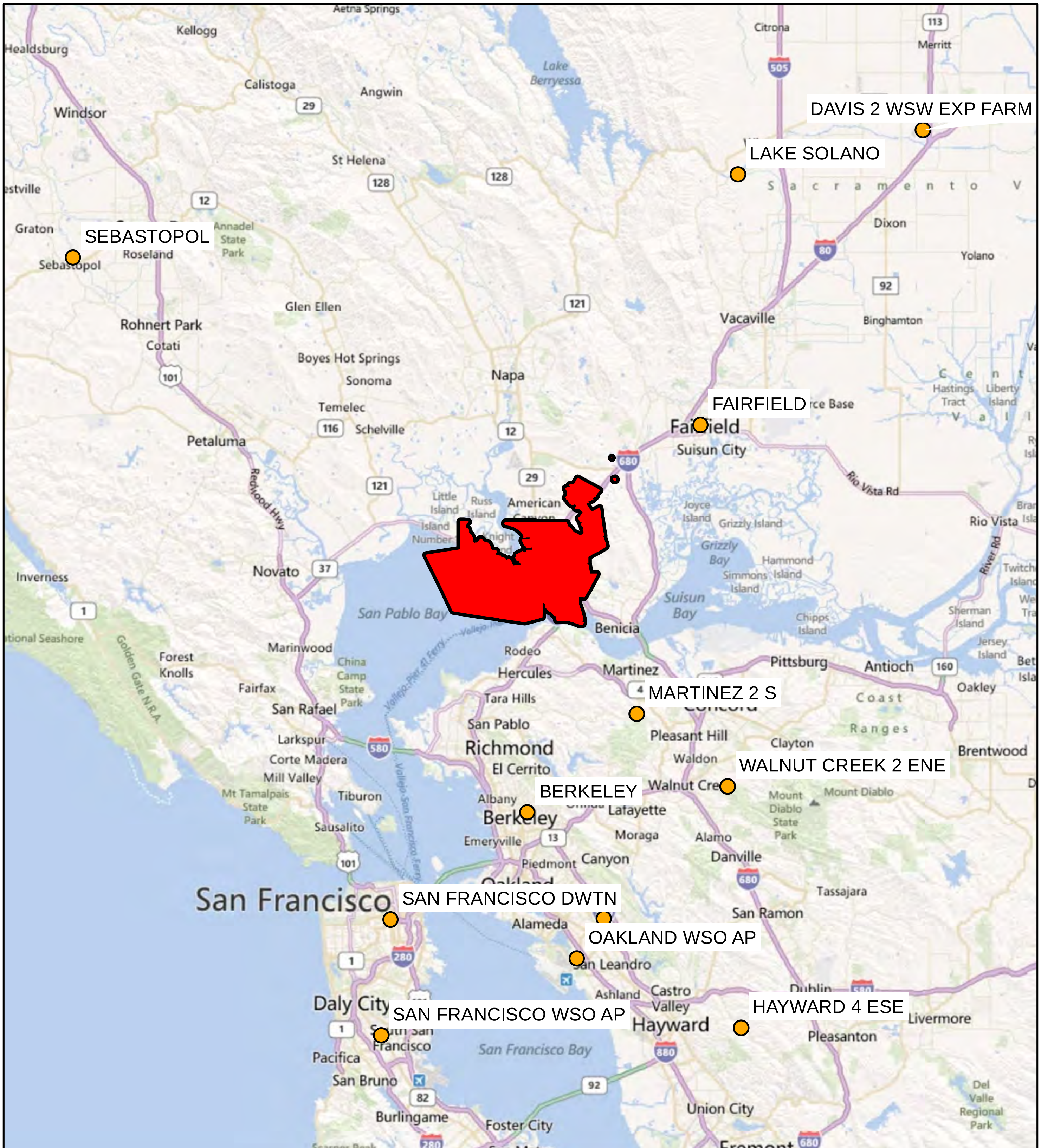

Legend

Hourly Precipitation Gages

Project Location

Note: Basemap from Bing maps

N

0 9 18 27 Miles

Precipitation Gage Locations

Vallejo HMP

Geosyntec consultants

WW1538	April 2013

Figure

E-3

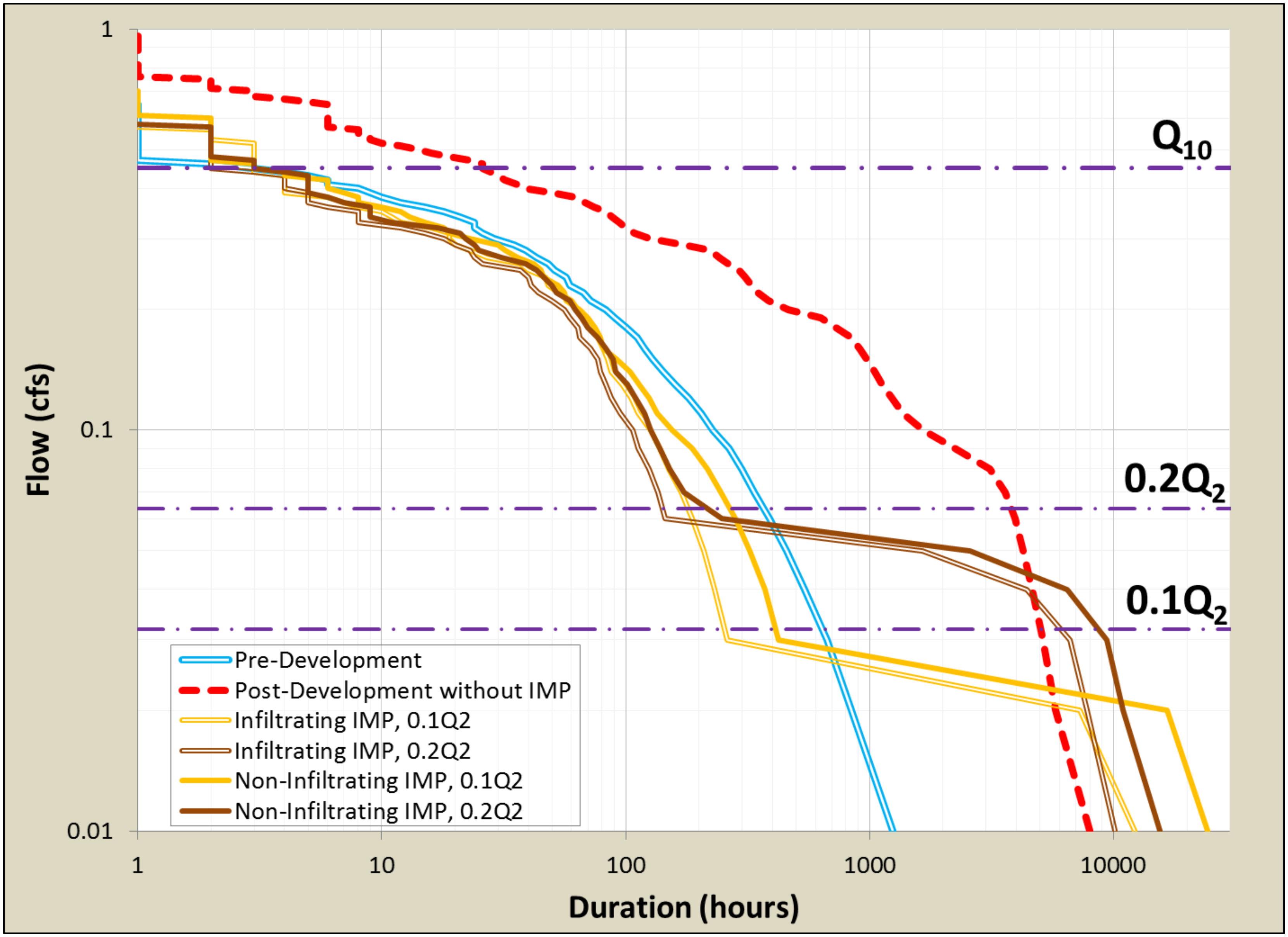

Figure E-4. Flow Duration Curve Results for C-Soils

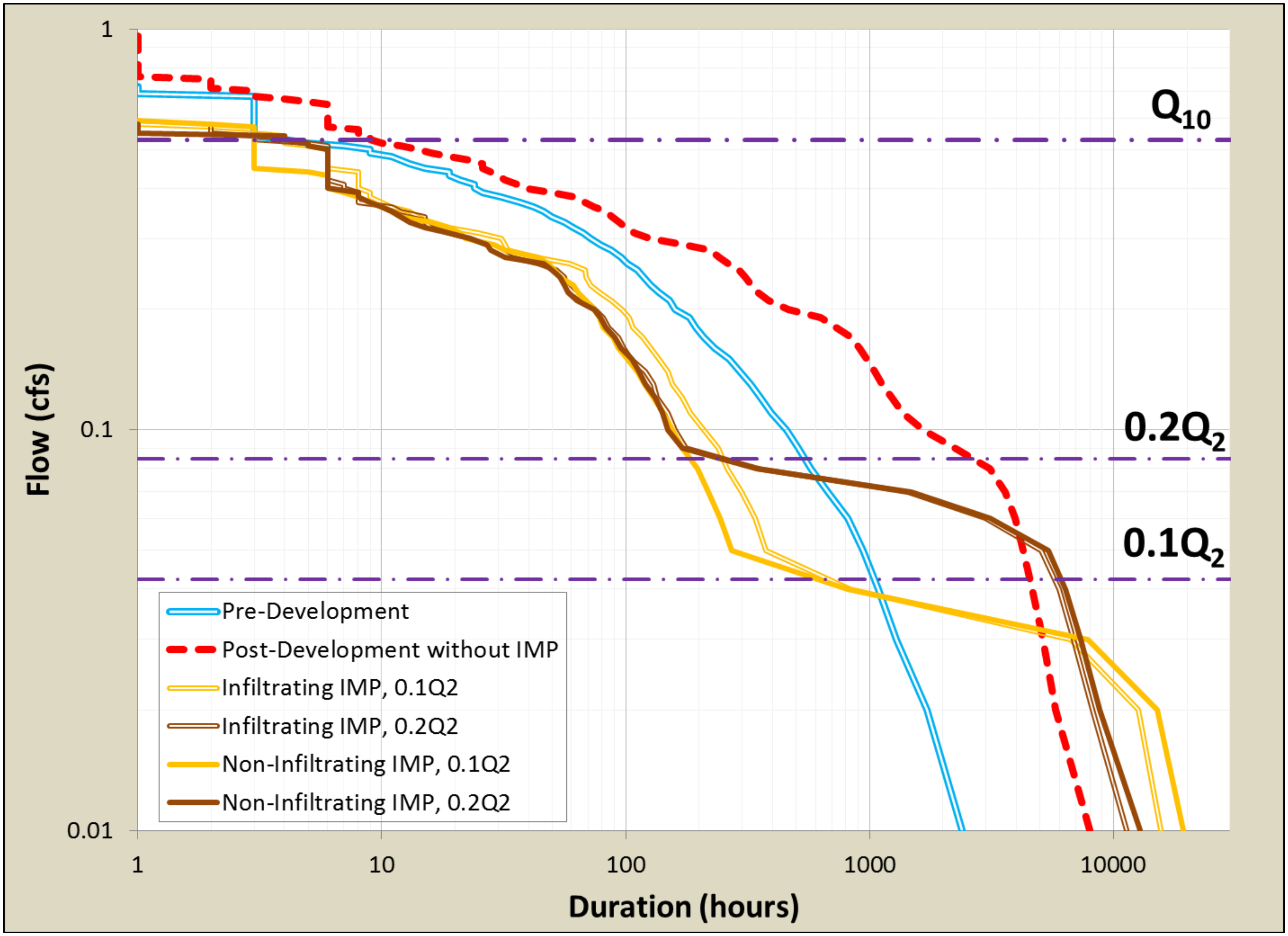

Figure E-5. Flow Duration Curves for D-Soils