Prepared for

Ventura Countywide Stormwater Quality Management Program

Represented by

Ventura County Watershed Protection District
800 South Victoria Avenue
Ventura, CA 93009

PRELIMINARY DRAFT

Ventura County Hydromodification Control Plan (HCP)

Prepared by

Geosyntec consultants

engineers | scientists | innovators

1111 Broadway, 6th Floor
Oakland, California 94607

WW1717

July 2013

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

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 flow 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, channel 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, loss of agricultural resources, monetary losses, and disruption 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 Ventura County Permittees[1] have developed this Hydromodification Control Plan (HCP) with the objective of minimizing hydromodification impacts associated with applicable future new development and redevelopment in Ventura County. This objective will be achieved through complying, in a cost effective manner, with the Hydromodification Control (HC) Criteria stipulated in the Ventura County municipal separate storm sewer system (MS4) Permit (Order No. R4-2010-0108) as outlined in this HCP.

1.2 Regulatory Background

Subpart 4.E.III.3 of Order No. R4-2010-0108, provided in Appendix A of this HCP, contains Hydromodification Control Criteria applicable to new development and redevelopment projects in Ventura County and requires the Permittees to develop and

[1] The MS4 Permittees include the Ventura County Watershed Protection District, the County of Ventura and the cities of Camarillo, Fillmore, Moorpark, Ojai, Oxnard, Port Hueneme, San Buenaventura (Ventura), Santa Paula, Simi Valley and Thousand Oaks.

implement watershed specific Hydromodification Control Plans (HCPs) for the Ventura River, Santa Clara River, Calleguas Creek, Malibu Creek, and Miscellaneous Ventura Coastal watersheds. As described in Subpart 4.E.III.3(a), the purpose of hydromodification controls is "to prevent accelerated downstream erosion and to protect stream habitat in natural drainage systems." (LARWQCB, 2010).

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

1.3 Hydromodification Control vs. Flood Control

Flood control and hydromodification control are inherently different in their objectives as well as methods of analysis. The objective of flood control is to prevent flood inundation and scour of property from high magnitude and rare storm events (e.g., the 100-year event). The objective of hydromodification management is to prevent excessive long-term erosion and deposition in natural channels for a range of channel flows that are typically much lower than flood design flow rates (e.g., from 10% of the 2-year storm to the 10-year storm event).

While hydrologic analyses for flood control, such as those contained in the Ventura County Hydrology Manual (VCWPD, 2010), are based on evaluating the magnitude of one or a few large discrete events (on the order of hours to days), hydromodification analysis focuses on continuous simulations (spanning over several decades) which take into account both flow magnitude and duration. Because hydromodification analysis looks at both magnitude and duration of the long-term record, the large but rare events that are crucial to flood control can be relatively insignificant when considering sediment transport and changes in channel form. In fact, geomorphic research has found that for most stream channels, the most important range of flows from the perspective of affecting channel form are the relatively frequent flows that are contained primarily within the active channel and not the rare, high magnitude flows which exceed the rate of flow that can be contained in the normally wetter perimeter of the channel.

Flows which create high enough shear stresses to initiate sediment transport within the channel and which occur frequently enough to have influence over long-term stream morphology are considered "geomorphically-significant" flows. To provide perspective on the timescales of interest, a peak storm event may result in a bed scour hole, which slowly fills in with sediment over days to months after the event takes place. But if the time scale considered for stream stability is on the order of several decades, then that scour hole may be a negligible perturbation on the overall record of channel form.

1.4 Organization of HCP Report

This report fulfills the HCP criteria stipulated in Subpart 4.E.III.3(a)(4) of the MS4 Permit and is organized to serve as a guide for preparation of site-specific HCPs by project proponents. This report is organized into the following seven chapters. A list of the HCP conditions that are satisfied by each chapter is provided in Table 1-1.

Chapter 1: Introduction

This chapter provides information about hydromodification, the objective of the HCP, and information about permit requirements.

Chapter 2: Physical Setting

This chapter qualitatively describes the physical setting for the five major watersheds in Ventura County. Discussion of each watershed includes a description of the location and HCP boundary, watershed characteristics, geology, climate, land cover, anticipated future development, and susceptibility of receiving waters.

Chapter 3: Applicability

Chapter 3 describes the projects for which the Hydromodification Management Standard applies and where it is exempt.

Chapter 4: Hydromodification Management Standard

Chapter 4 defines the Hydromodification Management Standard and describes implementation methods (onsite, regional, and in-stream controls) that may be used to meet the HM Performance Standard, as required by the MS4 Permit.

Chapter 5: Hydromodification Control BMPs

Chapter 5 describes the selection and types of BMPs that can be used to meet the Hydromodification Management Standard.

Chapter 6: Sizing Guidance

Chapter 6 provides guidance on how to size Hydromodification Control BMPs to meet the Hydromodification Management Standard.

Chapter 7: Monitoring and Effectiveness Assessment

Chapter 7 contains recommended general guidance on post-construction monitoring to evaluate the performance and effectiveness of Hydromodification Control BMPs.

Table 1-1. List of HCP Conditions Satisfied by Chapter

HCP Chapter	MS4 Permit Condition Satisfied
1. Introduction	
2. Physical Setting	(A)(i)(I) Stream Classifications
3. Applicability	(B)(ii) Hydromodification Management Control Areas (B)(iii) Projects Subject to the HCP
4. Hydromodification Management Standard	(A)(i)(II) Flow Rate and Duration Control Methods (A)(i)(III) Sub-Watershed Mitigation Strategies (B)(i) Hydromodification Management Standards (B)(vi) Range of Flows to Control and Goodness of Fit Criteria
5. Hydromodification Control BMPs	(A)(i)(IV) Stream Restoration Measures (B)(iv) Authorized BMPs
6. Sizing Guidance	(B)(v) BMP Design Criteria. (B)(vii) Allowable Low Critical Flow (B)(viii) Description of the Approved Hydromodification Model (B)(ix) Alternate Hydromodification Model and Design (B)(x) Stream Restoration Measures Design Criteria
7. Monitoring and Effectiveness	(B)(xi) Monitoring and Effectiveness Assessment (B)(xii) Record Keeping

2. PHYSICAL SETTING

Ventura County is located along the central coast of California, northwest of Los Angeles County, East of Santa Barbara County, and South of Kern County (Figure 2-1). The HCP boundary (Ventura County Line) includes ten cities as well as unincorporated urban areas. The ten cities include:

- Camarillo
- Fillmore
- Moorpark
- Ojai
- Oxnard
- Port Hueneme
- San Buenaventura (Ventura)
- Santa Paula
- Simi Valley
- Thousand Oaks

The HCP boundary is where new and redevelopment is anticipated to occur within Ventura County. Development is planned to occur within the existing urban areas which are designated using the City Urban Restriction Boundaries (CURB) and, in the case of unincorporated Ventura County, the Unincorporated Urban Centers. These boundaries are provided in Figure 2-2.

The major watersheds within Ventura County, per the MS4 Permit, include the Ventura River Watershed, Santa Clara River Watershed, Calleguas Creek Watershed, Malibu Creek Watershed, and Miscellaneous Ventura Coastal Watershed (Figure 2-1). This chapter provides a description of the watershed characteristics, geology, climate, land cover, and susceptibility of receiving waters to hydromodification in each of these major watersheds. The purpose of the HCP is to protect the susceptible rivers and tributaries in these watersheds from hydromodification impacts.

2.1 <u>General Physical Attributes</u>

For each of the five major watersheds in Ventura County, Sections 2.2 to 2.6 describe watershed characteristics, geology, climate, land cover, and susceptibility of receiving waters to hydromodification impacts. The data used to characterize each of these physical attributes are described below.

2.1.1 Watershed Characteristics

Watershed characteristics summarized in Sections 2.2 to 2.6 include the total watershed area, watershed area within Ventura County, range of ground elevations, general flow direction, and outlet location. These watershed characteristics are based on catchment delineations provided by the County, watershed delineations in the National Hydrography Dataset (NHD), and USGS topographic maps. A watershed and vicinity map is provided in Figure 2-1.

2.1.2 Geology

Geologic characteristics summarized in Section 2.2 to 2.6 include predominant geologic units, per the regional geology map in Figure 2-3 (USGS, 2000), and soil type, per the soils map provided in Figure 2-4. A breakdown of soil type within each major watershed is provided in Table 2-1. The soils map illustrates the distribution of soil textures within the southern portions of the County[2] using the seven hydrologically homogeneous families in the Ventura County Hydrology Manual (VCWPD, 2010), which is based on NRCS Hydrologic soil groups (HSG). HSG classifications range from A to D, with Group A representing the most infiltrative soils and Group D representing the least infiltrative soils (for further information, see http:soils.usda.gov/).

- Group A soils are typically sands, loamy sands, or sandy loams. Group A soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep and well to excessively drained sands or gravels and have a high rate of water transmission. Ventura County soil numbers 6 and 7 are Group A soils.

- Group B soils are typically silty loams or loams. They have a moderate infiltration rate when thoroughly wetted and consist chiefly of moderately deep to deep and moderately well to well drained soils with moderately fine to moderately coarse texture. Ventura County soil numbers 4 and 5 are Group B soils.

[2] The northern part of the County is comprised of Los Padres National Forest protected open space and is not included in this HCP.

- Group C soils are typically sandy clay loams. They have low infiltration rates when thoroughly wetted, consist chiefly of soils with a layer that impedes downward movement of water, and/or have moderately fine to fine soil structure. Ventura County soil numbers 2 and 3 are Group C soils.

- Group D soils are typically clay loams, silty clay loams, sandy clays, silty clays, or clays. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with high swelling potential, permanent high water table, claypan or clay layer at or near the surface, and/or shallow soils over nearly impervious material. Ventura County soil number 1 is a Group D soil.

2.1.3 Climate

Climate characteristics summarized in Sections 2.2 to 2.6 include the range of mean annual precipitation based on Figure 2-5 (NRCS, 1998). Ventura County has a Mediterranean climate, typical of most coastal Southern California cities, with warm summers and cool winters and a rainy season between November and March.

2.1.4 Land Cover

Land cover characteristics summarized in Sections 2.2 to 2.6 include natural vegetative cover, per the National Land Cover Dataset (MRLC, 2011) provided on Figure 2-6, and existing land use information provided on Figures 2-7 through 2-11 for each of the five major watersheds. The natural vegetative cover throughout the County is primarily shrub/scrub and herbaceous grasslands. Evergreen forests are present in the higher elevation regions in the mountains, and woody wetlands are present along riparian corridors (Figure 2-6). Table 2-2 provides a breakdown of existing land uses that are within the County for each watershed and Table 2-3 provides a breakdown of existing impervious cover for the same area (County of Ventura, 2011). Appendix B of this HCP describes the land use categories and relates land uses to percent impervious cover.

2.1.5 Susceptibility of Receiving Waters

The susceptibility of receiving waters to hydromodification impacts is summarized in Section 2.2 to 2.6 by identifying non-susceptible receiving waters and describing the location of modified conveyance systems. Water bodies within and downstream of each Permittee's jurisdiction have been mapped as either susceptible or non-susceptible to hydromodification impacts. Per the MS4 Permit, non-susceptible water bodies include: lakes, sumps, tidally influenced water bodies, large rivers, and modified conveyances.

Water bodies that are considered susceptible to hydromodification impacts are the remaining natural stream channels. The Receiving Water Susceptibility Map (Susceptibility Map) is provided in Figure 2-12. This map is considered a living document that will be updated by the Permittees if more accurate information on drainage infrastructure is obtained in the future. The methodology used to map each type of non-susceptible receiving water is described in a technical memorandum provided in Appendix C of this HCP.

2.2 Ventura River Watershed

2.2.1 Watershed Characteristics

The Ventura River Watershed is the westernmost major watershed in Ventura County (Figure 2-1). The watershed has a land area of approximately 226 square miles, 221 of which is located within the County. Elevations range from sea level to 5,938 feet above sea level at the highest peak. Topographically, the watershed drains to the south to the mouth of the Ventura River at the Pacific Ocean located in the northwest of the City of Ventura. All of Ojai, the northwestern portion of Ventura, and multiple unincorporated urban infill communities are located within the Ventura River Watershed.

2.2.2 Geology

Most of the urban centers in the Ventura River Watershed are underlain by alluvium that was deposited during the Pliocene and Holocene epochs (Figure 2-3). Outside of the developed areas, sandstone and mudstone are the dominant rock type.

Soils in the Ventura River Watershed primarily consist of Group C soils, with a few large pockets of Group B and D soils (Figure 2-4). B soils are distributed mostly around the main branch of the Ventura River and other small drainages. Small patches of Group A soil are also present, in the hills east of the Ventura River. See Table 2-1 for a quantitative summary of each NRCS soil type and Ventura County Soil Number.

2.2.3 Climate

In the Ventura River Watershed, average annual precipitation ranges from as little as 14 inches along the coast to as much as 36 inches per year around the higher elevations. Most of the existing urbanized areas fall within the 14 to 24 inches per year range (Figure 2-5).

2.2.4 Land Cover

The Ventura River Watershed within the County is mostly undeveloped land (54 percent), about another one-third is agriculture and mining, and about 12 percent is urban development (Figure 2-7, Table 2-2). Approximately 5 percent of the watershed area within the County is covered by impervious surfaces (Table 2-3).

2.2.5 Susceptibility of Receiving Waters

Non-Susceptible receiving waters in the Ventura River Watershed include Lake Casitas, Matilija Reservoir, the main branch of the Ventura River, and multiple modified creeks, streams and conveyances. The majority of the modified conveyances are located in the City of Ojai, major developments in County urban infill areas, and the northwest portion of the City of Ventura (Figure 2-12).

2.3 Santa Clara River Watershed

2.3.1 Watershed Characteristics

The Santa Clara River Watershed is the largest of the major watersheds in Ventura County and covers most of the north and eastern regions of the County (Figure 2-1). The watershed has a land area of approximately 1,622 square miles, of which, 838 square miles are in Ventura County. Elevations range from sea level to 8,831 feet above sea level at the highest peak, Mt. Piños. Topographically, the watershed drains to the south and the west to the mouth of the Santa Clara River at the Pacific Ocean located in the southern end of the City of Ventura shoreline. All of Fillmore and Santa Paula, the southeastern portion of Ventura, the northern portion of Oxnard, and multiple unincorporated urban infill communities are located within Santa Clara River Watershed.

2.3.2 Geology

The majority of urban centers in the Santa Clara River Watershed within Ventura County are underlain by alluvium that was deposited during the Pliocene and Holocene epochs, with small patches of sandstone bedrock around the borders of the cities and unincorporated infill areas (Figure 2-3). Outside of the developed areas, sandstone and mudstone are the dominant rock type with pockets of gneiss and grandiorite in the mountains to the north.

Soils in the Santa Clara River Watershed within the southern portion of the County consist of about one-half A and B soils and one-half C and D soils (Figure 2-4 and Table 2-1). The northern part of the County is protected open space and thus is not included in this soil description. The river valleys and flood plains consist primarily of B soils with pockets of A soils. Most of the C and D soils are located in the higher elevations in the headwaters of the watershed.

2.3.3 Climate

In the Santa Clara River Watershed, average annual precipitation ranges from as little as 12 inches along the coast to as much as 32 inches per year around the higher elevations. Most of the urbanized areas within the watershed fall within the 14 to 20 inches per year range (Figure 2-5).

2.3.4 Land Cover

Most of the Santa Clara River Watershed within Ventura County is undeveloped land (65 percent), 28 percent of the land is zoned for agriculture and mining and the remaining 7 percent is developed (Figure 2-8, Table 2-2). Approximately 3 percent of the land area of the watershed within the County is covered by impervious surfaces (Table 2-3).

2.3.5 Susceptibility of Receiving Waters

Non-Susceptible receiving waters in the Santa Clara River Watershed include Lake Piru, the main branch of the Santa Clara River, Santa Paula Creek, Sespe Creek, Ventura Harbor, and multiple modified creeks, streams and conveyances (Figure 2-12). The majority of the modified conveyances are associated with agricultural drainages along the Santa Clara Valley floor, as well as a number of modified channels and underground pipes in the Cities of Ventura, Oxnard, Santa Paula, and Fillmore.

2.4 Calleguas Creek Watershed

2.4.1 Watershed Characteristics

The Calleguas Creek Watershed spans the southeastern portion of Ventura County (Figure 2-1). The watershed has a land area of approximately 340 square miles, 336 of which are within the County. Elevations range from sea level to 3,734 feet above sea level at the highest peak located at Oak Mountain. Topographically, the watershed drains to the south and the west to the mouth of the Calleguas Creek at the Pacific Ocean, approximately 3.7 miles southeast of Oxnard. All of Moorpark and Camarillo, the majority of Thousand Oaks and Simi Valley, portions of Oxnard, and multiple unincorporated urban infill communities are located within the Calleguas Creek Watershed.

2.4.2 Geology

The majority of the urban centers in the Calleguas Creek Watershed in Ventura County are underlain by alluvium that was deposited during the Pliocene and Holocene epochs (Figure 2-3). In addition, major parts of Simi Valley are underlain by mudstone and Thousand Oaks is underlain by large regions of mudstone and basalt. Outside of the developed areas, the bedrock is a mix of alluvium, sandstone, mudstone, and basalt.

Soils in the Calleguas Creek Watershed within the County primarily consist of C and D soils (Figure 2-4 and Table 2-1). There are large swaths of A and B soils under the core areas of Camarillo, Moorpark, and Simi Valley as well as the mountain drainages that are underlain by alluvium. The regions with mudstone and basalt bedrock have primarily C and D soils.

2.4.3 Climate

In the Calleguas Creek Watershed, average annual precipitation ranges from as little as 12 inches in the inland valley between Camarillo and Moorpark to as much as 20 inches per year around the higher elevations. Most of the urbanized areas fall within the 12 to 20 inches per year range (Figure 2-5).

2.4.4 Land Cover

Agriculture and mining constitutes half of the land use in the Calleguas Creek Watershed within the County, with the remainder of the land split among urban land uses and only three-percent as undeveloped open space (Figure 2-9, Table 2-2). Approximately 15 percent of Calleguas Creek Watershed is covered by impervious surfaces (Table 2-3).

2.4.5 Susceptibility of Receiving Waters

Non-Susceptible receiving waters in the Calleguas Creek Watershed include Lake Bard, Magu Lagoon, Calleguas Creek up through part of Arroyo Las Posas, and multiple modified creeks, streams and conveyances (Figure 2-12). A majority of the modified conveyances are associated with agricultural drainages along the Calleguas Creek Valley floor, as well as a number of modified channels and underground pipes in The Cities of Camarillo, Moorpark, Thousand Oaks, Simi Valley, Oxnard, and associated urban infill areas.

2.5 Malibu Creek Watershed

2.5.1 Watershed Characteristics

The Malibu Creek Watershed has the smallest area of the major watersheds in Ventura County (Figure 2-1). The watershed has a total land area of approximately 109 square miles, of which only 43 square miles are located in Ventura County. Elevations range from sea level to 3,111 feet above sea level at Sandstone Peak. Topographically, the watershed drains to the south and the east to the mouth of the Malibu Creek at the Pacific Ocean in the City of Malibu. Portions of Thousand Oaks and Simi Valley along with multiple unincorporated urban infill communities are located within Malibu Creek Watershed.

2.5.2 Geology

The portion of Malibu Creek Watershed in Ventura County is underlain by a mixture basalt, rhyolite, and alluvium in the west and sandstone in the east (Figure 2-3).

Soils in the Malibu Creek Watershed within the County primarily consist of C and D soils (Figure 2-4 and Table 2-1). There is a pocket of A and B soils in the region underlain by alluvium and there are small corridors of B soils in the creek valleys of the areas underlain by sandstone. The other headwater regions and areas underlain by basalt, rhyolite, and sandstone have primarily C and D soils.

2.5.3 Climate

In the Malibu Creek Watershed within the County, average annual precipitation ranges from as little as 14 inches along the coast to as much as 28 inches per year around the higher elevations. Most of the urbanized areas on average receive around 18 to 24 inches of rainfall per year (Figure 2-5).

2.5.4 Land Cover

Land use in the portion of Malibu Creek Watershed within Ventura County has 5 percent undeveloped open space, 13 percent agriculture and mining, and the remainder has urban development land uses split primarily between recreation, commercial, and residential (Figure 2-10, Table 2-2). Approximately 19 percent of the Malibu Creek Watershed within Ventura County is covered by impervious surfaces (Table 2-3).

2.5.5 Susceptibility of Receiving Waters

Non-Susceptible receiving waters in the Malibu Creek Watershed include Lake Sherwood, Westlake, Magu Lagoon, and multiple modified creeks, streams and conveyances (Figure 2-12). The majority of the modified conveyances is associated with Thousand Oaks and associated urban infill areas in the County.

2.6 Miscellaneous Ventura Coastal Watersheds

2.6.1 Watershed Characteristics

The miscellaneous Coastal Watersheds, shown on Figure 2-1, have a combined total land area of approximately 330 square miles, of which 130 square miles are located in Ventura County. Elevations range from sea level to 4,787 feet above sea level at Divide Peak. Topographically, the watersheds drain southwest to multiple creeks along the Ventura County Coastline that outlet to the Pacific Ocean. All of Port Hueneme, most of Oxnard, Central Ventura, and multiple unincorporated urban infill communities are located within the Coastal Watersheds.

2.6.2 Geology

The Coastal Watersheds in Ventura County are underlain by a mixture of basalt, rhyolite, sandstone, and alluvium (Figure 2-3). The coastal watersheds around Ventura, Oxnard, and Port Hueneme are primarily underlain by alluvium, while the watersheds northwest are primarily sandstone, and the watersheds to the south east are underlain by sandstone in the lower elevations and basalt and rhyolite in the higher elevations.

Soils along the Coastal Watersheds within the County consist primarily of C and D soils (Figure 2-4 and Table 2-1). There are swaths of B soils in the river valleys of some of the drainage areas.

2.6.3 Climate

Along the Coastal Watersheds within the County, average annual precipitation range from as little as 12 inches along the coastline to as much as 24 inches per year around the higher elevations. Most of the urban areas fall within the 12 to 18 inches per year range (Figure 2-5).

2.6.4 Land Cover

Land use in the Coastal Watersheds within the County consists of 36 percent agriculture and mining, 11 percent undeveloped open space, and the remainder is urban development (Figure 2-11, Table 2-2). Approximately 16 percent of the watersheds within the County are covered by impervious surfaces (Table 2-3).

2.6.5 Susceptibility of Receiving Waters

Non-Susceptible receiving waters in the Coastal Watersheds include Magu Lagoon, Channel Island Harbor, Edison Canal, McGrath Lake, Ventura Harbor, and multiple modified creeks, streams and conveyances (Figure 2-12). The majority of the modified conveyances are associated with agricultural drainages around Oxnard and Port Hueneme; a number of modified channels and underground pipes in the Cities of Ventura, Oxnard, Port Hueneme, and associated urban infill areas in the County; and engineered channels to protect the Pacific Coast Highway.

2.7 <u>Hydromodification Screening Tools</u>

The Ventura County Permittees have participated in the Southern California Storm Water Monitoring Coalition (SMC) Hydromodification Control Study (HCS). The SMC HCS work products have largely been general in nature and have not provided a specific numerical model that could be used to establish a performance standard. Nonetheless, elements of the SMC HCS work products are incorporated throughout this HCP, including the Southern California Coastal Water Research Project's (SCCWRP) Technical Reports 752 and 753 (Stein and Bledsoe, 2013a,b).

With regard to a stream classification system, SCCWRP has developed two screening tools, with the support of the SMC HCS, to evaluate the degree of potential hydromodification impacts for a given natural stream channel. SCCWRP's Technical Report 605, *GIS-Based Catchment Analyses of Potential Changes in Runoff and Sediment Discharge*, outlines a process for evaluating potential change to stream channels resulting from watershed-scale changes in runoff and sediment yield based on differentiating areas with common geology, hillslope, and land cover (SCCWRP, 2010a). SCCWRP Technical Report 606, *Field Manual for Assessing Channel Susceptibility*, describes an in-the-field assessment procedure that can be used to evaluate the relative susceptibility of channel reaches to deepening and widening based on observed channel conditions.

These reports can be downloaded at the following web addresses:

http://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/605_HydromodScreeningTools_GIS.pdf
http://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/606_HydromodScreeningTools_FieldManual.pdf

For the purposes of this HCP, the Susceptibility Map presented in Figure 2-12 was developed to determine the stream channels in Ventura County that are susceptible to hydromodification impacts, per the definition of susceptibility in the MS4 Permit. The methodology used to map each type of non-susceptible receiving water is described in a technical memorandum provided in Appendix C of this HCP. The SCCWRP tools in Technical Reports 605 and 606 can be used to further evaluate the degree of susceptibility for those natural channels mapped on Figure 2-12.

Table 2-1. Area of Ventura County Soil Number in each Major Watershed (Acres)

Ventura County Soil Number	Hydrologic Soil Group	Calleguas Creek	Coastal	Malibu Creek	Santa Clara River	Ventura River
1	D	81,235 (38%)	35,321 (46%)	16,337 (60%)	40,257 (24%)	16,399 (25%)
2	C	28,846 (13%)	16,781 (22%)	30 (0%)	662 (0%)	250 (0%)
3	C	44,772 (21%)	12,924 (17%)	7,587 (28%)	50,496 (31%)	34,993 (54%)
4	B	50,718 (24%)	10,405 (14%)	3,174 (12%)	56,355 (34%)	8,798 (14%)
5	B	2,929 (1%)	67 (0%)	30 (0%)	8,134 (5%)	1,709 (3%)
6	A	4,261 (2%)	490 (1%)	0 (0%)	6,698 (4%)	574 (1%)
7	A	2,358 (1%)	650 (1%)	207 (1%)	2,045 (1%)	2,427 (4%)
Total		215,120	76,638	27,365	164,647	65,149

Note: Does not include areas within the County that are in the National Forest or areas outside of the County.

Table 2-2. Area of Land Use in each Major Watershed within Ventura County (Acres)

Land Use	Calleguas Creek	Coastal	Malibu Creek	Santa Clara River	Ventura River
Agriculture & Mining (Resource Production)	106,999 (50%)	29,739 (36%)	3,498 (13%)	151,834 (28%)	47,517 (34%)
Undeveloped	6,685 (3%)	8,843 (11%)	1,435 (5%)	348,250 (65%)	75,946 (54%)
Commercial (Services & Trade)	17,987 (8%)	7,211 (9%)	5,474 (20%)	9,134 (2%)	3,223 (2%)
Industrial	3,952 (2%)	1,696 (2%)	49 (0%)	1,308 (0%)	380 (0%)
Recreation	20,277 (9%)	16,601 (20%)	9,944 (36%)	5,244 (1%)	192 (0%)
Residential	37,389 (17%)	10,276 (12%)	4,918 (18%)	9,050 (2%)	8,333 (6%)
Roads and Highways	11,563 (5%)	5,623 (7%)	754 (3%)	4,773 (1%)	2,332 (2%)
Transportation/ Communication/ Utility	4,491 (2%)	1,957 (2%)	80 (0%)	6,047 (1%)	2,873 (2%)
Not Indicated	5,803 (3%)	1,052 (1%)	1,221 (4%)	502 (0%)	430 (0%)
Total	215,145	82,997	27,372	536,143	141,224

Note: Does not include areas within each watershed that are outside of Ventura County; areas within the Los Padres National Forest are included. The existing land use breakdown is based on a parcel dataset provided by the County (County of Ventura, 2011) and shown on Figures 2-7 to 2-11. Appendix B of this HCP describes the land use categories.

Table 2-3. Existing Impervious Cover in Each Major Watershed within Ventura County

	Calleguas Creek	Coastal	Malibu Creek	Santa Clara River	Ventura River
Existing Impervious Cover (Acres)	31,732	12,998	5,167	14,560	7,119
Imperviousness (%)	15	16	19	3	5

Note: Does not include areas within each watershed that are outside of Ventura County; areas within the Los Padres National Forest are included. The existing impervious cover calculations are based on parcel data provided by Ventura County (County of Ventura, 2011), shown on Figures 2-7 to 2-11, and assumptions relating land use to typical imperviousness for Ventura County, provided in Appendix B of this HCP.

3. APPLICABILITY

3.1 Exemptions to the Hydromodification Management Standard

Section 1.5 of the Ventura County Technical Guidance Manual for Stormwater Quality Control Measures (TGM) defines new and redevelopment projects subject to Permittee conditioning and approval for the design and implementation of post-construction controls to mitigate stormwater pollution, prior to completion of the project(s) (VCSQMP, 2011). These "regulated" projects are subject to the Hydromodification Management Standard, stated in Chapter 4 of this HCP, and are considered Hydromodification Control Projects unless the project meets any one of the following exemptions:

- Projects that disturb less than one acre.
- Projects that are single-family structures which create, add, or replace less than 10,000 square feet of impervious surface area.
- Projects that are replacement, maintenance or repair of a Permittee's existing flood control facility, storm drain, or transportation network.
- Redevelopment projects in the Urban Core[3] that do not increase the effective impervious area or decrease the infiltration capacity of pervious areas compared to the pre-project conditions.
- Projects which have applications deemed complete for processing prior to the HCP Effective Date, or meet one of the other requirements per HCP Section 3.2.
- Projects located in an area that is exempt according to the Hydromodification Control Applicability Maps, per HCP Section 3.3, or as modified to reflect current knowledge.
- Projects that demonstrate, through an approved study conducted by a licensed engineer, that adverse hydromodification effects to present and future beneficial

[3] The Urban Core is defined as the existing urban areas which are designated using the City Urban Restriction Boundaries (CURB) and, in the case of unincorporated Ventura County, the Unincorporated Urban Centers. These boundaries are provided in Figure 2-2 and in Appendix B of the TGM.

uses of susceptible receiving waters are unlikely. This "negligible risk" category is described in Section 3.4.

3.2 HCP Effective Date

The Final Hydromodification Control Criteria contained in Subpart 4.E.III.3(a)(4) of the MS4 Permit shall become effective upon Executive Officer approval of this HCP (the "HCP Effective Date"). After the HCP Effective Date, all applicable projects, except those identified below, shall comply with Subpart 4.E.III.3(a)(4) of the MS4 Permit.

The Final Hydromodification Control Criteria contained in Subpart 4.E.III.3(a)(4) of the MS4 Permit shall not apply to the projects described in paragraphs 1 through 5 below. Projects meeting the criteria listed in paragraphs 1 through 5 below shall instead continue to comply with the Interim Hydromodification Control Criteria contained in Subpart 4.E.III.3(a)(3) of the MS4 Permit. If the requirements of Order R4-2010-0108 apply to the project, or with the performance criteria set forth in the 2002 Technical Guidance Manual for Stormwater Quality Control Measures under Board Order 00-108, then the requirements of Order R4-2010-0108 do not apply to the project, as outlined in Section 1.5 of the TGM.

1. Projects or phases of projects where the project's applications have been "deemed complete for processing" (or words of equivalent meaning), including projects with ministerial approval, by the applicable local permitting agency in accordance with the local permitting agency's applicable rules within 90 days after the HCP Effective Date; or
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), by the applicable local permitting agency in accordance with the local permitting agency's applicable rules, and thereafter during the term of such Development Agreement and/or Specific Plan unless earlier cancelled or terminated; or
3. All private projects in which, within 90 days after the HCP 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 local agency for public improvements upon the development of such private project; or

4. Local agency projects for which the governing body or their designee has approved initiation of the project design within 90 days after the HCP Effective Date; or
5. A Tentative Map or Vesting Tentative Map deemed complete or approved by the local permitting agency within 90 days after the HCP Effective Date, and subsequently a Revised Map is submitted, the project would be exempt from the HCP provisions if the revisions substantially conform to original map design, consistent with Subdivision Map Act requirements. Changes must also comply with local and state law.

The intent of these guidelines is to provide an opportunity for the communication and understanding of the requirements of the HCP, and ensure that projects for which the applicants have worked with local permitting agency staff to develop a final, or substantially final, drainage concept and site layout that includes controls based upon previous performance criteria prior to the MS4 Permit Effective Date and/or the HCP Effective Date, are not required to redesign their proposed projects for purposes of complying with the Final Hydromodification Control Criteria contained in Subpart 4.E.III.3(a)(4) of the MS4 Permit.

In addition, 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) that does not have a final or substantially final drainage concept as determined by the local permitting agency or a site layout that includes hydromodification controls must comply with the performance standards set forth in the HCP.

3.3 Applicability Maps

Hydromodification Control Applicability Maps (Applicability Maps) are provided in Figures 3-1 to 3-11 to map areas exempt to the Hydromodification Management Standard (Chapter 4) based on criteria in subparts 4.E.III.3.(a)(2)(D) and (E) of the MS4 Permit. These exemptions consider existing drainage infrastructure as follows:

(D) Projects that have any increased discharge go directly or via a storm drain to a sump, lake, area under tidal influence, into a waterway that has a 100-year

peak flow (Q100) of 25,000 cfs or more, or other receiving water that is not susceptible to Hydromodification impacts[4].

(E) *Projects that discharge directly or via a storm drain into concrete or improved (not natural) channels (e.g., rip rap, sackcrete, etc.), which, in turn, discharge into receiving water that is not susceptible to Hydromodification impacts (as in D above).*

While the purpose of the Susceptibility Map, provided in Figure 2-12, is to identify receiving waters in Ventura County that are considered "not susceptible to hydromodification impacts", the purpose of the Applicability Maps is to identify areas within the HCP jurisdictional boundary where the Hydromodification Management Standard applies and where it is exempt. Applicable and exempt areas are defined as follows:

- Applicable areas drain to one or more channels susceptible to hydromodification impacts (i.e., blue or red lines on the Susceptibility Maps or other unmapped natural streams) prior to entering a lake, sump, or the Pacific Ocean.

- Exempt areas drain directly or via a continuously non-susceptible flow path (i.e., green, purple, and yellow lines on the Susceptibility Maps) to a lake, sump, or the Pacific Ocean.

The Applicability maps are provided for illustrative purposes to assist project proponents in determining the applicability of hydromodification requirements to the project site. The determination of applicability is to be based on the requirements of the MS4 Permit, and will be made by the land development permitting agency. Both the Susceptibility Map and Applicability Maps are considered living documents that may be updated by the Permittees if more accurate information on drainage infrastructure is obtained in the future. The methodology used to create the maps is described in a technical memorandum provided in Appendix C of this HCP.

[4] A demonstration of negligible risk to hydromodification impacts, as described in Section 3.4, is consistent with an evaluation of "other receiving water that is not susceptible to hydromodification impacts".

3.4 Negligible Risk

The last exemption criteria is for projects located in an applicable area, per the Applicability Map, that discharge to receiving waters which have negligible risk of in-stream erosion and hydromodification impacts. Such receiving waters are considered non-susceptible for reasons other than they drain directly or via a tidally influenced waterway, large river (Q100 > 25,000 cfs), or continuously modified conveyance (i.e., green, purple, and yellow lines on the Susceptibility Maps) to a lake, sump, or the Pacific Ocean. The Applicability Maps and exemptions to the Hydromodification Management Standard, listed in Section 3.1, do not specifically consider the following negligible risk categories:

- Natural threshold channels with bed and banks consisting of bedrock, boulders, or other natural materials that have a critical threshold for erosive flow (Qc) greater than or equal to the pre-development 10-year peak flowrate (Q_{10}).
- Future project runoff diversions to receiving waters exempt from the Hydromodification Management Standard.
- Excessively aggrading channels which are consistently subject to the accumulation of sediments and which will not become erosive after project development.
- Future direct discharges to existing facilities (i.e., regional detention basins or in-stream controls) which can accommodate increases in runoff magnitude and duration from the project such that the Hydromodification Management Standard is met.
- Future additional impervious cover at the build out condition in watersheds tributary to susceptible receiving waters that are below the allowable threshold for cumulative hydromodification impact.
    - Hydromodification impacts are typically most severe just downstream of development and tend to decrease if more undeveloped watershed area contributes to the channel in the downstream direction. Analyses were performed to evaluate thresholds for additional impervious cover at buildout conditions, below which the risk of hydromodification impacts is considered negligible for a given susceptible channel. The following

thresholds are provided as a function of a channel's tributary area (A) and median grain size (D_{50}):

- If A $\geq$ 1 square mile and $D_{50} \leq$ 16 mm, then the threshold of additional imperviousness is evaluated using the nomograph in Figure 3-12. Results range from 0.46% to 1.00% additional imperviousness depending on watershed size and mean annual precipitation (MAP).
- If A < 1 square mile and $D_{50} \leq$ 16 mm, then the threshold of additional imperviousness is 0.44%.
- If $D_{50} \geq$ 16 mm, then the threshold of additional imperviousness is 1.65%.

The basis for these thresholds is provided in Appendix D of this HCP.

To demonstrate that the negligible risk criteria is met, the project applicant shall provide a report, signed by a licensed engineer, demonstrating that every susceptible receiving stream (i.e., natural channel) between the project site and a lake, sump, or the Pacific Ocean fall into one of the negligible risk categories.

4. HYDROMODIFICATION MANAGEMENT STANDARD

4.1 Management Standard

The Hydromodification Management Standard for Ventura County is as follows:

Hydromodification control BMPs shall be selected and applied to maintain the Erosion Potential[5] *(Ep) in-stream at a value of 1.0, unless an alternative value can be shown to be protective of the downstream natural drainage system from erosion, incision, and sedimentation. If the median grain size (D_{50}) of the receiving channel's bed sediment is greater than 8 mm, then an allowable alternative Ep value is*[6]*:*

$$Ep = 0.78 * D_{50}^{0.12}$$

This hydromodification management standard shall be achieved through onsite BMPs, regional BMPs, in-stream controls, or a combination thereof. Onsite BMPs 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 management standard and comply with this HCP. Regional BMPs that are designed to provide flow duration control to the pre-project condition, at the point where the Regional BMP discharges, meet the erosion potential management standard and comply with this HCP.

Goodness-of-Fit Criteria:

Flow duration controls shall be designed such that post-project stormwater discharge rates and durations match pre-project discharge rates and durations above 10 percent of the pre-project 2-year peak flow[7] *(or an alternative low flow discharge determined based on a stream-specific critical threshold analysis*[8]*) up to*

---

[5] Determination of Erosion Potential is outlined in Attachment E of the MS4 Permit (Order No. R4-2010-0108), which is provided in Appendix A of this HCP.

[6] This alternative Ep numeric control standard is based on the findings of Stein and Bledsoe (2013) in SCWWRP Technical Report 753. The equation provided is the logistic regression function for 25% risk of channel instability as shown in Figure 14b of SCCWRP Technical Report 753. A 25% probability of channel instability is acceptable because the logistic regression model of the 61 sites evaluated in Southern California, as shown on Figure 15 of SCCWRP Technical Report 753, indicates that an Ep of 1.0 relates to a 25% risk of channel instability.

[7] The basis for the default 10% Q_2 low-flow threshold is provided in Appendix E of this HCP.

[8] Guidance for performing a stream-specific critical threshold analysis is provided in Section 6.1.

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[9].

4.2 Methods to Meet the Management Standard

Hydromodification Control Projects shall use one or a combination of the following implementation methods to comply with the Hydromodification Management Standard.

4.2.1 Method 1 - Onsite Control

The current state of the practice for hydromodification management in California for new and redevelopment is to mimic pre-development hydrology on the project site. The theory is that if the pre-development distribution of in-stream flows is maintained, then the baseline capacity to transport sediment, a proxy for the geomorphic condition, will be maintained as well. A popular method of mimicking the pre-development flow regime is by maintaining the pre-development distribution of runoff, known as flow duration control (FDC). This can be done onsite by routing post-development runoff through structural stormwater BMPs such that runoff is stored and slowly released to match pre-development flow duration characteristics. Applying FDC to achieve the pre-project condition is considered to be fully protective of the existing condition of the channel segment to which the project discharges.

Flow duration matching does not require additional watershed or receiving channel 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 or bed mobilization 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 Section 6.1.

While theoretically FDC maintains the pre-project sediment transport capacity for the full distribution of erosive flows, in practice it is difficult to achieve a good match for

[9] The basis for the Q_{10} high-flow threshold is provided in Appendix E of this HCP.

the entire range of flows evaluated if typical onsite LID BMPs are used. This is because the outlet structure configuration of a typical LID BMP consists of a simple overflow weir and a low flow orifice (if needed). However, in order to get a good match of the flow duration curve with passive controls such as LID BMPs, a more complicated system of intermediate weirs and/or orifices is often required. As a result, LID BMPs sized for FDC can over-mitigate site runoff and the consequence can be larger BMPs than necessary. An example flow duration curve comparison showing such over-mitigation is provided in Figure 4-1.

To avoid this potential over-mitigation, one solution is to use Ep to design onsite distributed BMPs. Using such an approach would maintain a project's overall contribution of erosive work to its respective receiving channel, but would not attempt to directly match the distribution of flow durations. An Ep numeric design approach can take into account losses of bed sediment supply, but FDC cannot.

Design of stormwater BMPs for FDC or Ep control requires continuous long-term hydrologic modeling of the project site. If different portions of the project site discharge to different receiving channels downstream, then a separate hydrologic analysis is needed for each associated outlet and tributary area onsite.

Onsite hydromodification control can be demonstrated in any of the following ways:

- <u>Nomographs or Sizing Factors for LID BMPs</u>: Continuous hydrologic modeling can be used to develop a series of simplified sizing charts (nomographs) to standardize the sizing of specific types of onsite LID BMPs for hydromodification control. Nomographs allow project proponents to easily determine the necessary BMP storage volume and footprint area for FDC or Ep control as a function of: (1) BMP configuration; (2) proposed level of imperviousness tributary to the BMP; (3) onsite soil type or percolation rate; (4) the local continuous precipitation record; (5) vegetative cover; (6) terrain slope; (7) existing and build-out development conditions in the watershed; and (8) receiving channel conditions, which only applies to Ep control. Nomographs developed for Ep control require a scaling of flowrates generated from the modeled project catchment scale to the receiving stream watershed scale (e.g., multiply by the ratio of the pre-development Q_2). The sizing tool takes into account a reasonable range of design and environmental conditions for a specific receiving stream of concern and its tributary watershed. In addition, because the BMP footprint and storage volume are normalized on the nomograph as a percentage of the project catchment area and unit watershed depth, respectively, the BMPs can range in size. This flexibility allows a project proponent to strategically situate many small-scale distributed facilities or fewer larger facilities, up to a maximum allowable acreage, depending on site constraints. Potentially, simple rules-of-thumb for sizing structural hydromodification control BMPs can be substantiated by comparing a hydromodification control nomograph to a similar nomograph for stormwater quality control. One example of such a comparison is provided in Figure 4-2.

- California Hydrology Model (CAHM) for Ventura County: The California Hydrology Model - Hydro Modification Program (CAHM) is a regional hydrology model that has been created to size FDC BMPs for any California County, including Ventura County. CAHM uses a Hydrological Simulation Program – Fortran (HSPF) computational engine developed by USGS and USEPA, long-term precipitation data for each selected County, and is a visually-oriented interactive tool for automated modeling and facility sizing. Project proponents can use CAHM to size onsite hydromodification control BMPs to provide flow duration control, but not Ep control. CAHM, and regional models like it, have been adopted for use in Northern California (Alameda, San Mateo, Santa Clara, and Sacramento Counties) and Southern California (San Diego and South Orange Counties).

- System-Specific Flow Duration Control Analysis: Project proponents can perform a system-specific continuous hydrologic simulation analysis to design onsite hydromodification control BMPs 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), 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 Chapter 6. Although the nomographs and regional hydrology models (CAHM) provide a straightforward means for sizing hydromodification control BMPs, project applicants may prefer to conduct their own sizing analysis in order to: 1) best reflect specific hydrologic conditions at the project site; 2) use a type of BMP that is not included in the nomographs or CAHM; and/or 3) optimize a BMP design to reduce storage and footprint requirements.

- System-Specific Erosion Potential Analysis: Designing out-of-stream onsite controls using a system-specific Ep analysis involves a hydrologic and geomorphic evaluation of the receiving channel system downstream of the project. This method requires computing channel flows within a stream system and the work done on the channel 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. Typically, hydromodification impacts are most severe just downstream of development and they tend to decrease as more undeveloped area contributes to the channel in the downstream direction, thus diluting the impact of the project. Unless there is a more sensitive receiving channel downstream of the discharging outfall, the governing calculation point for sizing onsite BMPs will be the point of discharge to the nearest susceptible receiving channel. Because a system-specific Ep analysis is done at the watershed-scale, such an analysis for onsite controls shall account for future buildout conditions in the watershed. Thus, a system-specific Ep analysis for onsite BMPs is most feasible: (1) for projects that make up a significant proportion of the watershed's buildout condition, or (2) where a watershed-scale continuous hydrologic model has been developed for the purpose of comprehensive land planning or other purposes. A system-specific Ep analysis for onsite BMPs is not practical for individual projects that are small relative to the buildout condition. Sizing guidance for hydromodification control BMPs using the Ep methodology is also provided in Chapter 6.

4.2.2 Method 2 – Regional Control

Off-site regional hydromodification controls may be implemented in lieu of, or in combination with, onsite controls, where an approved plan, including an appropriate funding mechanism, is in place that accounts for the stream channel changes expected to result from changes in the project's runoff conditions. The regional controls (or combination of controls) shall be designed to achieve the hydromodification management standard objective threshold of Ep = 1.0, or an alternative value shown to be protective, at the point of discharge to the susceptible receiving water.to as far downstream as potential impacts could occur[10]. Typically, hydromodification impacts

---

[10] A demonstration of negligible risk to hydromodification impacts, as described in Section 3.4, is one way to evaluate the extent of potential impacts. Guidance on the extent of downstream monitoring provided by Stein and Bledsoe (2013a) in SCCWRP Technical Report 752 can also be used to evaluate the extent of potential impact for regional control. This criteria includes: (1) at least one reach downstream of the first grade-control point (but preferably the second downstream grade-control

are most severe just downstream of development and they tend to decrease as more undeveloped area contributes to the channel in the downstream direction, thus diluting the impact. Unless there is a more sensitive receiving channel downstream of the discharging outfall, the governing calculation point for sizing regional BMPs will be the point of discharge to the nearest susceptible receiving channel. Regional controls that are designed to provide FDC to the pre-project condition, at the point where the regional control discharges, meet the erosion potential performance standard and comply with this HCP.

When a combination of onsite and off-site out-of-stream BMPs are proposed for hydromodification control, applying FDC to achieve the pre-project condition is considered to be fully protective of the existing condition of the channel segment to which the project discharges. Flow duration matching for regional BMPs can be implemented similarly as for onsite controls, except the point of compliance is where the regional BMP discharges instead of at the project outlet. Existing detention facilities may be modified for FDC or Ep control. Also, regional controls can allow multiple projects to meet the Hydromodification Management Standard with one mitigation facility and can be designed to mitigate existing development if desired. Regional hydromodification control can be demonstrated in any of the following ways:

- California Hydrology Model (CAHM) for Ventura County: Project proponents can use CAHM to size regional hydromodification control BMPs to provide flow duration control.
- System-Specific Flow Duration Control Analysis: Project proponents can perform a system-specific continuous hydrologic simulation analysis to design regional hydromodification controls that provide flow duration control to the pre-project condition at the point of compliance. Sizing guidance for flow duration control facilities using a system-specific continuous simulation is provided in Chapter 6.
- System-Specific Erosion Potential Analysis: Project proponents can perform a system-specific continuous hydrologic simulation analysis and geomorphic evaluation of the creek system downstream of the project to size out-of-stream regional hydromodification controls that provide Ep control to the pre-project

location); (2) tidal backwater/lentic waterbody; (3) equal order tributary; or (4) a two-fold increase in drainage area.

condition. Sizing guidance for hydromodification control BMPs using the Ep methodology is provided in Chapter 6.

4.2.3 Method 3 – In-Stream Control

In-stream hydromodification control, or stream restoration/rehabilitation measures, may be implemented to address potential project impacts in lieu of or in combination with onsite and regional hydromodification 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 modified channel). The in-stream measures (or combination of controls) shall be designed to achieve the hydromodification management standard threshold of Ep = 1.0, or an alternative value shown to be protective, from the point of discharge to the stream to as far downstream as potential impacts would occur.

When a combination of out-of-stream and in-stream BMPs is proposed for hydromodification control, the amount of increase in erosive work done on the channel from the site's discharge (i.e., after the application of any onsite and off-site measures) is used to design the in-stream measures. A project with onsite 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 stream is protected using in-stream controls downstream of the project discharge point.

In-stream hydromodification control can be demonstrated in the following way:

- System-Specific Erosion Potential Analysis: Project proponents can perform a system-specific continuous hydrologic simulation analysis and geomorphic evaluation of the creek system downstream of the project to size in-stream hydromodification controls that maintain the Ep in-stream at a value of 1.0, or an alternative value shown to be protective. Sizing guidance for hydromodification control BMPs using the Ep methodology is provided in Chapter 6.

5. HYDROMODIFICATION CONTROL BMPS

5.1 Selection of Hydromodification Control BMPs

5.1.1 Stormwater Quality Control Measures (LID)

All hydromodification control projects are also subject to the LID retention requirement for stormwater quality. Selection of hydromodification control BMPs to meet the Hydromodification Management Standard (Chapter 4) shall comply with the step-by-step process for incorporating stormwater management control measures described in Section 2 of the TGM (VCSQMP, 2011). The flowchart illustrating this process is presented in Figure 2-1 of the TGM and Figure 5-1 in this HCP.

In many cases, stormwater quality control measures (i.e., site design principles and techniques, source control measures, retention BMPs, biofiltration BMPs, and treatment control 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.

5.1.2 Hydromodification Control Measures

In general, once the stormwater quality control measures have been selected and sized, the project site can be assessed for compliance with the hydromodification control requirements. This step is represented as Step 8b in Section 2 of the TGM. A flowchart illustrating the step-by-step process for implementing hydromodification control measures is presented in Figure 5-2. Discussion of possible exemptions to the Hydromodification Management Standard is provided in Chapter 3 and discussion of each of the three implementation methods, including appropriate design options, is provided in Chapter 4. A summary of the design options is provided below:

- Method 1 – Onsite Controls
    - Nomographs or Sizing Factors for LID BMPs
    - California Hydrology Model (CAHM) for Ventura County
    - System-Specific Flow Duration Control Analysis (per Section 6.2)
    - System-Specific Erosion Potential Analysis (per Section 6.3)

- Method 2 – Regional Controls
    - California Hydrology Model (CAHM) for Ventura County
    - System-Specific Flow Duration Control Analysis (per Section 6.2)
    - System-Specific Erosion Potential Analysis (per Section 6.3)
- Method 3 – In-Stream Controls
    - System-Specific Erosion Potential Analysis (per Section 6.3)

The recommended project planning approach to meet the Hydromodification Management Standard depends on the relative magnitude of hydromodification control requirements compared to stormwater quality control requirements. If the volume of water that needs to be reduced to address stormwater quality control requirements is greater than the BMP volume for hydromodification control, then stormwater quality control BMPs may satisfy both requirements.

5.1.3 Process Iteration for Hydromodification Management Standard Compliance

The step-wise process should be continued until the Hydromodification Management Standard has been met. It may be necessary to evaluate whether source controls, site design, and stormwater quality treatment measures have been maximized to the full extent possible in order to meet the Hydromodification Management Standard. This iterative process can be represented in Figure 2-1 of the TGM by including a feedback loop from Step 8 back to Step 2, as represented in Figure 5-1.

5.2 <u>Non-Structural BMPs</u>

5.2.1 Hydrologic Source Controls

The site design principles and techniques described in Chapter 4 of the TGM provide hydrologic source controls which reduce the hydromodification impact of land development on receiving water bodies and reduce the size of structural BMPs necessary to meet the Hydromodification Management Standard. These non-structural BMPs should be considered in the early site planning stages.

5.2.2 Sediment Management

Introducing impervious surfaces, in addition to causing hydrologic changes that can result in hydromodification impacts, reduces the available surface area on which natural erosion processes can occur, thus decreasing the amount of sediment being supplied to stream channels. This effect is typically more pronounced in arid areas with sparse vegetation and naturally exposed soils, and less so in forested areas. Urbanized areas also often trap sediment that is generated from natural areas upstream of a development to prevent storm drain system clogging and preserve drain capacity and/or prevent damage. These reductions in sediment load, if severe enough, can starve downstream channel reaches of the bed load naturally transported by the channel and thus the water flowing in the channel becomes “sediment hungry flow”, meaning the water is more prone to eroding in-stream bed and bank material (Kondolf, 1997). Sediment hungry flow is more erosive because if the supply of sediment stops while the stream flow continues conveying bed load, then the only source of sediment available for transport is from the material that forms the channel itself. To minimize the impacts of sediment hungry flow, the following sediment source controls should be considered in the early site planning stages of hydromodification control projects.

Avoid Significant Bed Material Supply Sources in Site Design

The most effective approach to ensuring stability of receiving streams is to avoid changes in bed sediment supply by avoiding development on natural areas and channels that are significant contributors of bed material load. Where possible, development within a project should be located outside of natural channels and on existing soils that have a low potential to contribute bed material to the receiving stream.

Pass Through Sediments from Natural Areas

Where possible, drainage pathways for open spaces upstream of developments should be designed to pass coarse bed sediments from natural areas and channels to the receiving stream. Maintaining natural bed sediment supplies to stream channels helps to reduce the potential for excess erosion. Additional consultation with the local MS4 operator, flow analysis or maintenance protocols may be required to ensure downstream flood protection.

Replace Significant Bed Material Sources that are Eliminated

If, after implementing the other sediment source controls to the maximum extent practicable, there is still potential for adverse response due to bed sediment supply reduction, then one option is to add bed sediment to the receiving stream by placing coarse sediment just downgradient of outfall that the project(s) discharges to[11]. The annual replenishment of this supplemented bed sediment, in tons, should approximately equate to the estimated annual bed-load deficit caused by project development, as calculated in a bed sediment supply evaluation. This rate of replenishment can be modified after a given period of time as part of an adaptive management and monitoring plan. Added bed sediment material should be placed at the outfall such that it can be readily transported by fluvial forces exiting the outfall's energy dissipation system. It is anticipated that natural bed sediment deposited in regional debris basins can be utilized as source material for the replacement of bed material. Sediment collected in water quality treatment facilities or detention basins that serve developed areas shall not be used for this purpose.

5.3 Structural BMPs

Structural BMPs are classified in this HCP as either being outside of a receiving stream (out-of-stream) or within a receiving stream (in-stream). Out-of-stream BMPs include both distributed onsite measures and regional off-site ones. Distributed BMPs are smaller-scale facilities that receive runoff from a parcel, a portion of one parcel, or several neighboring parcels. Distributed facilities are most feasible where the land use is lower density. Regional BMPs are larger-scale facilities that receive runoff from multiple parcels and are located adjacent to an outfall. In-stream BMPs receive runoff from the entire watershed tributary to it. Figure 5-3 illustrates these different scales of BMPs. Per subpart 4.E.III.3(a)(1)(B) of the MS4 Permit, preference is given to out-of-stream hydromodification control BMPs over in-stream BMPs. However, unlike the stormwater quality control requirements, out-of-stream BMPs can be located onsite (distributed) or off-site (regional) without preference. In-stream BMPs may serve a restorative and stabilizing function in widely-urbanized watersheds.

[11] Consideration can be given to whether the caliber of this sediment should be of the same grain size distribution as the receiving stream, since adding significant amounts of fine sediment associated with the suspended wash-load may not be desirable from a water quality standpoint. Prior to placing sediment at an outfall, one option is to sieve the material to mimic the coarser grain size distribution of the receiving stream of interest.

5.3.1 Out-of-Stream BMPs

Out-of-stream hydromodification control BMPs utilize the following two basic principles:

- 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 bed sediment supply[12].

- Manage excess runoff volumes through one or more of the following pathways: (1) infiltration; (2) evapotranspiration; (3) storage and use; (4) discharge at a rate below the critical low flowrate; or (5) discharge downstream to a receiving water that is not susceptible to hydromodification impacts.

While flow-based BMPs may be able to provide some amount of flow attenuation and runoff volume loss via infiltration and evapotranspiration, volume-based BMPs are better suited for hydromodification control. Volume-based BMPs that have low flow controls (i.e., an underdrain or bottom orifice) are typically designed to draw down in 48 to 72-hours, per Section 2.6 of the TGM. Hydromodification control BMPs, however, have the additional requirement that low flow controls discharge at a rate less than the allowable low flow threshold (Qcp), estimated as 10% of the pre-project 2-year peak flow ($0.1Q_2$) if additional incipient motion or bed/bank mobilization analysis of the receiving stream is not performed (see Chapter 6).

Out-of-stream BMPs can be designed to support flood control and LID objectives in addition to hydromodification control, if desired.

To the maximum extent possible, regional basins should be designed to receive flows from developed areas only. This facilitates design optimization as well as avoiding intercepting coarse sediments from open spaces that should ideally be passed through to

---

[12] Changes in bed sediment supply are accounted for by deviating the target Ep from 1, or an alternative value shown to be protective, in proportion to the change in bed sediment supply (post-development/pre-development), expressed as Sp. This represents the best current understanding of how to quantitatively account for sediment supply changes without replacing bed sediment sources (Palhegyi and Rathfelder, 2007). For example, if there is a 30% reduction in bed-load due to proposed urbanization, then Sp equals 0.7 and the target Ep becomes 0.7. To meet this target Ep, detention storage must be added until the post-development flow duration curve is lowered such that the long-term sediment transport capacity becomes 70% of the baseline condition. Appropriate tolerances on the target Ep are discussed in Section 6.3.7.

the stream channel. Reductions in coarse sediment loads contribute to channel instability, as discussed in Section 5.2.2.

Out-of-Stream BMPs which may be used to meet the Hydromodification Management Standard include Retention BMPs, Biofiltration BMPs, and Treatment Control Measures, but may also include detention-type facilities such as underground vaults and pipes which are commonly used for flood control. BMPs sized to achieve the stormwater quality control standards in Section 1.2 of the TGM may be enlarged to accommodate hydromodification control. Fact sheets are provided in Section 6.3 of the TGM for the following BMPs which can be used to achieve hydromodification control on their own or in combination with other BMPs:

- INF-1: Infiltration Basin
- INF-2: Infiltration Trench
- INF-3: Bioretention
- INF-4: Drywell
- INF-5: Permeable Pavement
- INF-6: Proprietary Infiltration
- INF-7: Bioinfiltration
- RWH-1: Rainwater Harvesting
- ET-1: Green Roof
- ET-2: Hydrologic Source Control BMPs
- BIO-1: Bioretention with Underdrain
- BIO-2: Planter Box
- BIO-3: Vegetated Swale
- BIO-4: Vegetated Filter Strip
- BIO-5: Proprietary Biotreatment
- TCM-1: Dry Extended Detention Basin
- TCM-2: Wet Detention Basin
- TCM-3: Constructed Wetland

An additional fact sheet is provided in Appendix F of this HCP for underground vaults and pipes.

5.3.2 In-Stream BMPs

Hydromodification control can be achieved by in-channel BMPs including drop structures, grade control structures, bed and bank reinforcement, increased channel sinuosity or meandering, and increased channel width. The objective of these in-stream controls, or stream restoration measures, is to reduce or maintain the overall Erosion Potential (Ep) of the stream by modifying the receiving channel hydraulic properties and bed/bank material resistance without fully controlling runoff. In-stream BMPs 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. Existing in-stream controls are designated as non-susceptible modified channels on the Susceptibility Map (Figure 2-12). A fact sheet, which includes sketches, for in-stream BMPs is provided in Appendix F of this HCP.

In-stream BMPs are subject to the permitting requirements of the resource agencies. In-stream BMPs may require the following permits:

- California Department of Fish and Wildlife – 1602 Streambed Alteration Agreement.
- US Fish and Wildlife Service – Authorization Under the Endangered Species Act.
- US Army Corps of Engineers – Clean Water Act Section 404 Permit.
- Regional Water Quality Control Board – Clean Water Act Section 401 Water Quality Certification.

The following describes different types of in-stream BMPs.

Drop Structures

Drop structures are designed to reduce the average channel slope, thereby reducing the shear stresses generated by stream flows. These controls can be incorporated as natural looking rock structures with a step-pool design which allows drop energy to be dissipated into 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 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 structure provides a reduced footprint and impact as 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. A number of vegetated approaches are being more widely used. Such approaches include large woody debris, live crib walls, vegetated mechanically stabilized earth, live siltation, live brushlayering, willow posts and poles, live staking, live fascine, rootwad revetment, live brush mattresses, and vegetated reinforcement mats. These technologies provide erosion control 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 (meandering) can serve to reduce the channel slope, thereby reducing the shear stresses generated by stream flows. However, forcing a channel to be too sinuous is likely to lead to subsequent channel avulsion (cutting a new stream path) 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).

6. SIZING GUIDANCE

6.1 Critical Low Flow Threshold Analysis

The default assumption of a low-flow threshold of 10% Q_2[13] can be revisited based on a stream-specific critical threshold analysis. Such an investigation requires both a hydrologic and geomorphic evaluation of the nearest downstream susceptible channel, as outlined below.

6.1.1 Step 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 condition of the watershed tributary to the stream, before the proposed development, shall be considered. This provides a means of apportioning the critical flow in a channel to individual projects that discharge to that channel, such that cumulative discharges do not exceed the critical flow (Q_{crit}) in the stream of concern. 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 Ventura County Hydrology Manual, USGS regional regression, or Hawley and Bledsoe (2011)). It is preferred, however, 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, per Section 6.2.4, should be utilized to evaluate Q_2 if continuous flow data or simulated flow data is available.

6.1.2 Step 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 channel, 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, Q_{crit} 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 channel form and bed/bank roughness components can be performed as well.

---

[13] A regional basis for the default 10% Q_2 low-flow threshold is provided in Appendix E of this HCP.

6.1.3 Step 3: Normalizing the Critical Flow

For management purposes and ease of implementation, the Q_{crit} is normalized by dividing it by the Q_2 so that Q_{crit} can be expressed as a fraction of Q_2 (Qcp). This will allow for the determination of the low-flow threshold from a specific project area within the tributary watershed.

6.2 System-Specific Flow Duration Control Analysis

This section describes suggested steps for sizing flow duration control facilities using a system-based approach. This guidance can apply to distributed onsite or regional off-site hydromodification control BMPs. The approach relies on continuous hydrologic simulations of the drainage system and BMPs tributary to the point of compliance. This approach allows for customization, instead of using sizing relationships (i.e., nomographs) based on generic modeling or a regional hydrology model (i.e., CAHM) which relies on regional input parameters. For onsite BMPs associated with one project, the point of compliance is traditionally where stormwater runoff discharges from the project of interest. For regional controls, the point of compliance is the outlet at which all projects of interest are tributary.

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

6. Characterize site specific hydrologic conditions,
7. Locate structural BMPs,
8. Establish hydrologic modeling parameters,
9. Define the flow range of interest,
10. Establish structural BMP configurations,
11. Iteratively size BMP footprints to meet the flow duration control criteria,
12. Iterate BMP location (step 2) and configuration (step 5) to best meet proposed layout, and
13. Document the proposed BMP plan and analysis

6.2.1 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 (i.e., texture classification), vegetation cover, 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 onsite. If, however, two or more outlets from the project discharge to the identical receiving creeks and have similar time of concentration, then flow duration control analysis can be applied to the combined tributary areas.

Soil type or texture class (i.e., clay, sandy loam, etc.) associated with the pre- and post-project conditions should be summarized by acreage and percentage for the site. While the Ventura County Soils Map or 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 condition.

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.

6.2.2 Step 2: Locate Structural BMPs

Structural BMPs 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 BMP location and catchment delineations should be refined from step 1 such that each BMP location has at least one sub-catchment tributary to it. Locating BMPs may be an iterative process as site layouts change in the planning process. While locating BMPs, consideration of the type of BMP should be taken into account.

6.2.3 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 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 SWMM, HSPF, and 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. Generally, Ventura County Watershed Protection District can provide such data for most areas in the county.

Sub-catchment areas should be delineated in a logical fashion based on anticipated BMP locations, the points of compliance, and the proposed storm drain system. At a minimum, there should be a distinct sub-catchment area associated with the outlet of each BMP and point of compliance. Assumed catchment shape and flow path is also a key parameter which is input 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, evapotranspiration rates, and overland roughness parameters should be provided for pre- and post-development conditions. The basis for these inputs will depend on the type of continuous simulation model 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 BMPs.

6.2.4 Step 4: Define the Flow Range of Interest

In order to establish the flow range of interest for flow duration control, the low flow threshold discharge 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 continuous simulation output as follows:

- The entire runoff time series generated by the pre-project hydrologic simulation is divided into a set of discrete events. Flow events should be considered separate when the flow rate drops below a threshold value[14] (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 6.1 to evaluate an alternative fraction of Q_2 using such an approach.

---

[14] A threshold value of 0.002 cfs/acre was used in the San Diego County HMP (2009) although the technical basis for this assumption is not well documented.

6.2.5 Step 5: Establish a Structural BMP Configuration

For each structural BMP, a hydraulic outlet configuration, infiltration rate, and geometric configuration must be assumed so that each BMP 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 6-1. 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 BMP and can be iteratively designed to size the most space efficient BMP. One simple outlet configuration is to have a low flow orifice at the bottom of the BMP and an overflow weir at the top, as shown in Figure 6-2. While the orifice would be sized to discharge the low flow threshold at the pressure head associated with the overflow weir crest, the weir itself would be designed to convey the peak design discharge, per the Ventura County Hydrology Manual (VCWPD, 2010), with sufficient freeboard. The simple outlet configuration may be appropriate for distributed BMPs, but regional BMPs would likely have a more complex configuration to more efficiently size the stormwater facilities.

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 sharp-crested 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). Weir coefficients less than 3.33 are acceptable for different types of weirs and design considerations.

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 6-1, 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 BMP 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, as discussed in TGM Section 3.1.

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 BMP will infiltrate runoff at a greater rate than a deeper BMP with a smaller footprint. The simplest BMP 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 BMP, then the stage-storage curve should account for only the storage capacity within the media and not include the volume of the grains.

6.2.6 Step 6: Iteratively Size the BMP Footprint

Once the BMP configurations are established, the BMP 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 BMP footprint[15] and capture volume[16] 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 6-3). In order to plot a flow duration curve, a table of flow rates and corresponding cumulative 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 6-1) can be helpful in confirming that the goodness of fit criteria (Section 4.1) is met:

> *Flow duration controls shall be designed such that post-project stormwater discharge rates and durations match pre-project discharge rates and durations above 10 percent of the pre-project 2-year peak flow (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.*

---

[15] BMP footprint area is defined as the area, in square feet, of the BMP at the overflow weir crest.

[16] BMP capture volume is the storage capacity, in cubic feet, of the BMP below the overflow weir crest.

There are a number of ways of establishing the flow bin values used in the flow duration table[17]. 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.

6.2.7 Step 7: Iterate BMP Location, Type, Configuration, and Size to Best Meet Proposed Layout

Once the BMPs are sized, the modeled BMP 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 BMPs 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 BMPs to have a smaller size, then adjustments to the BMP configurations should be made and the designer should return to Step 5.

6.2.8 Step 8: Document the Proposed BMP Plan and Analysis

The final BMP plan should be documented with: (1) a map or maps showing BMP locations, catchments, soil boundaries, and impervious surfaces for the project; (2) a summary of modeling inputs (e.g., soil type, percent 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 BMP locations can accommodate the calculated sizing; (5) a summary of the hydraulic outlet control dimensions for each BMP; (6) a stage-storage-discharge curve and associated draw down time for each BMP; and (7) the final pre- and post-project modeling files used to design the flow duration control facilities.

6.3 System Specific Erosion Potential Analysis

One method of quantifying hydromodification impacts to stream channels which takes into account changes in: (1) hydrology, (2) channel geometry, (3) bed and bank material, and (4) sediment supply; is to compare long-term changes in sediment transport capacity, or in-stream work, and sediment supply for the pre- and post-project

[17] 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

conditions. The ratio of post/pre-project transport capacity or work is termed Erosion Potential (Ep) while the ratio of post/pre-project bed sediment supply is termed Sediment Supply Potential (Sp). To calculate Ep, the hydrology, channel geometry and bad/bank material factors mentioned above should be characterized for the pre- and post-project scenarios. To calculate Sp, the sediment supply factor should be characterized for the pre- and post-project scenarios. Accounting for bed sediment supply changes is not required per the MS4 Permit, but is included as an optional element which Permittees can decide to implement. While evaluating changes in discharge and sediment supply is done primarily as a desktop analysis, a geomorphic field assessment is needed to characterize bed/bank material, channel geometry, as well as to ground truth assumptions for the desktop analyses.

Ep analysis should be performed for the susceptible receiving stream of interest downstream of the point of discharge. If only out-of-channel BMPs are being implemented to provide additional mitigation in site runoff, Ep should be calculated for a couple cross-sections in the most upgradient susceptible channel receiving project runoff. Another set of calculations may be needed if there is a particularly sensitive stream reach further downstream. If in-stream BMPs are implemented, Ep should be calculated for multiple cross-sections between the points of discharge through all susceptible receiving waters unless it can be demonstrated that the susceptible receiving waters have negligible risk of hydromodification impact, per Section 3.4.

Suggested steps for performing an Ep analysis are provided in Figure 6-4. The following describes each analysis step shown in Figure 6-4, including the inputs and outputs of each step.

6.3.1 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 Section 6.2 can be used for guidance in setting up such continuous simulations. Modeling software appropriate for this type of simulation includes SWMM, HSPF, and 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 6-5) 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 continuous 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 6-6. 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 6-3 provides an example flow duration curve.

6.3.2 Step 2: Hydraulic Analysis

Hydraulic parameters, such as stage, effective shear stress[18], 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[19] and obtaining results for the central channel or as complicated as using hydraulic models which account for backwater effects, such as HEC-RAS.

Channel geometry inputs should be characterized by surveying cross-sections and longitudinal profiles of the active channel at strategic locations. Methods of collecting

---

[18] 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].

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

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] 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).

6.3.3 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 or transport rating curve. An example of such a rating curve is provided on Figure 6-6. The work equations used can be simplistic indices[20], material specific sediment transport equations, or more complex functions based on site-calibrated sediment transport rating curves. In addition to a work or transport rating curve, the critical flow rate (Qcrit) is also evaluated in this step. Qcrit is the flowrate that results in an effective shear stress equal to the estimated critical shear stress for incipient motion. Qcrit 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 analysis is used to obtain a grain size distribution, which can be converted to a critical shear stress using an empirical relationship[21] 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, the applied shear stress can be partitioned into form and bed/bank roughness components.

---

[20] An example of a simplified effective work equation (LARWQCB, 2010) 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]

[21] 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.

6.3.4 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 or tons[22]]

W_i = Work per flow bin [dimensionless or tons/yr]

Δt = Duration per flow bin [hours]

n = number of flow bins

The distribution of cumulative work, also referred to as a work curve (or work histogram), is helpful in understanding which flowrates are doing the most work in the channel of interest. An example work curve is provided in Figure 6-6.

6.3.5 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:

E_p = Erosion Potential [unitless]

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

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

[22] Units of tons or tons/yr apply if sediment transport capacity is calculated instead of work.

6.3.6 Step 6: Sediment Potential Analysis (Optional)

Sediment supply potential (Sp) is the ratio of total bedload yield in the post-development conditions to that in the pre-development condition (post/pre). If sediment supply changes may be significant to channel stability, then Sp can be calculated for each receiving channel of interest downstream of the point of discharge.

Sp is calculated by simply dividing the total bedload supply rate of the post-project condition by that of the pre-project condition. Sp is expressed as:

$$S_p = B_{t,post} / B_{t,pre}$$

Where:

S_p = Sediment Supply Potential [unitless]

$B_{t,post}$ = Total Bedload Supply Rate associated with the post-project condition [tons/yr]

$B_{t,pre}$ = Total Bedload Supply Rate associated with the pre-project condition [tons/yr]

6.3.7 Step 7: Implementation of BMPs to Meet the Hydromodification Management Standard

The Erosion Potential (Ep) ratio should be maintained to within a given percentage (i.e., 5%) of the target value in the receiving channel. The following bullet points provide basis for using a +/- 5% allowance for susceptible channels with a median gran size (D_{50}) less than or equal to 16 mm and a +/- 20% allowance for susceptible channels with a D_{50} greater than 16 mm.

- According to the Journal of Hydrology article titled *Channel Enlargement in Semiarid Suburbanizing Watersheds: A Southern California Case Study* (Hawley and Bledsoe, 2013):

> *The threshold corresponding to the presence/absence of headcutting varied based on substrate type, and was roughly quantified as a sediment-transport ratio greater than ~1.20 in systems with a median grain size > 16mm, and [Ep] ~ 1.05 when d_{50} < 16 mm.*

- According to a study conducted in the San Francisco Bay Area as part of the Santa Clara Urban Runoff Pollution Prevention Program's (SCVURPPP) Hydromodification Management Plan (HMP) (2005), "the transition between stable and unstable channels occurs between Ep values of 1 and 1.2" providing a basis for a +/- 20% allowance on Ep. Based on findings of Stein and Bledsoe (2013b), however, Southern California channels appear to be more sensitive to hydromodification impacts than those analyzed in Santa Clara County (i.e., same Ep results in higher probability of instability). A comparison of the two regional logistic regression models is provided on Figure 6-7. Although the calculation methods for Ep differ between the two regional studies, a conservative assumption is that an Ep numeric control standard in Southern California should have a smaller allowable tolerance than in Northern California. Considering that the Hydromodification Management Standard for Ventura County aims to "maintain the Ep in-stream at a value of 1.0", it is assumed that an Ep value less than 5% of the target value meets the Management Standard (i.e. an Ep value of 1.04 rounds to 1.0).

- Soar and Thorne (2001) indicate that a greater than 10% reduction in sediment supply can have potentially significant effects on stream stability. On this basis, Ep values less than 10% can be appropriately used as a quantitative significance threshold. It should be noted that sediment transport and supply measurements and calculations are inherently inexact. Discrepancies of 5% should not be a source of concern. With this in mind, it is appropriate to allow for up to a 5% variance in Ep without assumed negative impact.

Changes in bed sediment supply can be accounted for by deviating the target Ep from 1.0, or an alternative value shown to be protective, in proportion to the change in bed sediment supply (post/pre), expressed as Sp (Step 6). This represents the best current understanding of how to quantitatively account for sediment supply changes without replacing bed sediment sources (Palhegyi and Rathfelder, 2007). For example, if there is a 30% reduction in bedload due to proposed urbanization and a 5% allowance around the target Ep is assumed, then Sp equals 0.70 and the target Ep becomes 0.70 +/-5%. To meet this target Ep, BMPs can be added until the long-term total sediment transport capacity, or work, becomes 67% to 74% of the baseline condition. Additionally, sediment source controls can be implemented to limit the reductions in bed sediment supply.

Without BMPs and sediment source controls, the calculated Ep can be well above the target, 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 distributed, regional, and/or in-stream BMPs as well as sediment source controls to meet the Ep standard requires an iterative process. The following describes which steps in the Ep modeling framework (Figure 6-4) need to be iterated for specific types of BMPs.

Out-of-Stream BMPs (Step 1)

Out-of-stream BMPs, which include distributed and regional BMPs, 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 BMPs which affect the post-project hydrologic analysis include protection and restoration of natural areas, minimization of land disturbance, and minimization of impervious cover as described in Chapter 4 of the TGM. Specific structural BMPs associated with Step 1 include those listed in Section 5.3.1. Fact sheets for each of these BMPs are provided in the TGM in Section 6.3[23].

In-Stream BMPs (Step 2 and 3)

In-stream BMPs do not generally 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 and armoring) 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 BMPs 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.

[23] The sizing guidance provided in the TGM fact sheets is for stormwater quality control, not hydromodification control.

Sediment Source Controls (Step 6)

Sediment source controls, including avoiding significant bed material supply sources and passing through sediments from open spaces, are ways of maintaining natural bed sediment supply rates and keeping Sp closer to 1.0. These measures are incorporated into the Ep modeling framework in Step 6. Similarly, replacing significant bed material sources that are eliminated also serves to increase Sp in Step 6. Additional mitigation in site runoff to compensate for bed sediment supply loss is associated with out-of-stream BMPs and affects Step 1.

6.3.8 Step 8: Document the Proposed BMPs and Analysis

The final stormwater management plan submittal should include: (1) a watershed-scale longitudinal profile (see Figure 6-8 for example) indicating the extent of proposed in-channel BMPs, 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 series of maps indicating the flow path assumed for the watershed-scale longitudinal profile, BMP 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 (or histogram) 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 6-2 for example); (6) documentation for each Sp calculation; (7) a summary of total work, Ep, and Sp results; (8) a demonstration that the proposed project can accommodate the proposed design; (9) a summary of the configuration of each structural BMP; and (10) the final pre- and post-project continuous hydrologic simulation files and other files used to complete the Ep analysis and size BMPs.

6.3.9 Particulars of In-Stream BMPs

Design Goals Beyond the Erosion Potential Management Objective

In addition to meeting the Ep management objective, the design objective of in-stream BMPs 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 or to restore it to a previous, higher level function (San Diego County, 2009). Additionally, it should be determined whether in-stream BMPs should be designed with a level of conservatism to account for anticipated future buildout in the watershed.

Suggested Extent of In-Stream Stabilization

The upstream limit of in-stream BMPs is suggested to extend upstream of where project runoff discharges into the receiving channel to an existing or proposed grade control. The suggested downstream limit is where: (1) Ep is consistently near the target Ep (i.e. within 10%) or less without in-stream BMPs; or (2) the stream connects to a non-susceptible receiving water. For the latter case at least one additional Ep calculation should be performed downstream of a non-susceptible receiving stream if it drains to a creek segment that is susceptible to hydromodification impacts.

Table 6-1. Example Flow Duration Table

Flow (cfs)	Cumulative Duration at which the specified flow rate is equaled or exceeded (hrs)	
	Pre-Development	Post-Project with Hydromodification 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
0.35	18	12
0.36	15	10
0.37	12	8
0.38	10	8
0.39	9	7

Flow (cfs)	Cumulative Duration at which the specified flow rate is equaled or exceeded (hrs)	
	Pre-Development	Post-Project with Hydromodification Control
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

Table 6-2. Example Work Calculation

Stage (ft)	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)
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	

Stage (ft)	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)
4.5	2099	1979	2224.5	7	42	9.4	2.09	0.17	24.9	168.1	
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	

7. MONITORING AND EFFECTIVENESS ASSESSMENT

7.1 Elements of Hydromodification Monitoring

The need for, and role of, hydromodification monitoring is described in the draft Southern California Coastal Water Research Project (SCCWRP) report *Framework for Developing Monitoring Programs to Support Hydromodification Management* (Stein and Bledsoe, 2013a). The draft report states that:

> *Ongoing and well-structured monitoring is a critical component of watershed and water-quality management. Practices intended to prevent or mitigate effects of land use on in-stream conditions should be refined and improved based on monitoring results. Monitoring is also important for assessing compliance with regulatory requirements and for evaluating program effectiveness… Monitoring of hydromodification management is particularly critical given the complexity and uncertainty associated with managing effects of hydrologic change on channel structure. Due to the relative immaturity of hydromodification management practices as compared to traditional water-quality management, their effectiveness is also less certain. Thus, monitoring is essential to allow adaptation and adjustment of early-generation practices to improve their performance over time.*

In an effort to provide guidance to regulators and MS4 permittees, the State Water Resources Control Board produced a broad set of recommendations for hydromodification monitoring in their report *Hydromodification Assessment and Management in California* (Stein *et al*., 2012). The proposed monitoring framework is a tiered approach to inform and help guide management actions. Elements of the proposed monitoring framework for MS4 permittees include: (1) **performance monitoring** to evaluate whether a facility or practice meets its intended or designed performance, independent of whether that intended design is beneficial for receiving waters, and (2) **effectiveness monitoring** to evaluate how well management actions or a suite of actions reduce or eliminate hydromodification impacts on receiving waters (Stein *et al*., 2012). Performance monitoring (i.e., maintenance inspections and/or flow monitoring) is conducted where hydromodification controls are constructed or at the point of compliance. Effectiveness monitoring (i.e., physical channel surveys, biological monitoring, and/or sediment transport monitoring) is conducted in the receiving water channel.

7.2 Data Collection

The hydromodification monitoring measures required in Ventura County include measures to assess performance and effectiveness. These measures are described below and are organized according to whether they assess performance or effectiveness. Table 7-1 summarizes the measures by specifying: (1) who is responsible for performing the measure; (2) how many monitoring sites there should be; (3) the frequency of data collection; and (4) the duration that the measure should be implemented.

Table 7-1. Summary of Hydromodification Monitoring Approach

Monitoring Measure	Responsibility	# of Sites	Frequency	Duration
Maintenance Inspection	Project Owner	All projects with Hydromodification Control BMPs	Annually or once every 2 years	Indefinitely
Aerial Photographic Monitoring	Program	Regional review with at least one specific reach per watershed[24]	Annually or once every 2 years	Indefinitely
In-Stream Photographic Monitoring	Project Owner	One reach per Large Project which requires 401 certification or disturbs 50 acres or greater	Annually or once every 2 years	5 to 10 years
Physical Channel Survey	Project Owner	One reach per Large Project which requires 401 certification or disturbs 50 acres or greater	Upon observation of channel adjustment, minimum of once every 3 years	5 to 10 years
Biological Assessment	Program, assuming the SMC program exists	Per SMC protocol	Per SMC protocol	5 to 10 years

[24] Watersheds include the five mentioned in the MS4 Permit: Ventura River Watershed; Santa Clara River Watershed; Calleguas Creek Watershed; Malibu Creek Watershed; and Miscellaneous Coastal Watersheds

7.2.1 Performance Monitoring

Maintenance Inspection

Maintenance inspection is currently being implemented by the Ventura County Permittees as part of the Tracking, Inspection, and Enforcement program for new development and redevelopment post-construction BMPs. The program includes performing a field inspection and filling out a post-construction BMP maintenance checklist at least once every two years to assess operation conditions with particular attention to criteria and procedures for post-construction treatment control and hydromodification control BMP repair, replacement, or re-vegetation. If the post-construction BMPs are operated and maintained by parties other than the Permittees, then those project proponents are required to provide annual reports demonstrating proper maintenance and operations. These same requirements and the Maintenance Plan in Section 7 of the TGM apply to all hydromodification control BMPs.

7.2.2 Effectiveness Monitoring

Aerial Photographic Monitoring

Low-cost qualitative photographic measures are considered the minimum effort needed to fulfill the effectiveness element. Aerial photographic monitoring includes comparing aerial images and aerial LiDAR data, when available, of susceptible streams within and downgradient of the County over time to assess when and where physical geomorphic changes have occurred due to new and redevelopment. Currently, Ventura County collects countywide aerial photographs annually or every other year, so these images could be used for comparison. Other online sources for aerial imagery can be used as well. The emphasis is on monitoring susceptible streams which have hydromodification control projects tributary to them, although past impacts due to existing urbanization can be characterized as well by reviewing historical aerial images. Characterizing hydromodification impacts from the past and noting whether adjustment has occurred in natural reference streams may, in fact, be essential to evaluating whether a particular stream's adjustment is due to hydromodification control projects, past land development, or natural events.

At minimum a regional aerial image review of susceptible streams downgradient of hydromodification control projects will be performed once a year or during years that countywide aerial imagery is collected. Even if no hydromodification projects exist, at least one specific susceptible stream reach of concern shall be monitored per major watershed. It is anticipated that aerial photographic monitoring will help identify susceptible streams that are impacted and thus are candidates for in-stream BMPs.

The Ventura Countywide Stormwater Quality Management Program is the responsible party for performing aerial photographic monitoring.

In-Stream Photographic Monitoring

In-stream photographic monitoring applies only to hydromodification control projects which require 401 certification or which disturb land areas of 50 acres or greater. In-stream photographic monitoring consists of taking georeferenced photographs at monumented locations in the receiving stream of concern,[25] noting physical channel changes, and comparing the monumented field photographs over time to evaluate geomorphic trends.

Spatially, photographic monitoring should be performed from the closest susceptible downstream receiving channel from a qualifying project to an appropriate downstream extent. The SCCWRP report on hydromodification control monitoring, *Framework for Developing Hydromodification Monitoring Programs* (Stein and Bledsoe, 2013a), states that downstream monitoring should occur to:

- At least one reach downstream of the first grade-control point (but preferably the second downstream grade-control location),
- Tidal backwater/lentic waterbody,
- Equal order tributary, or
- A two-fold increase in drainage area.

---

[25] One option for continuous photographic monitoring under development is the use of Google Map's Streetview technology in stream channels. With the right equipment (Google's units have nine directional cameras to create 360° views that can be stitched together along a georeferenced linear route), photographic monitoring can take as long as a hike through a reach of interest. By repeating such photo surveys, channel evolution can be tracked over time and documented with relative ease. Geosyntec has been utilizing GoogleEarth's historical imagery feature to qualitatively track geomorphic changes caused by land use alteration. Street view for streams could be the next step for more detail, particularly if the stream channel is underneath dense canopy.

In terms of timing, in-stream photo monitoring should be done once prior to project construction so that the eventual post-project condition can be compared to the pre-project condition to evaluate if the receiving channel has physically changed since project completion. In-stream photographs should also be completed for an undisturbed reference reach in the watershed, if available, to better evaluate whether physical changes in a receiving channel of concern are due to naturally occurring geomorphic processes or are caused by the hydromodification control project. At least one reference reach per watershed should be established if possible, but the initial monitoring should take place only after an applicable project with hydromodification controls is approved in that same watershed. In-stream photographic monitoring should be conducted in the late spring or early summer (May to June), after the conclusion of the wet season but early enough so that data review can be completed before the beginning of the next wet season. In-stream photo monitoring should continue for at least five years but ideally longer to detect change.

With regard to determining which projects must conduct effectiveness monitoring, one item of consideration is whether the development project is situated such that hydromodification impacts in the receiving channel can feasibly be linked to the project. The larger the development acreage is in comparison to the total tributary acreage of the receiving stream, the more likely effectiveness can reliably be measured in-stream. For this reason, it makes sense to only require effectiveness monitoring for projects with development area ratios greater than a given percentage (i.e., 10 percent of the watershed area at the point of discharge to the natural stream channel).

The responsible party for performing in-stream photographic monitoring is the project owner.

Physical Channel Survey

Physical channel surveying applies only to hydromodification control projects which require 401 certification or disturb land areas of 50 acres or greater. The most straight forward way to quantify effectiveness is to measure the receiving stream’s longitudinal profile and cross-sectional geometry over time and compare it to geometric changes of similar undisturbed reference streams. According to the SCCWRP report *Framework for Developing Hydromodification Monitoring Programs* (Stein and Bledsoe, 2013a), Channel cross-sectional area and longitudinal profile is a state variable and often serves as an assessment endpoint for determining hydromodification response or recovery. Geomorphic surveys of channel cross-sections should be guided by the field protocol of Harrelson et al. (1994) and performed by a knowledgeable/experienced survey crew using a total station and data collector or level/rod. Surveys should occur over 10 bankfull channel widths. Surveys should include at least three cross-sectional profiles (upper, mid, lower reach) that extend to either the valley edge or above the apparent 25 year floodplain. Channel surveys and photo points looking upstream and downstream should be tied to “permanent” control points or monuments tied to a geodetic framework (such as NAD 27 or 83).

Additionally, within each surveyed reach, the bed and bank material should be characterized so that any changes (i.e., bed armoring) can be documented.

Survey reaches should be located where physical channel adjustment is most likely to occur, which is typically immediately downstream of where project runoff discharges into the receiving channel. This is because hydromodification impacts are expected to decrease as more undeveloped area contributes to the channel in the downstream direction, thus diluting the impact. Physical surveys should be conducted in the late spring or early summer (May to June), after the conclusion of the wet season but early enough so data review can be completed before the beginning of the next wet season. In any given year, a repeat channel survey is only necessary if physical channel changes are observed during the annual aerial photo review, stream walk, or field photograph comparison. By triggering the more costly quantitative effectiveness measures based on the qualitative monitoring measures, physical survey monitoring can be avoided in years when no noticeable geomorphic change has occurred and monitoring costs can be minimized. Physical channel surveying should be conducted at least once every three years.

The responsible party for performing physical channel survey monitoring is the project owner.

Biological Assessment

The biological assessment efforts conducted by the Southern California Storm Water Monitoring Coalition (SMC) in Ventura County will be utilized for hydromodification monitoring and effectiveness assessment where available. Currently biological assessment is performed in Ventura County at 18 sites per year (six in the Calleguas

Creek watershed, three in the Santa Clara River watershed, and six in the Ventura River watershed). One site per major watershed (three total) is fixed, meaning bioassessment is repeated annually at these locations. Biological assessment includes benthic macroinvertebrate indices of biological integrity (IBI), although once SCCWRP develops a Benthic Macroinvertebrate Index (BMI), which accounts for the typical seasonal variability of non-perennial streams, BMI should be used in non-perennial streams. The BMI should not be used alone as an indication of hydromodification acting as a stressor on benthic macroinvertebrates, as certain species have greater sensitivity to sediment stress and flow alteration. When hydromodification is suspected as a contributor to reduced biological integrity causal assessments should be performed to assist in identifying the candidate causes and determine if hydromodification is the likely cause. Additional biological assessment methods that could be conducted by SMC in the future include Physical Habitat Assessment (PHAB), stream algae index, and California Rapid Assessment Method (CRAM). Biological assessment should be performed in May or June.

The responsible party for performing biological assessment in Ventura County is the Ventura Countywide Stormwater Quality Management Program in accordance with SMC protocol. Performing biological assessment for the purpose of hydromodification monitoring and effectiveness evaluation is contingent on SMC continuing its program.

7.3 Record Keeping

The Ventura Countywide Stormwater Quality Management Program will keep records of hydromodification control projects by: (1) archiving the sizing analysis and design documents for constructed hydromodification control BMPs; (2) maintaining a map of where hydromodification control BMPs are installed; and (3) reviewing and archiving the hydromodification monitoring data. Review of the hydromodification monitoring data will be completed annually prior to the beginning of the next wet season.

8. ACKNOWLEDGEMENTS

The Ventura County Permittees would like to acknowledge the other MS4 Permittees in California. This HCP 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), Fairfield-Suisun Urban Runoff Management Program (FSURMP), the City of Vallejo, San Diego County's Project Clean Water, and the Orange County Watersheds Program.

9. REFERENCES

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

California Stormwater Quality Association. 2009. White Paper: Introduction to Hydromodification. May 20, 2009.

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

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

County of Ventura. 2011. Parcel and Land Use GIS Data.

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.

Hawley, R.J., and Bledsoe, B.P. 2011. "How do flow peaks and durations change in suburbanizing semi-arid watersheds? A southern California Study," Journal of Hydrology, Elsevier, Vol 405, pp 69-82.

Hawley, R.J., and Bledsoe, B.P. 2013. "Channel enlargement in semiarid suburbanizing watersheds: A southern California case study," Journal of Hydrology, Elsevier, Vol 496, pp 17-30.

Kondolf, G.M., 1997. "Hungry Water: Effects of Dams and Gravel Mining on River Channels." Environmental Management, Vol.21, No.4, pg 533-551.

Los Angeles Regional Water Quality Control Board. 2010. Municipal Separate Storm Sewer Systems NPDES Permit. Order R4-2010-0108. NPDES Permit Number CAS004002.

Multi-Resolution Land Characteristics Consortium (MRLC). 2011. National Land Cover Database for the Conterminous United States 2006.

Natural Resources Conservation Service (NRCS). 1998. California Average Monthly or Annual Precipitation, 1961-90. Water and Climate Center of the Natural Resources Conservation Service.

National Resources Conservation Service (NRCS). U.S. Department of Agriculture. n.d. SSURGO computerized soils and interpretive maps (automating soil survey maps).

Soil Data Mart. Online Database. http://soildatamart.nrcs.usda.gov/County.aspx?State=CA.

Palhegyi, G.E. and Rathfelder, K. 2007. "Applying the Erosion Potential Methodology to Natural Channel Design Procedures in Southern California". Presented at CASQA, Sept 2007, Orange County, California.

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

Soar, P.J., and Thorne, C.R., 2001. Channel Restoration Design for Meandering Rivers. US Army Corps of Engineers, Final Report, ERDC/CHL CR-01-1. September 2001.

Southern California Coastal Water Research Project (SCCWRP). 2010. Hydromodification Screening Tools: GIS-based catchment analyses of potential changes in runoff and sediment discharge. Technical Report 605.

Southern California Coastal Water Research Project (SCCWRP). 2010a. Hydromodification Screening Tools: Field Manual for Assessing Channel Susceptibility. Technical Report 606.

.Stein, E.D. and Bledsoe, B.P. 2013a. Framework for Developing Monitoring Programs to Support Hydromodification Management. Technical Report 752. Southern California Coastal Water Research Project (SCCWRP). March.

Stein, E.D. and Bledsoe, B.P. 2013b. Modeling and Managing Hydromodification Effects: summary of Available Tools and Decision-Making Approach. Technical Report 753. Southern California Coastal Water Research Project (SCCWRP). March.

Stein, E.D., F. Federico, D.B. Booth, B.P. Bledsoe, C. Bowles, Z. Rubin, G.M. Kondolf, and A. Sengupta. 2012. Hydromodification Assessment and Management in California. Technical Report 667. Southern California Coastal Water Research Project. Costa Mesa, CA.

US Geological Survey (USGS). 2000. GIS Data for the Geologic Map of California. modified from California Geological Survey, CD-ROM 2000-007.

Ventura County Stormwater Quality Management Program (VCSQMP). 2011. Ventura County Technical Guidance Manual for Stormwater Quality Control Measures. Manual Update 2011.

Ventura County Watershed Protection District (VCWPD). 2010. Design Hydrology Manual.

FIGURES

Legend

- Ventura_County
- Urban County
- CURB Boundary
- Ventura County Rivers and Creeks
- Roads

Major Watersheds

- Calleguas Creek
- Coastal
- Malibu Creek
- Santa Clara River
- Ventura River

Watershed and Vicinity Map

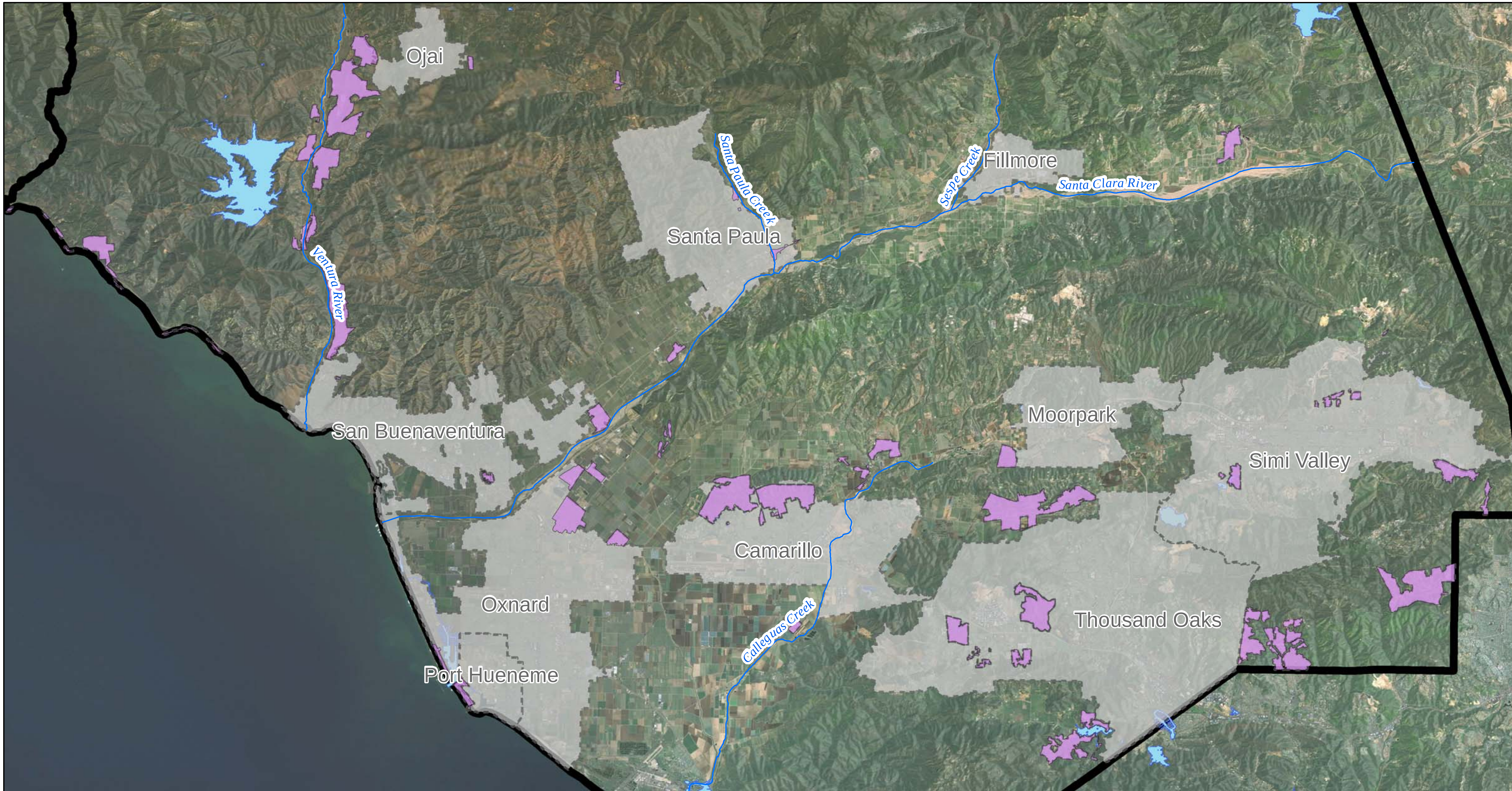
Ventura County, CA

Geosyntec consultants

WW1717 | July 2013

Figure 2-1

P:\GIS\Ventura_County_HCP\Projects\Figure2-1_WatershedandVicinity_Portrait.mxd



Legend

- Urban County
- CURB Boundary
- Ventura County

Basemap Source: ESRI

CURB Areas and Unincorporated Urban Centers in Ventura County

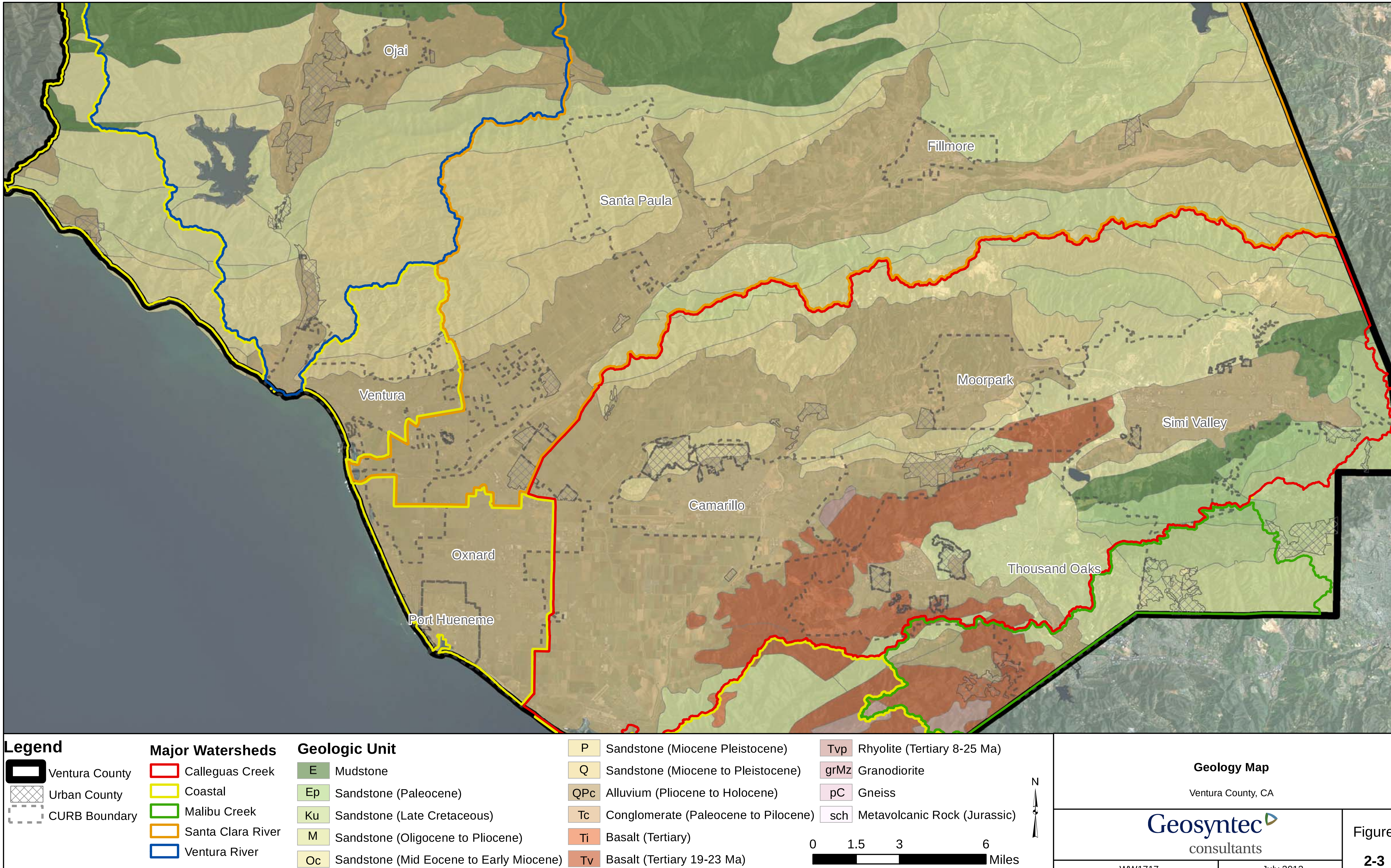
Ventura County, CA

Geosyntec consultants

WW1717 | July 2013

Figure 2-2

P:\GIS\Ventura_County_HCP\Projects\JursidictionalBoundaries_Fig_1.mxd



Geology Map

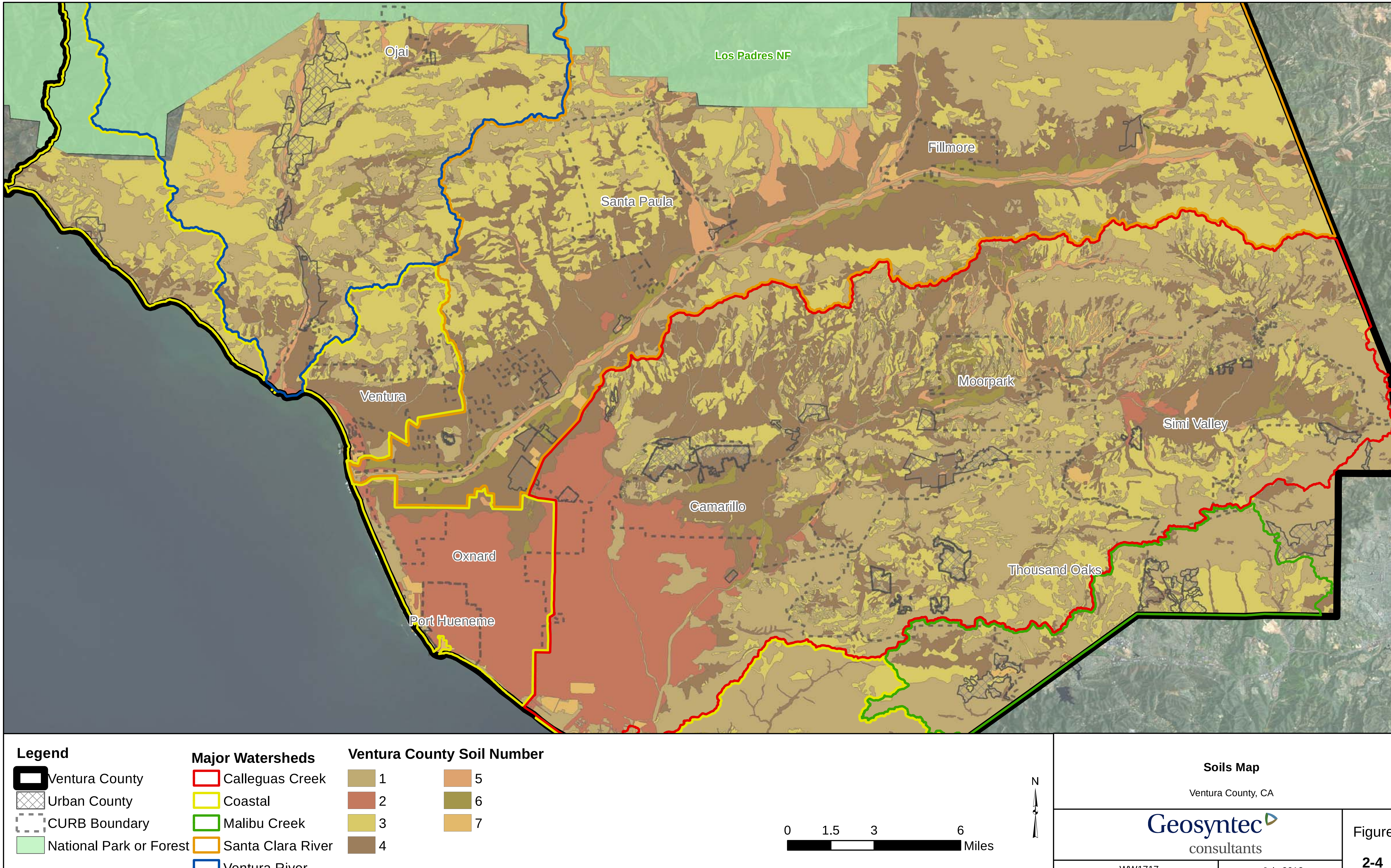
Ventura County, CA

Geosyntec consultants

Figure 2-3

WW1717 | July 2013

P:\GIS\Ventura_County_HCP\Projects\Figure2-4Geology.mxd



Soils Map

Ventura County, CA

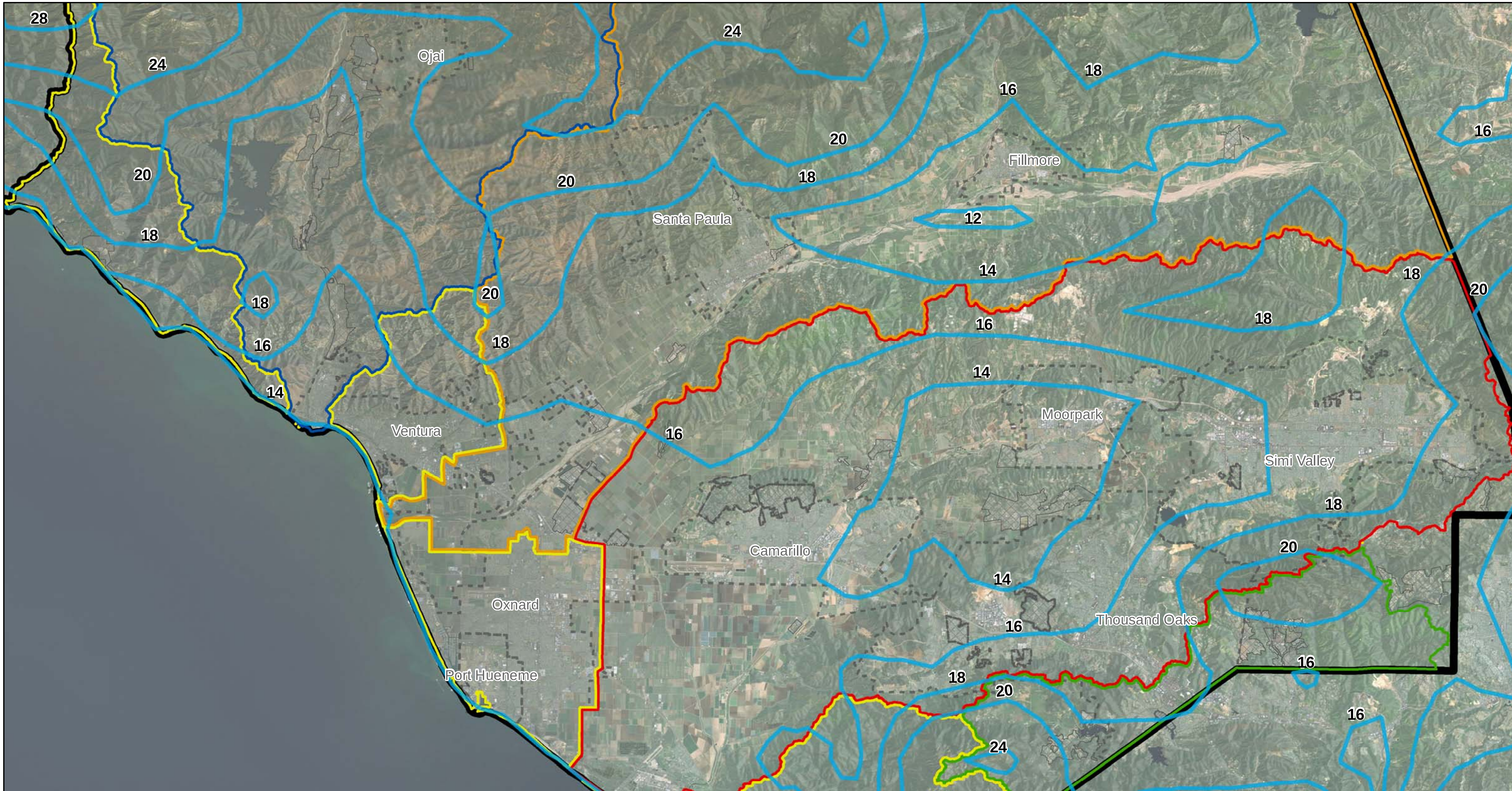
Geosyntec consultants

WW1717

July 2013

Figure 2-4

P:\GIS\Ventura_County_HCP\Projects\Figure2-5SoilsMap.mxd



Legend

Mean Annual Precipitation (1961-90)
Ventura County
Urban County
CURB Boundary

Major Watersheds

Calleguas Creek
Coastal
Malibu Creek
Santa Clara River
Ventura River

0 1.5 3 6 Miles

N

Source: ESRI, NRCS

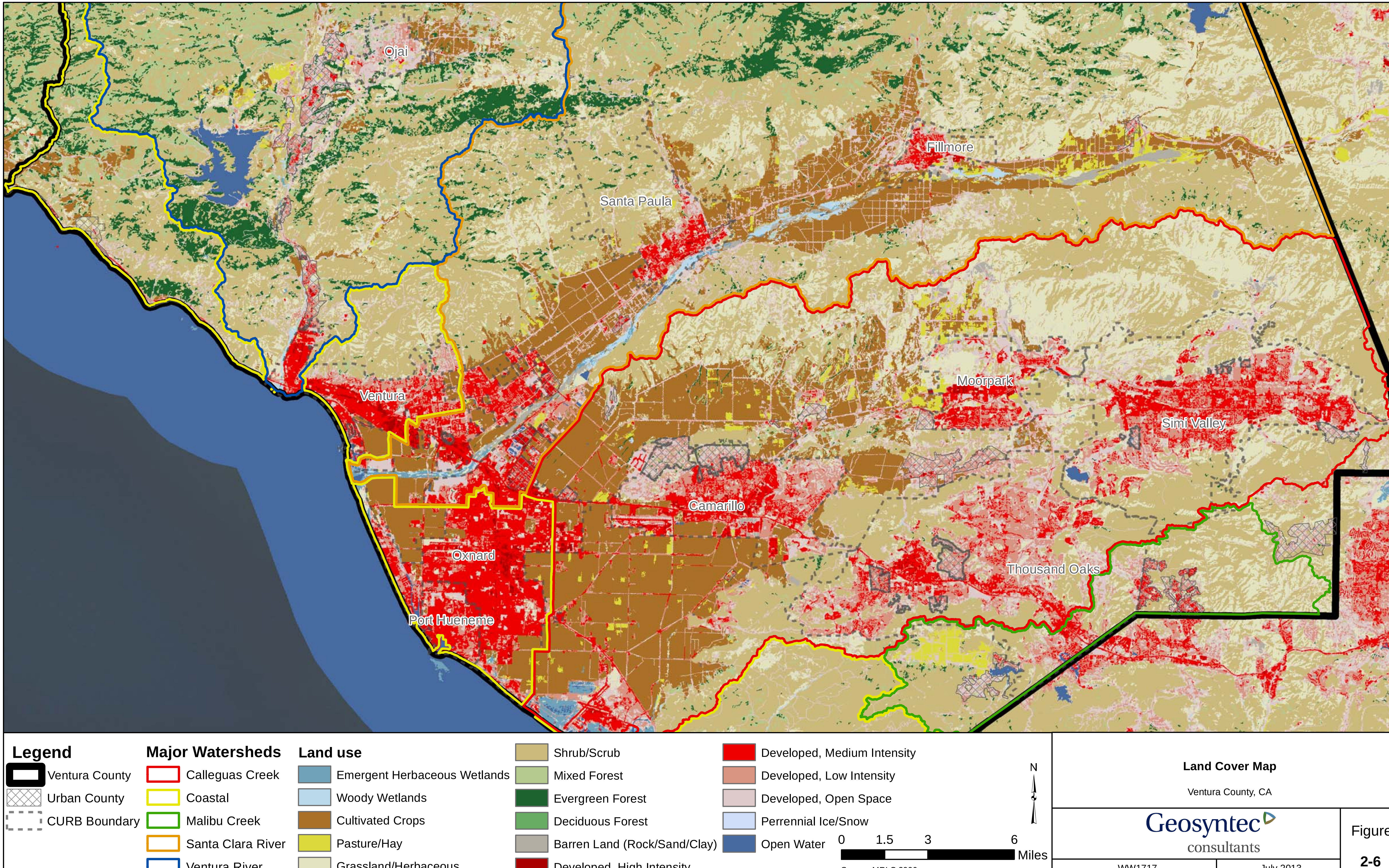
Mean Annual Precipitation Map

Ventura County, CA

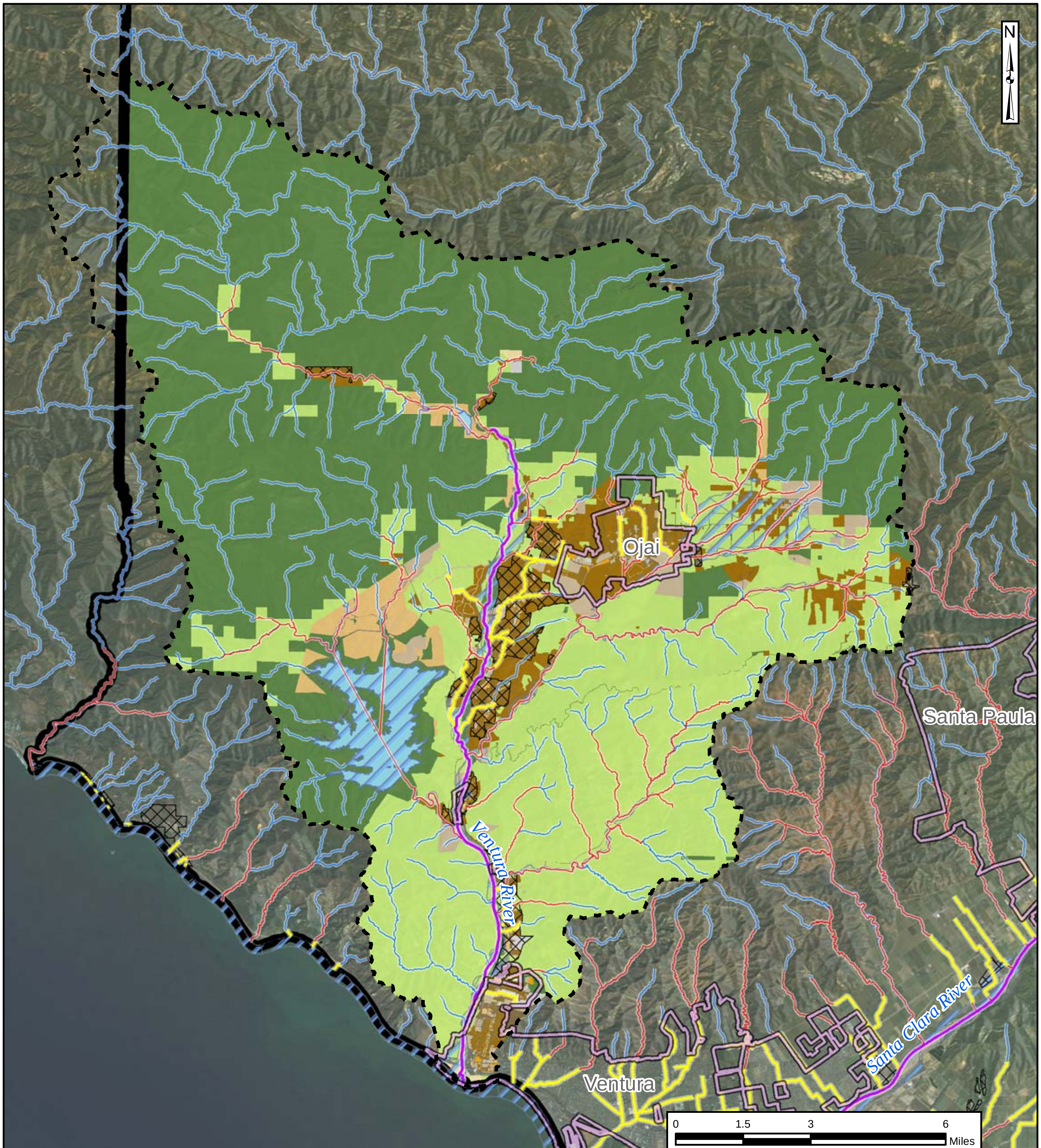
Geosyntec consultants

WW1717	July 2013	Figure 2-5

P:\GIS\Ventura_County_HCP\Projects\Figure2-6MeanAnnualPrecipitationMap.mxd



P:\GIS\Ventura_County_HCP\Projects\Figure2-7LandCoverMap.mxd



Legend

- Ventura County
- CURB Boundary
- Urban County
- Major Watersheds
- Lakes
- 100 Year Floodplain
- Large Channel (Q100>25,000 cfs)
- Modified Channel
- TidalChannel
- Natural Redline Channel
- Natural Blueline Channel

Existing Land Use

- Recreation
- Trans/Comm/Util
- Trade
- Services
- Residential
- Industrial
- Resource Production
- Undeveloped
- Unknown

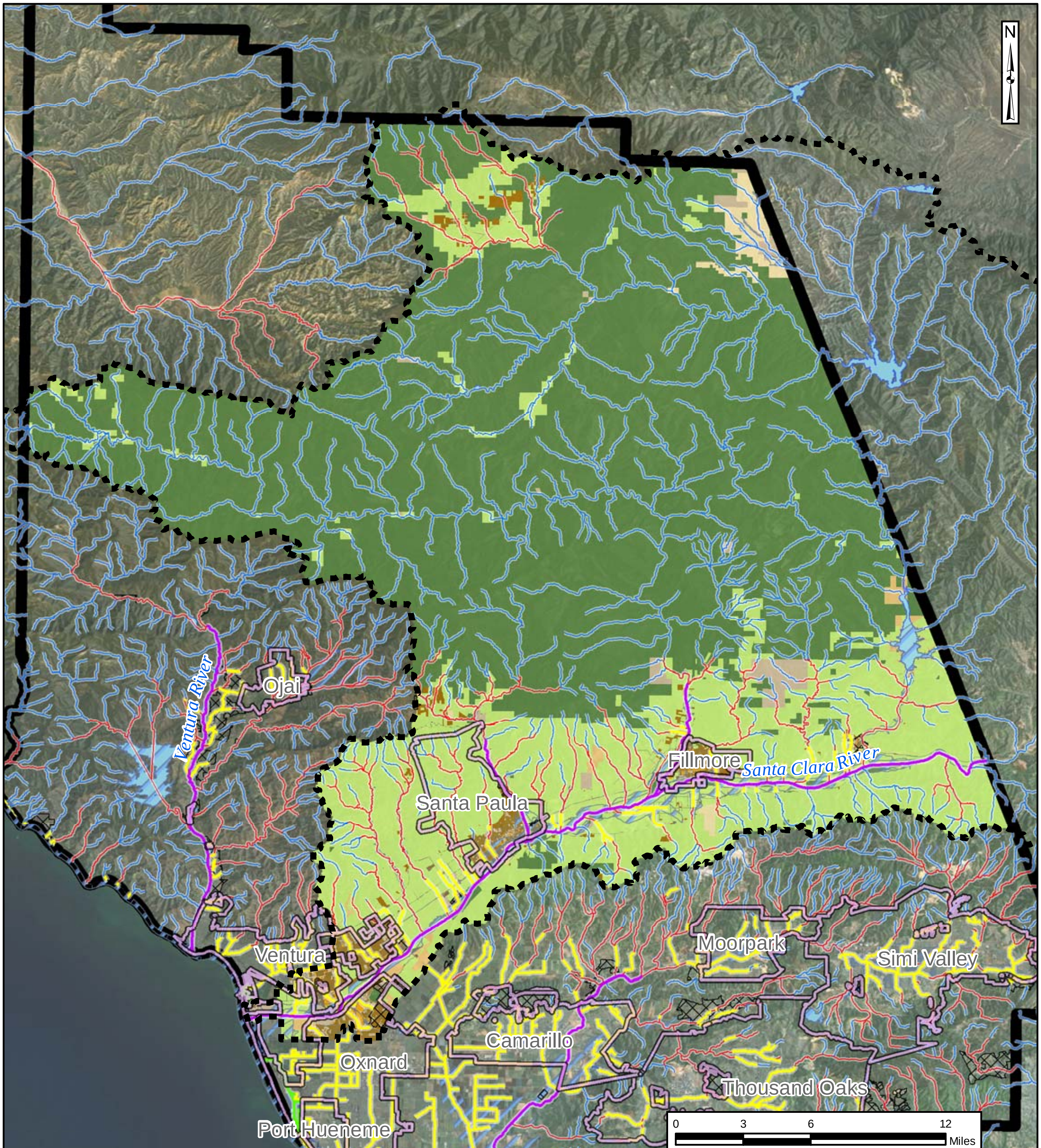
Ventura River Watershed Map

Ventura County, CA

Geosyntec consultants

WW1717	July 2013	Figure 2-7

P:\GIS\Ventura_County_HCP\Projects\Figure2-3VenturaRiverWatershedMapSmall.mxd



Legend

- Ventura County
- CURB Boundary
- Major Watersheds
- Urban County
- Lakes
- 100 Year Floodplain
- Large Channel (Q100>25,000 cfs)
- Modified Channel
- TidalChannel
- Natural Redline Channel
- Natural Blueline Channel

Existing Land Use

- Recreation
- Trans/Comm/Util
- Trade
- Services
- Residential
- Industrial
- Resource Production
- Undeveloped
- Unknown

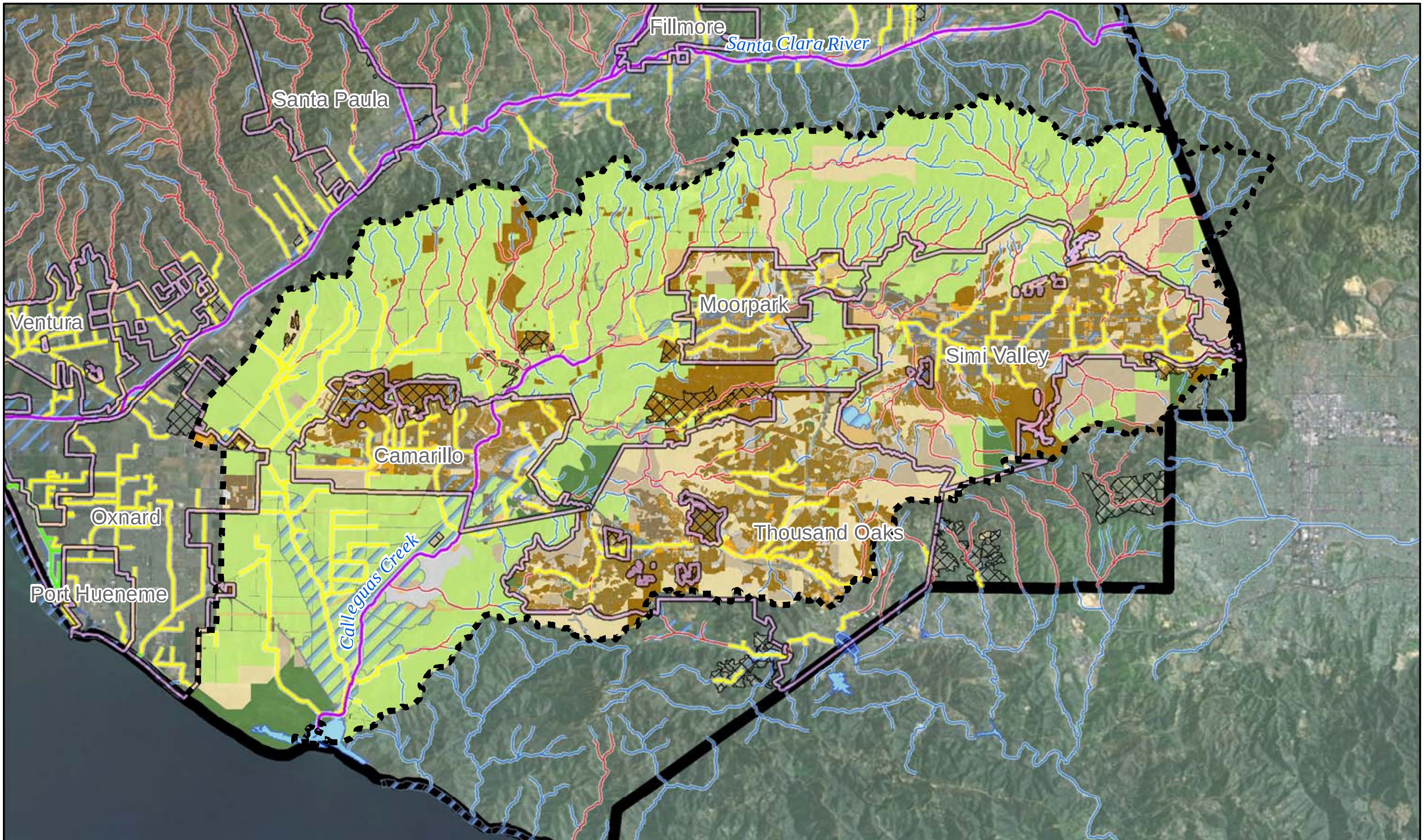
Santa Clara River Watershed Map

Ventura County, CA

Geosyntec consultants

WW1717	July 2013	Figure 2-8

P:\GIS\Ventura_County_HCP\Projects\Figure2-9SantaClaraRiverWatershedMapSmall.mxd



Legend

- Ventura County
- CURB Boundary
- Urban County
- Major Watersheds
- Lakes
- 100 Year Floodplain
- Large Channel (Q100>25,000 cfs)
- Modified Channel
- TidalChannel
- Natural Redline Channel
- Natural Blueline Channel

Existing Land Use

- Recreation
- Trans/Comm/Util
- Trade
- Services
- Residential
- Industrial
- Resource Production
- Undeveloped
- Unknown

N

0 4 8 Miles

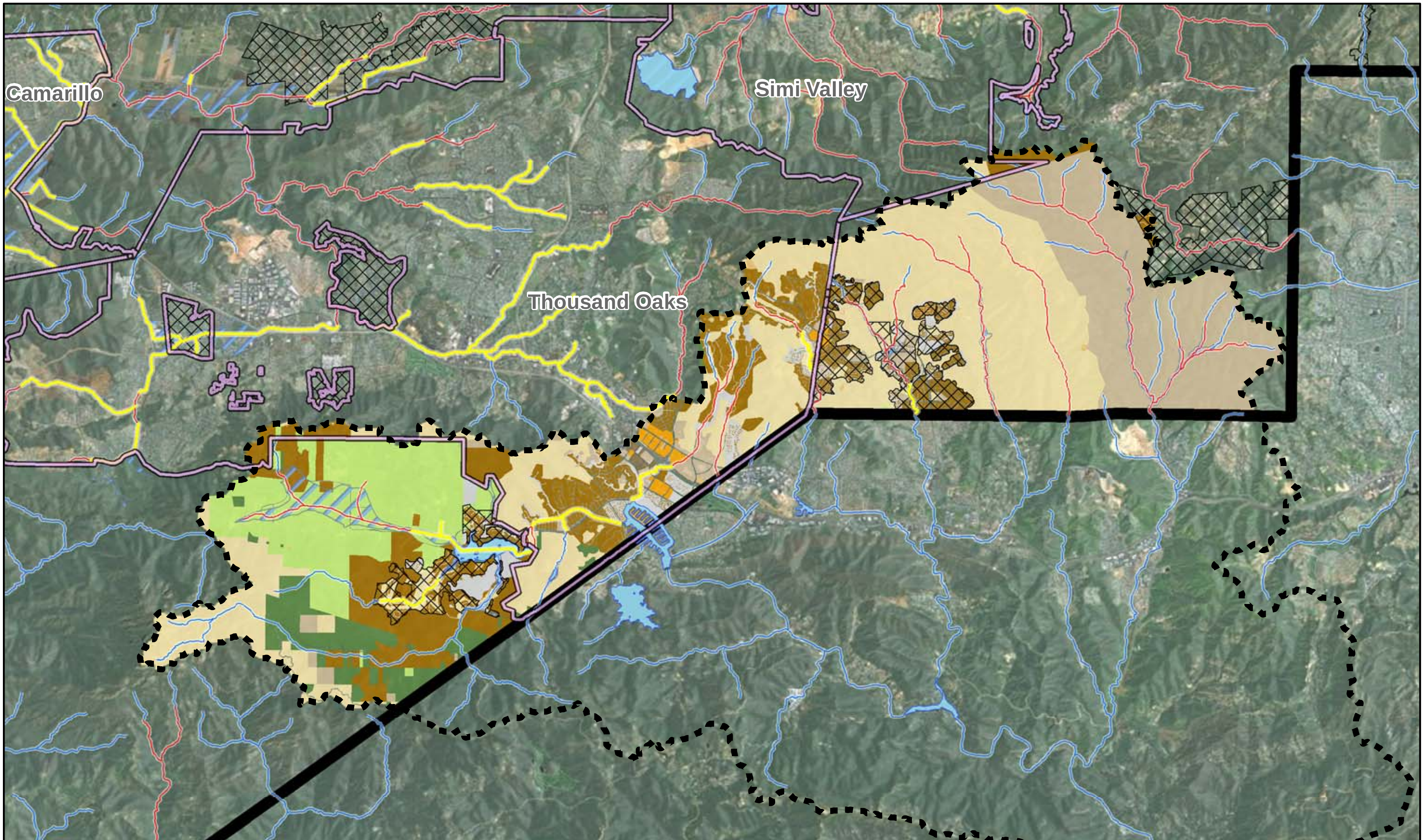
Calleguas Creek Watershed Map

Ventura County, CA

Geosyntec consultants

WW1717	July 2013	Figure 2-9

P:\GIS\Ventura_County_HCP\Projects\Figure2-10CalleguasCreekrWatershedMapSmall.mxd



Legend

- Ventura County
- CURB Boundary
- Urban County
- Major Watersheds
- Lakes
- 100 Year Floodplain
- Large Channel (Q100>25,000 cfs)
- Modified Channel
- TidalChannel
- Natural Redline Channel
- Natural Blueline Channel

Existing Land Use

- Recreation
- Trans/Comm/Util
- Trade
- Services
- Residential
- Industrial
- Resource Production
- Undeveloped
- Unknown

N

0 4 Miles

Malibu Creek Watershed Map

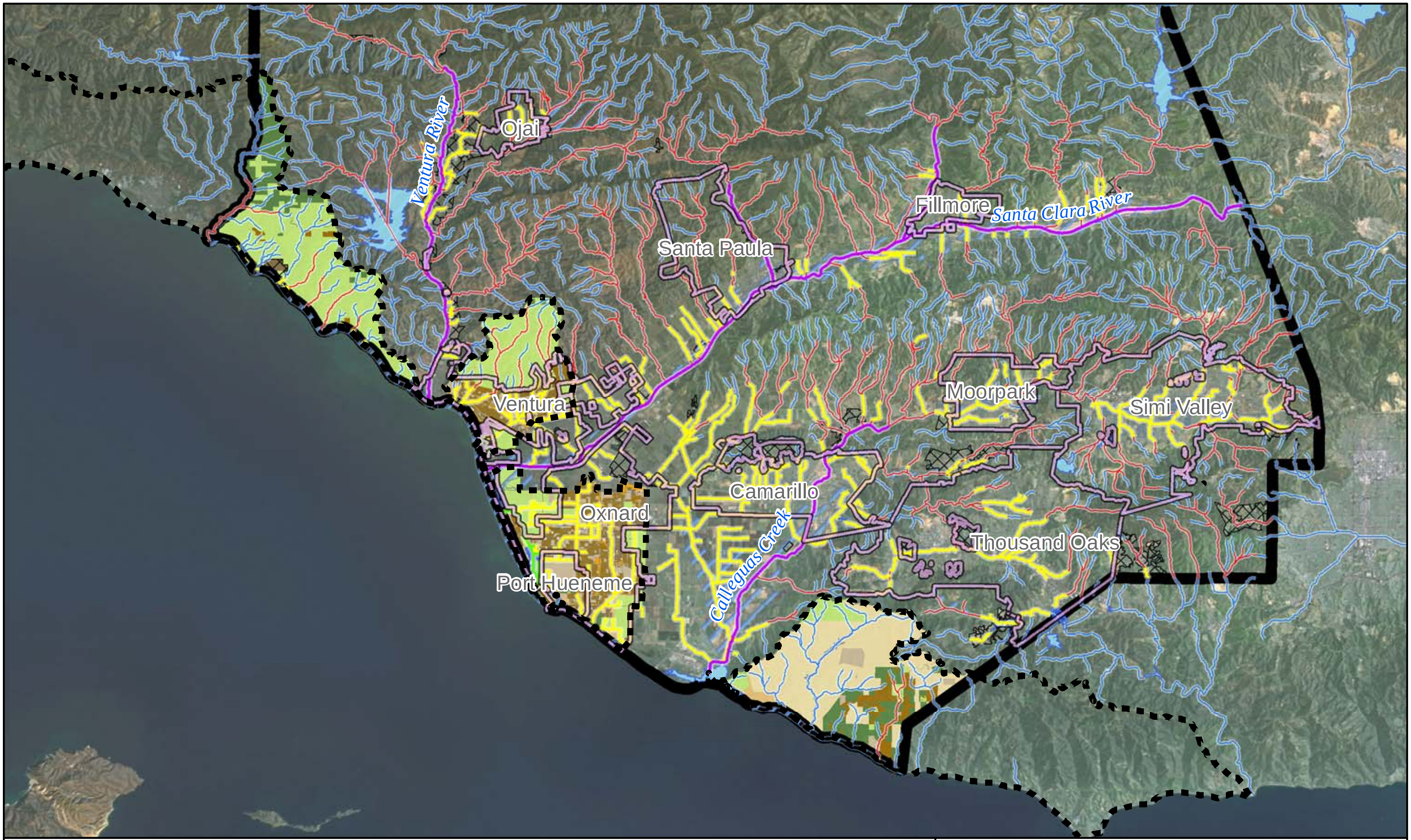
Ventura County, CA

Geosyntec consultants

WW1717 | July 2013

Figure 2-10

P:\GIS\Ventura_County_HCP\Projects\Figure2-11MalibuCreekWatershedMapSmall.mxd



Legend

Ventura County	Large Channel (Q100>25,000 cfs)
CURB Boundary	Modified Channel
Urban County	TidalChannel
Major Watersheds	Natural Redline Channel
Lakes	Natural Blueline Channel
100 Year Floodplain	

Existing Land Use

Recreation	Residential
Trans/Comm/Util	Industrial
Trade	Resource Production
Services	Undeveloped
	Unknown

N

0 6 12 Miles

Miscellaneous Ventura Coastal Watersheds Map

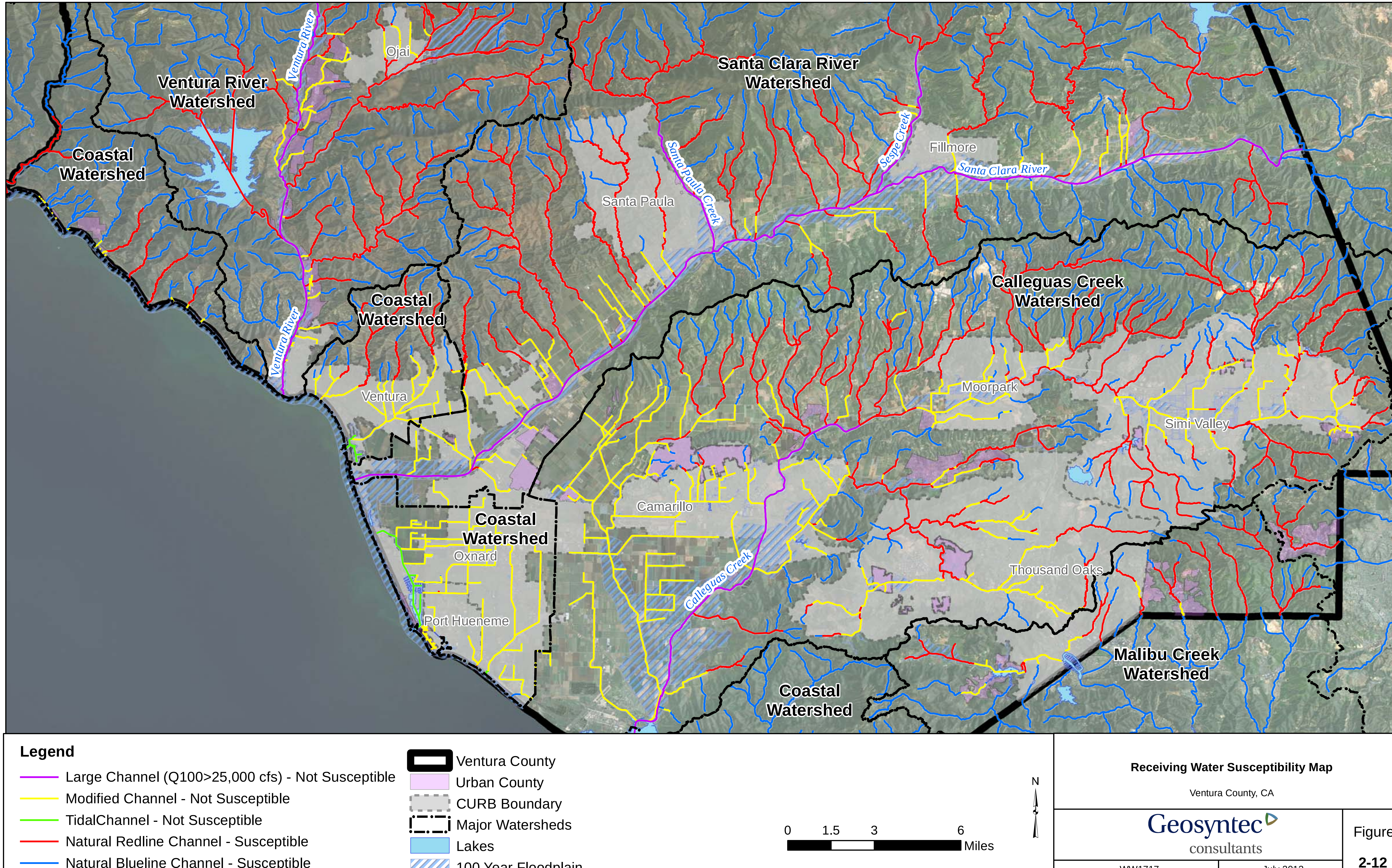
Ventura County, CA

Geosyntec consultants

WW1717 | July 2013

Figure 2-11

P:\GIS\Ventura_County_HCP\Projects\Figure2-12CoastalWatershedMapSmall.mxd



Receiving Water Susceptibility Map

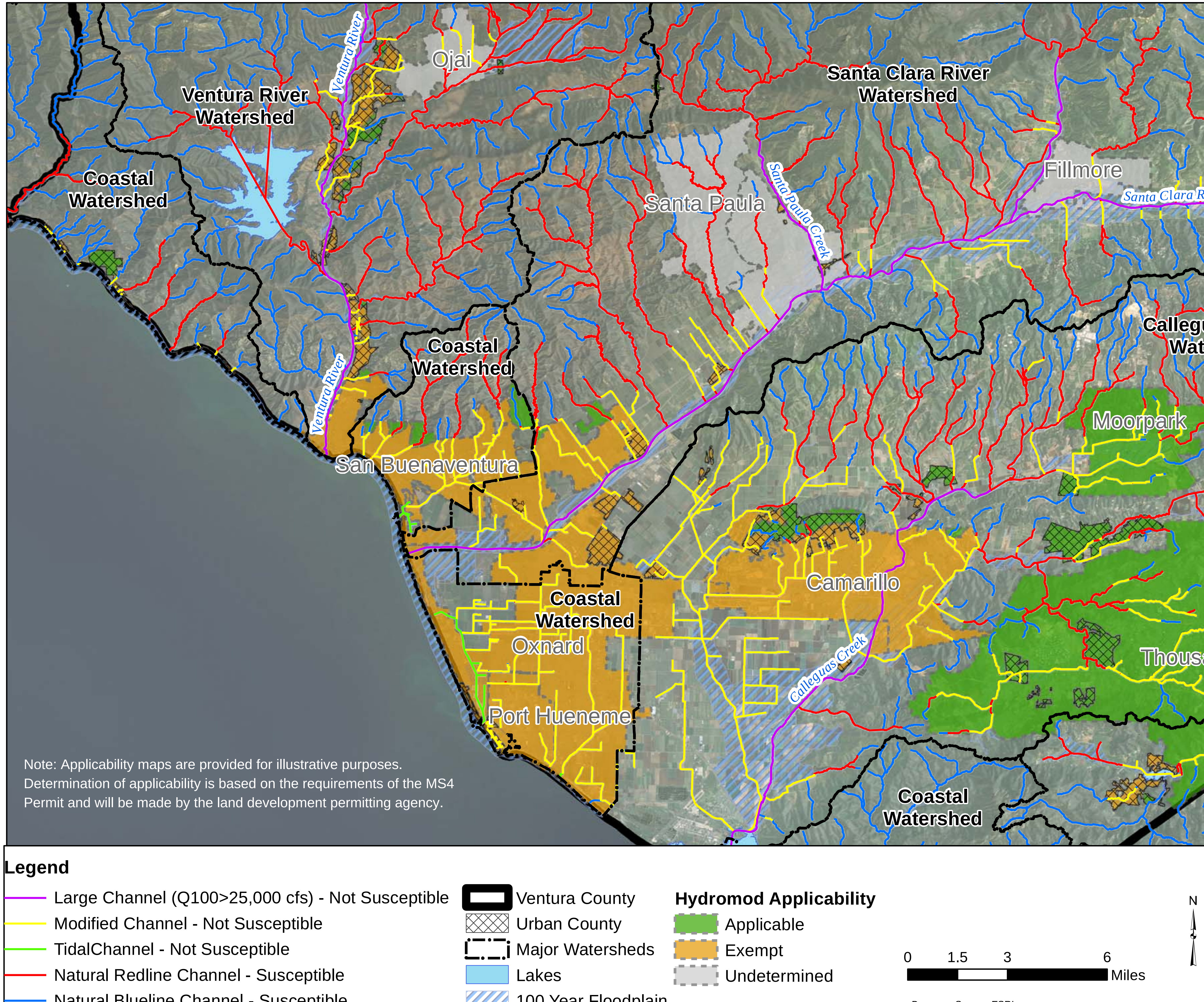
Ventura County, CA

Geosyntec consultants

WW1717 | July 2013

Figure 2-12

P:\GIS\Ventura_County_HCP\Projects\Figure2-8Susceptibility.mxd



Hydromodification Control Applicability Map

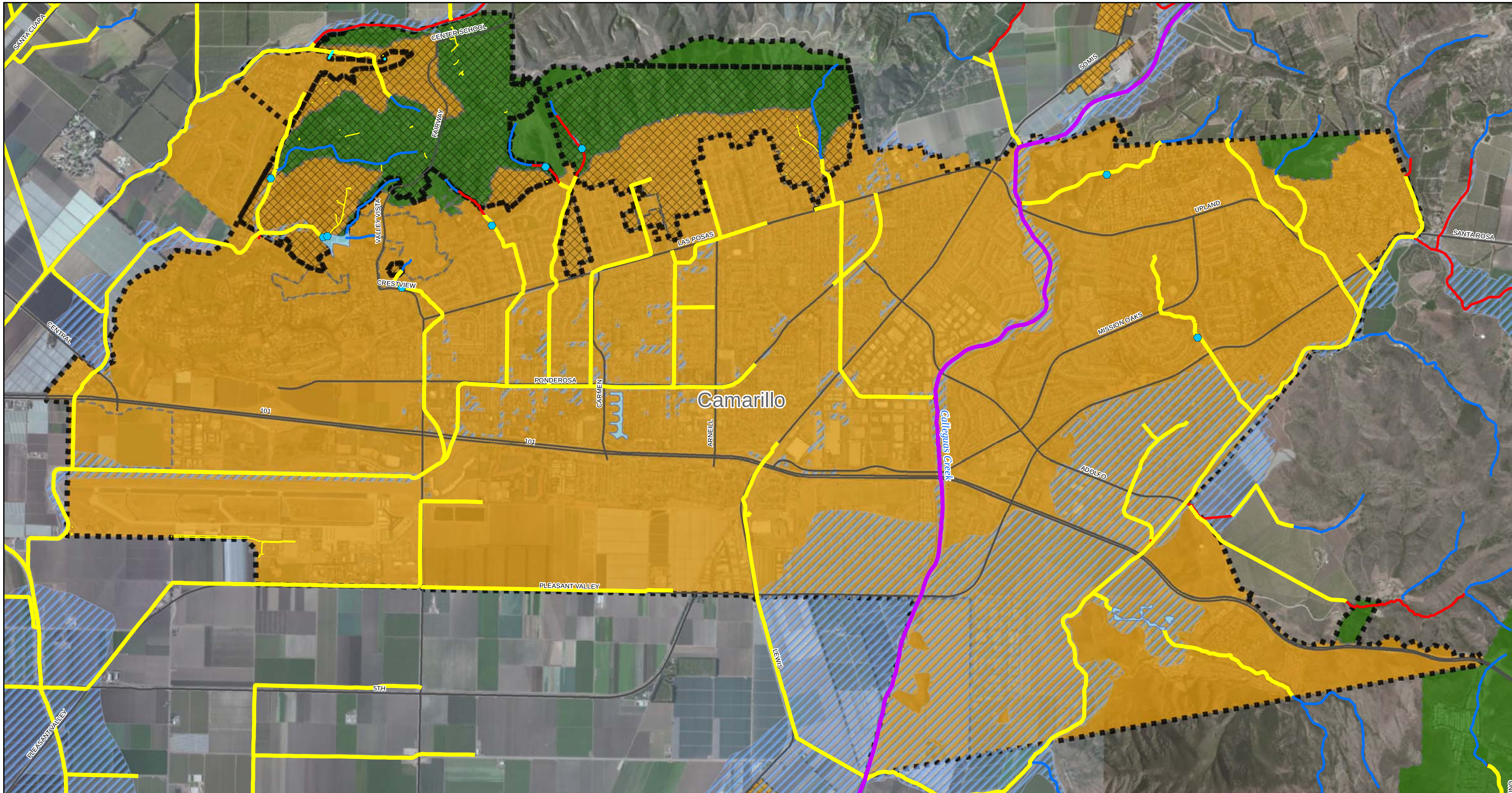
Ventura County, CA

Geosyntec consultants

WW1717 | July 2013

Figure 3-1

P:\GIS\Ventura_County_HCP\Projects\Fig3-1_ApplicabilityMap.mxd



Legend

- Large Channel (Q100>25,000 cfs) - Not Susceptible
- Modified Channel - Not Susceptible
- Tidal Channel - Not Susceptible
- Natural Redline Channel - Susceptible
- Natural Blueline Channel - Susceptible
- Storm Drain - Not Susceptible
- Lakes
- 100 Year Floodplain
- Urban County
- Street
- Basins

Hydromod Applicability

- Applicable
- Exempt
- Undetermined

Note: Applicability maps are provided for illustrative purposes. Determination of applicability is based on the requirements of the MS4 Permit and will be made by the land development permitting agency.

N

0 1,500 3,000 6,000 Feet

Basemap Source: ESRI

Hydromodification Control Applicability Map

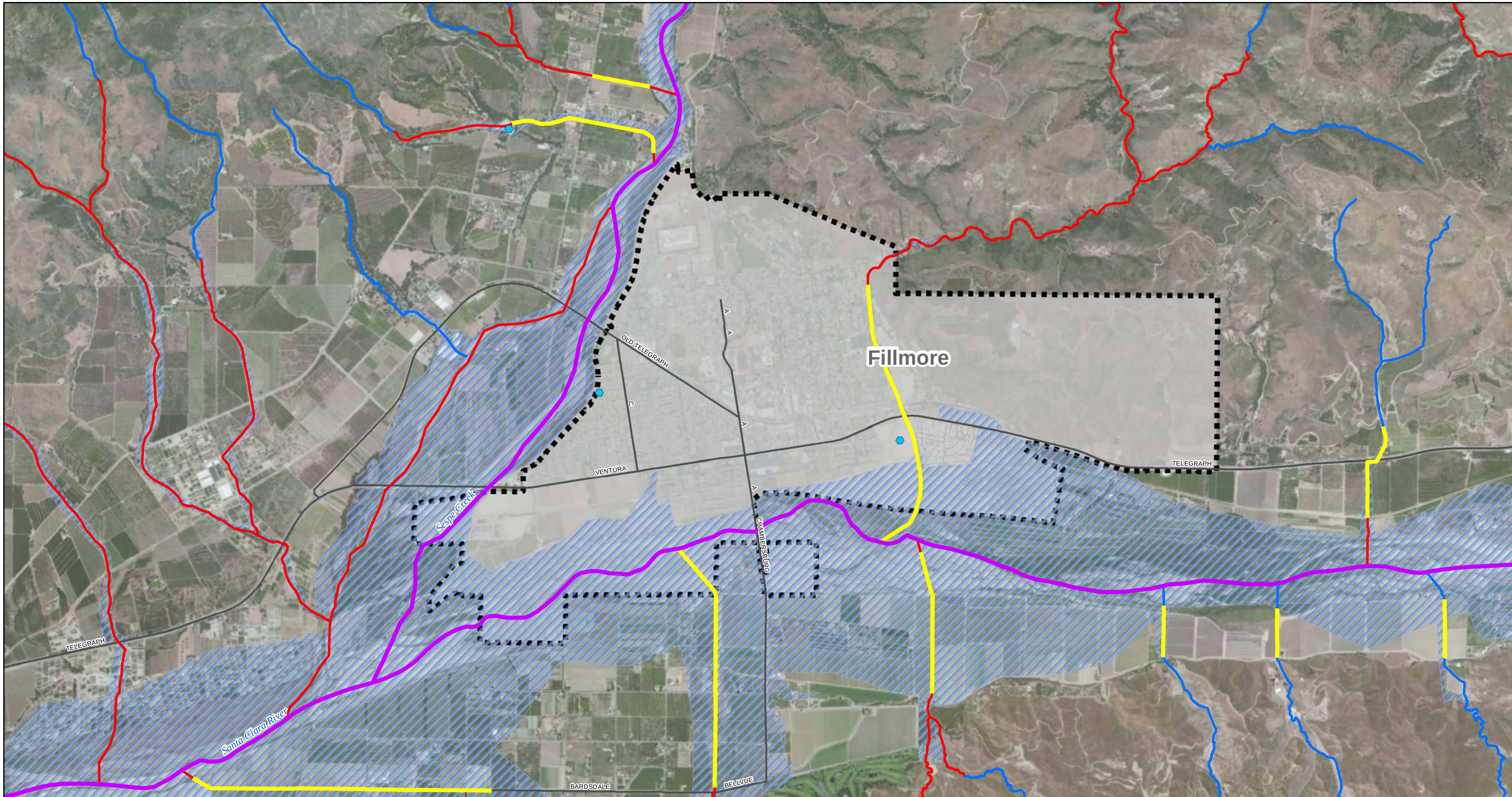
Camarillo, CA

Geosyntec consultants

WW1717 | July 2013

Figure 3-2

P:\GIS\Ventura_County_HCP\Projects\Cities\Figure3-2Camarillo.mxd



Legend

- Large Channel (Q100>25,000 cfs) - Not Susceptible
- Modified Channel - Not Susceptible
- Storm Drain - Not Susceptible
- Tidal Channel - Not Susceptible
- Natural Redline Channel - Susceptible
- Natural Blueline Channel - Susceptible
- Lakes
- 100 Year Floodplain
- Urban County
- Street
- Basins

Hydromod Applicability

- Applicable
- Exempt
- Undetermined

Note: Applicability maps are provided for illustrative purposes. Determination of applicability is based on the requirements of the MS4 Permit and will be made by the land development permitting agency.

N

0 1,250 2,500 5,000 Feet

Basemap Source: ESRI

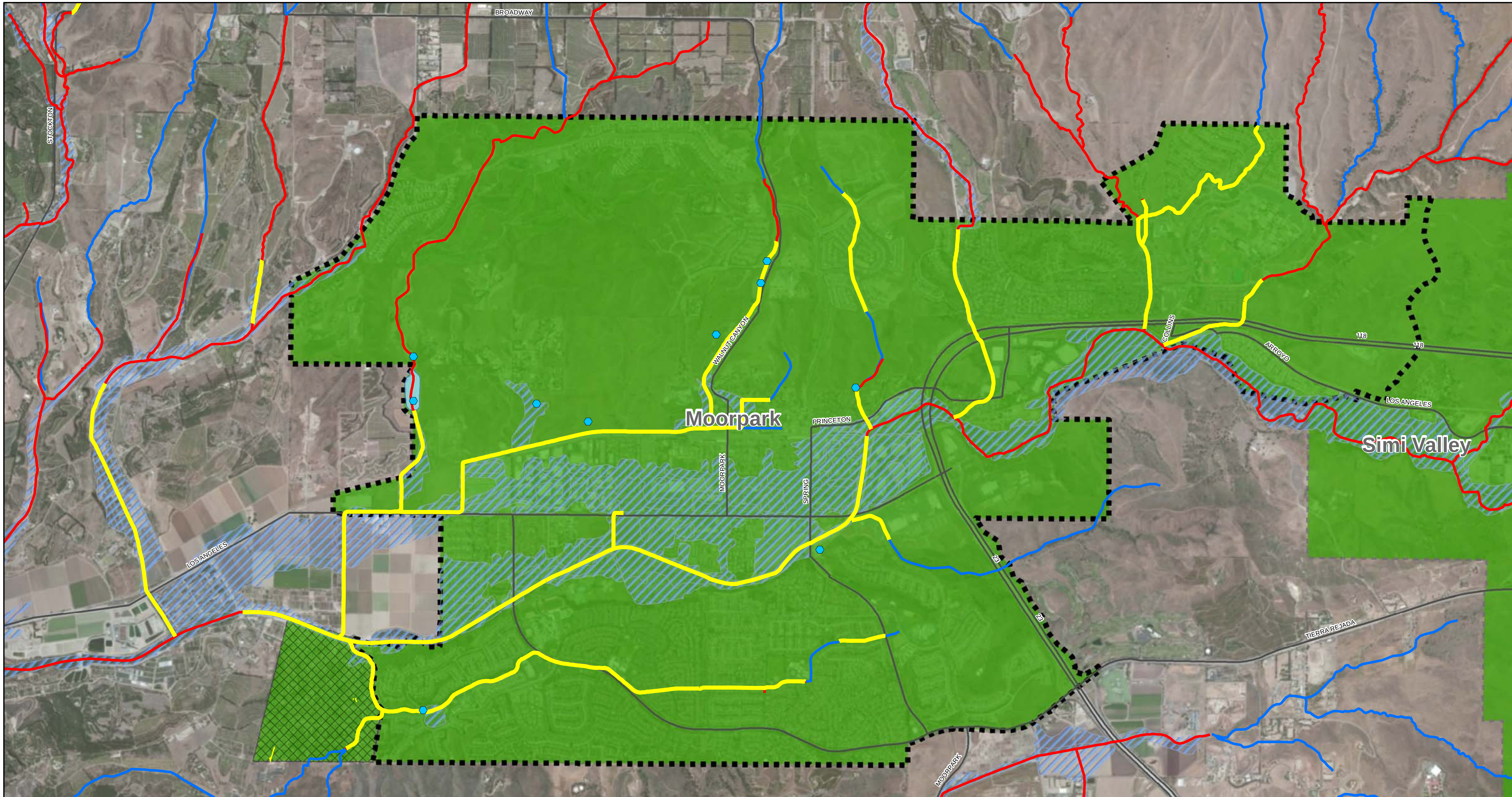
Hydromodification Control Applicability Map

Fillmore, CA

Geosyntec consultants

WW1717	July 2013	Figure 3-3

P:\GIS\Ventura_County_HCP\Projects\Cities\Figure3-3Filmore.mxd



Legend

- Large Channel (Q100>25,000 cfs) - Not Susceptible
- Modified Channel - Not Susceptible
- Storm Drain - Not Susceptible
- Tidal Channel - Not Susceptible
- Natural Redline Channel - Susceptible
- Natural Blueline Channel - Susceptible
- Lakes
- 100 Year Floodplain
- Urban County
- Street
- Basins

Hydromod Applicability

- Applicable
- Exempt
- Undetermined

Note: Applicability maps are provided for illustrative purposes. Determination of applicability is based on the requirements of the MS4 Permit and will be made by the land development permitting agency.

N

0 1,250 2,500 5,000 Feet

Basemap Source: ESRI

Hydromodification Control Applicability Map

Moorpark, CA

Geosyntec consultants

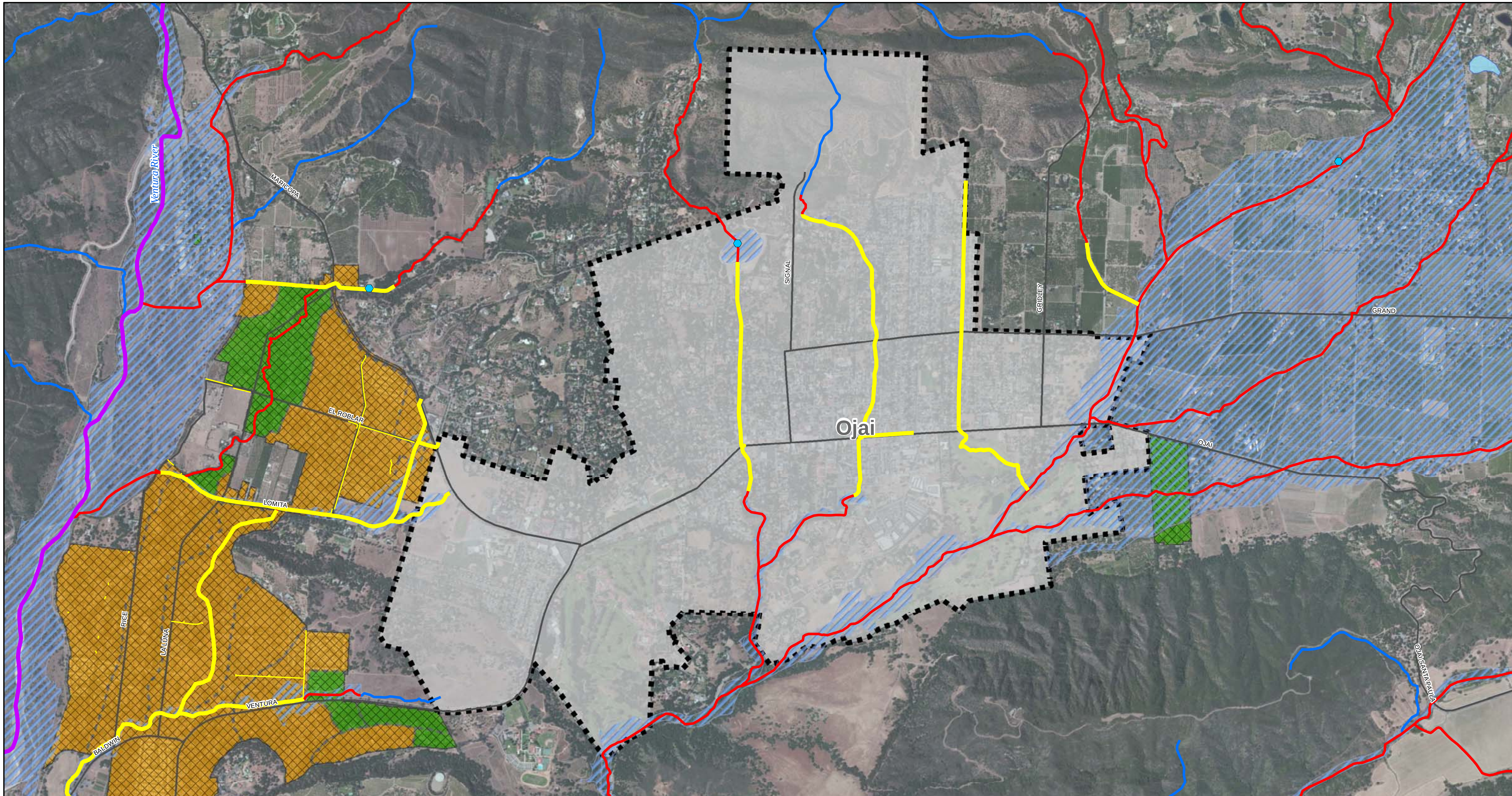
WW1717

July 2013

Figure

3-4

P:\GIS\Ventura_County_HCP\Projects\Cities\Figure3-4Moorepark.mxd



Legend

- Large Channel (Q100>25,000 cfs) - Not Susceptible
- Modified Channel - Not Susceptible
- Storm Drain - Not Susceptible
- Tidal Channel - Not Susceptible
- Natural Redline Channel - Susceptible
- Natural Blueline Channel - Susceptible

- Lakes
- 100 Year Floodplain
- Urban County
- Street
- Basins

Hydromod Applicability

- Applicable
- Exempt
- Undetermined

Note: Applicability maps are provided for illustrative purposes. Determination of applicability is based on the requirements of the MS4 Permit and will be made by the land development permitting agency.

0 1,000 2,000 4,000 Feet

N

Basemap Source: ESRI

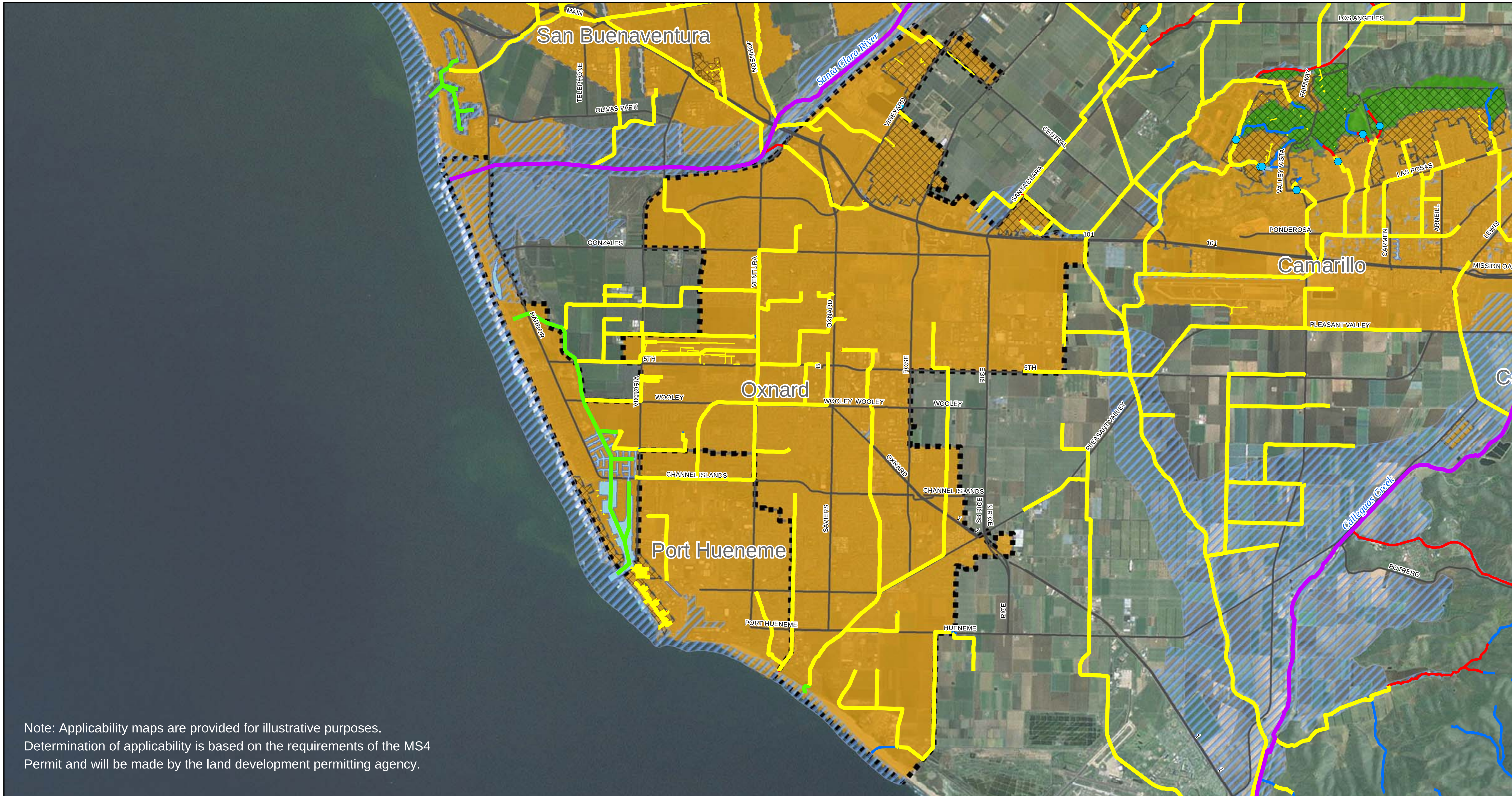
Hydromodification Control Applicability Map

Ojai, CA

Geosyntec consultants

WW1717	July 2013	Figure 3-5

P:\GIS\Ventura_County_HCP\Projects\Cities\Figure3-5Ojai.mxd



Legend

- Large Channel (Q100>25,000 cfs) - Not Susceptible
- Modified Channel - Not Susceptible
- Storm Drain - Not Susceptible
- Tidal Channel - Not Susceptible
- Natural Redline Channel - Susceptible
- Natural Blueline Channel - Susceptible
- Lakes
- 100 Year Floodplain
- Urban County
- Street
- Basins

Hydromod Applicability

- Applicable
- Exempt
- Undetermined

0 3,250 6,500 13,000 Feet

N

Basemap Source: ESRI

Hydromodification Control Applicability Map

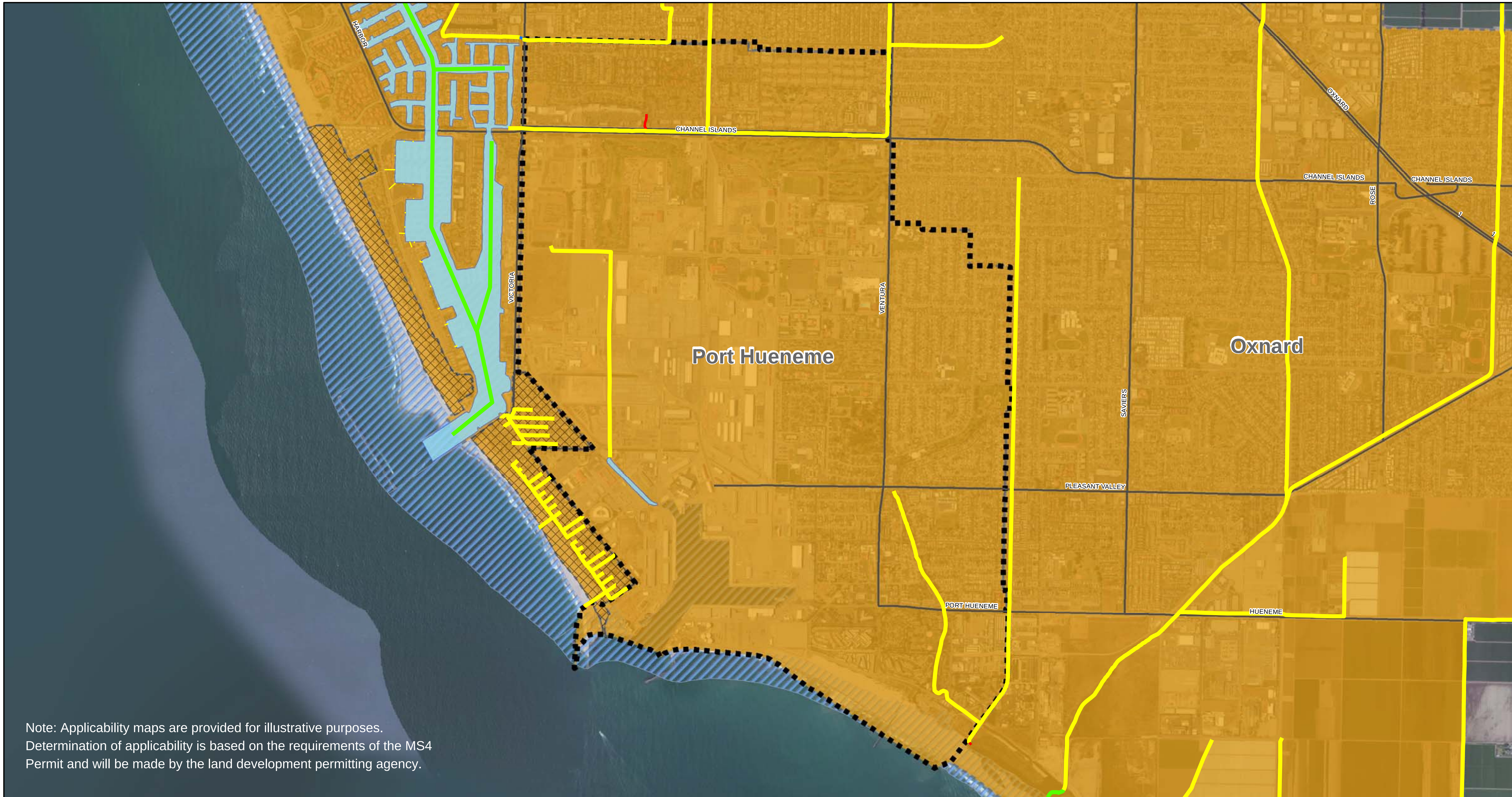
Oxnard, CA

Geosyntec consultants

WW1717 | July 2013

Figure 3-6

P:\GIS\Ventura_County_HCP\Projects\Cities\Figure3-6Oxnard.mxd



Note: Applicability maps are provided for illustrative purposes.
Determination of applicability is based on the requirements of the MS4 Permit and will be made by the land development permitting agency.

Legend

- Large Channel (Q100>25,000 cfs) - Not Susceptible
- Modified Channel - Not Susceptible
- Storm Drain - Not Susceptible
- Tidal Channel - Not Susceptible
- Natural Redline Channel - Susceptible
- Natural Blueline Channel - Susceptible
- Lakes
- 100 Year Floodplain
- Urban County
- Street
- Basins

Hydromod Applicability

- Applicable
- Exempt
- Undetermined

N

0 1,000 2,000 4,000 Feet

Basemap Source: ESRI

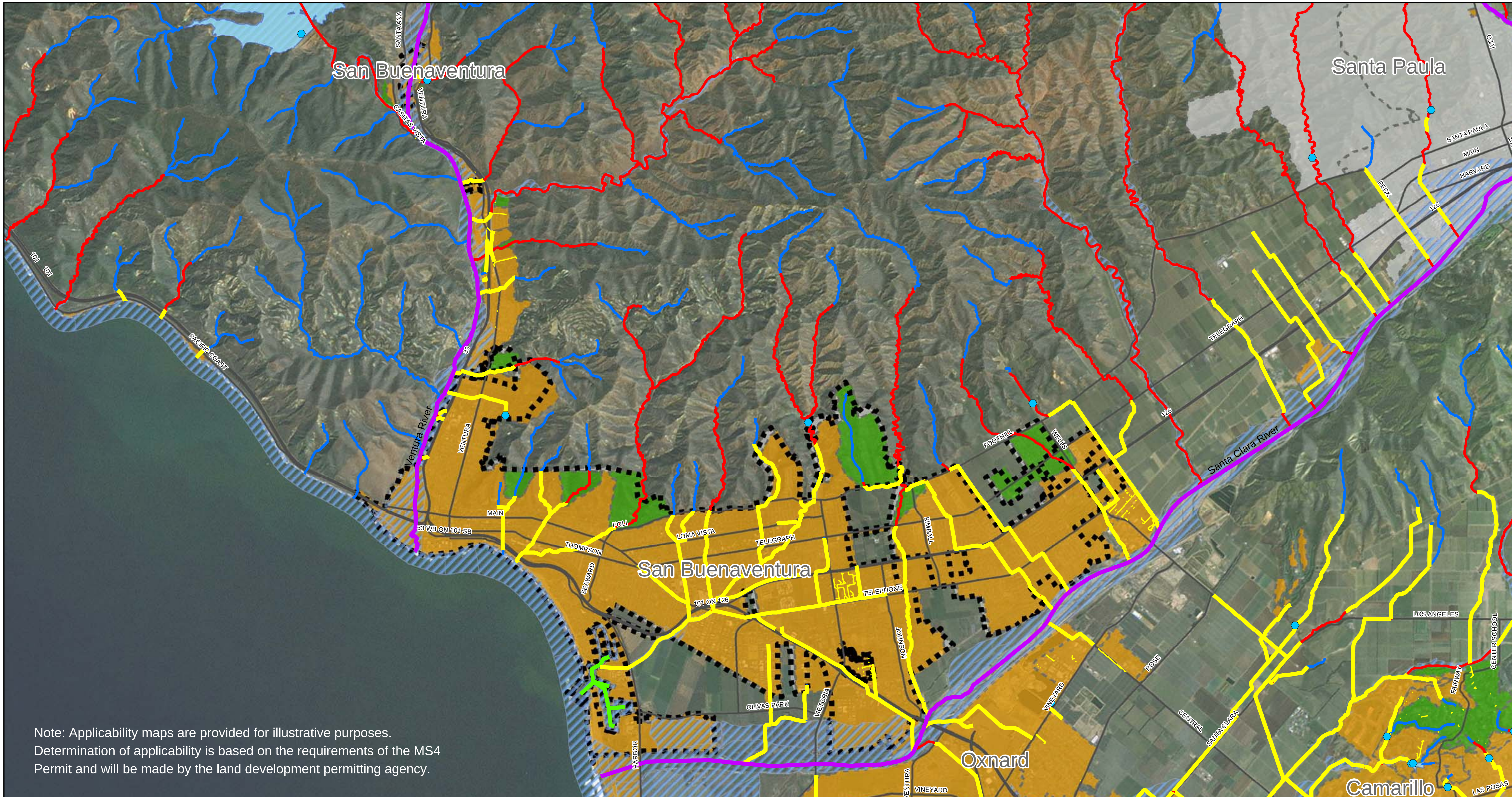
Hydromodification Control Applicability Map

Port Hueneme, CA

Geosyntec consultants

WW1717	July 2013	Figure 3-7

P:\GIS\Ventura_County_HCP\Projects\Cities\Figure3-7PortHueneme.mxd



Legend

- Large Channel (Q100>25,000 cfs) - Not Susceptible
- Modified Channel - Not Susceptible
- Storm Drain - Not Susceptible
- Tidal Channel - Not Susceptible
- Natural Redline Channel - Susceptible
- Natural Blueline Channel - Susceptible
- Lakes
- 100 Year Floodplain
- Street
- Basins

Hydromod Applicability

- Applicable
- Exempt
- Undetermined

0 3,250 6,500 13,000 Feet

N

Basemap Source: ESRI

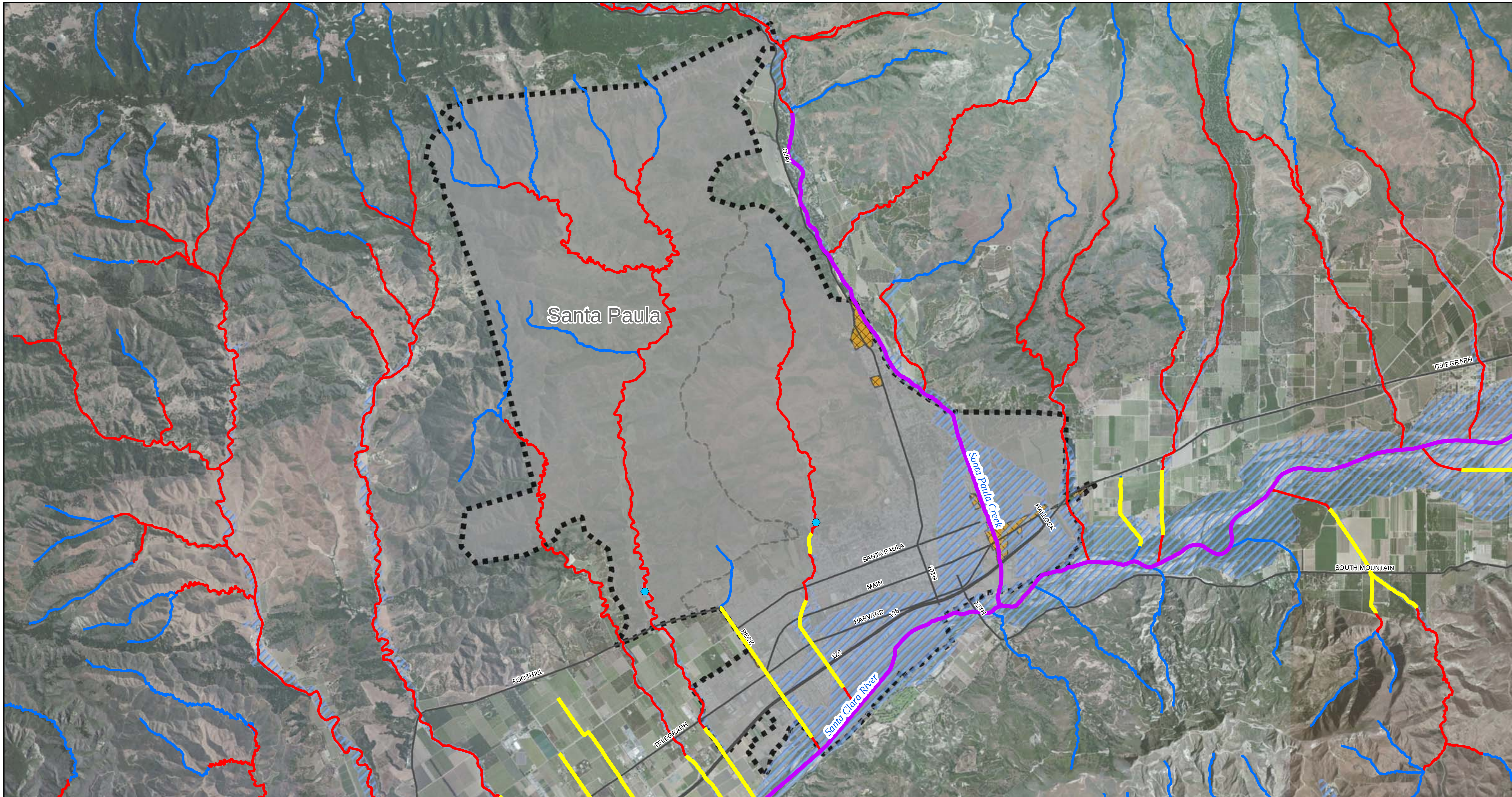
Hydromodification Control Applicability Map

San Buenaventura, CA

Geosyntec consultants

WW1717	July 2013	Figure 3-8

P:\GIS\Ventura_County_HCP\Projects\Cities\Figure3-8Ventura.mxd



Legend

- Large Channel (Q100>25,000 cfs) - Not Susceptible
- Modified Channel - Not Susceptible
- Storm Drain - Not Susceptible
- Tidal Channel - Not Susceptible
- Natural Redline Channel - Susceptible
- Natural Blueline Channel - Susceptible
- Lakes
- 100 Year Floodplain
- Urban County
- Street
- Basins

Hydromod Applicability

- Applicable
- Exempt
- Undetermined

Note: Applicability maps are provided for illustrative purposes. Determination of applicability is based on the requirements of the MS4 Permit and will be made by the land development permitting agency.

N

0 2,250 4,500 9,000 Feet

Basemap Source: ESRI

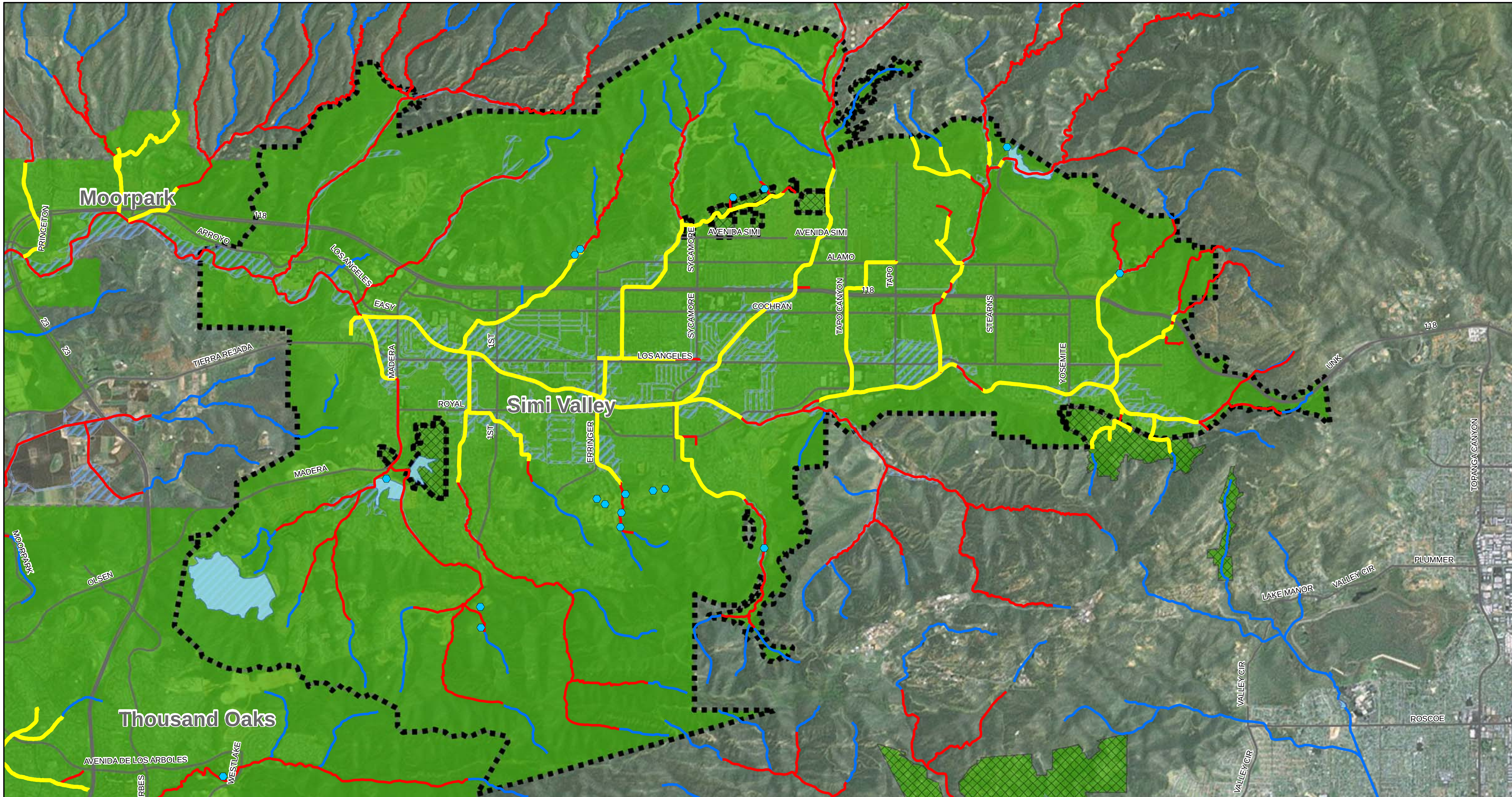
Hydromodification Control Applicability Map

Santa Paula, CA

Geosyntec consultants

WW1717	July 2013	Figure 3-9

P:\GIS\Ventura_County_HCP\Projects\Cities\Figure3-9SantaPaula2.mxd



Legend

- Large Channel (Q100>25,000 cfs) - Not Susceptible
- Modified Channel - Not Susceptible
- Storm Drain - Not Susceptible
- Tidal Channel - Not Susceptible
- Natural Redline Channel - Susceptible
- Natural Blueline Channel - Susceptible
- Lakes
- 100 Year Floodplain
- Urban County
- Street
- Basins

Hydromod Applicability

- Applicable
- Exempt
- Undetermined

Note: Applicability maps are provided for illustrative purposes. Determination of applicability is based on the requirements of the MS4 Permit and will be made by the land development permitting agency.

N

0 2,500 5,000 10,000 Feet

Basemap Source: ESRI

Hydromodification Control Applicability Map

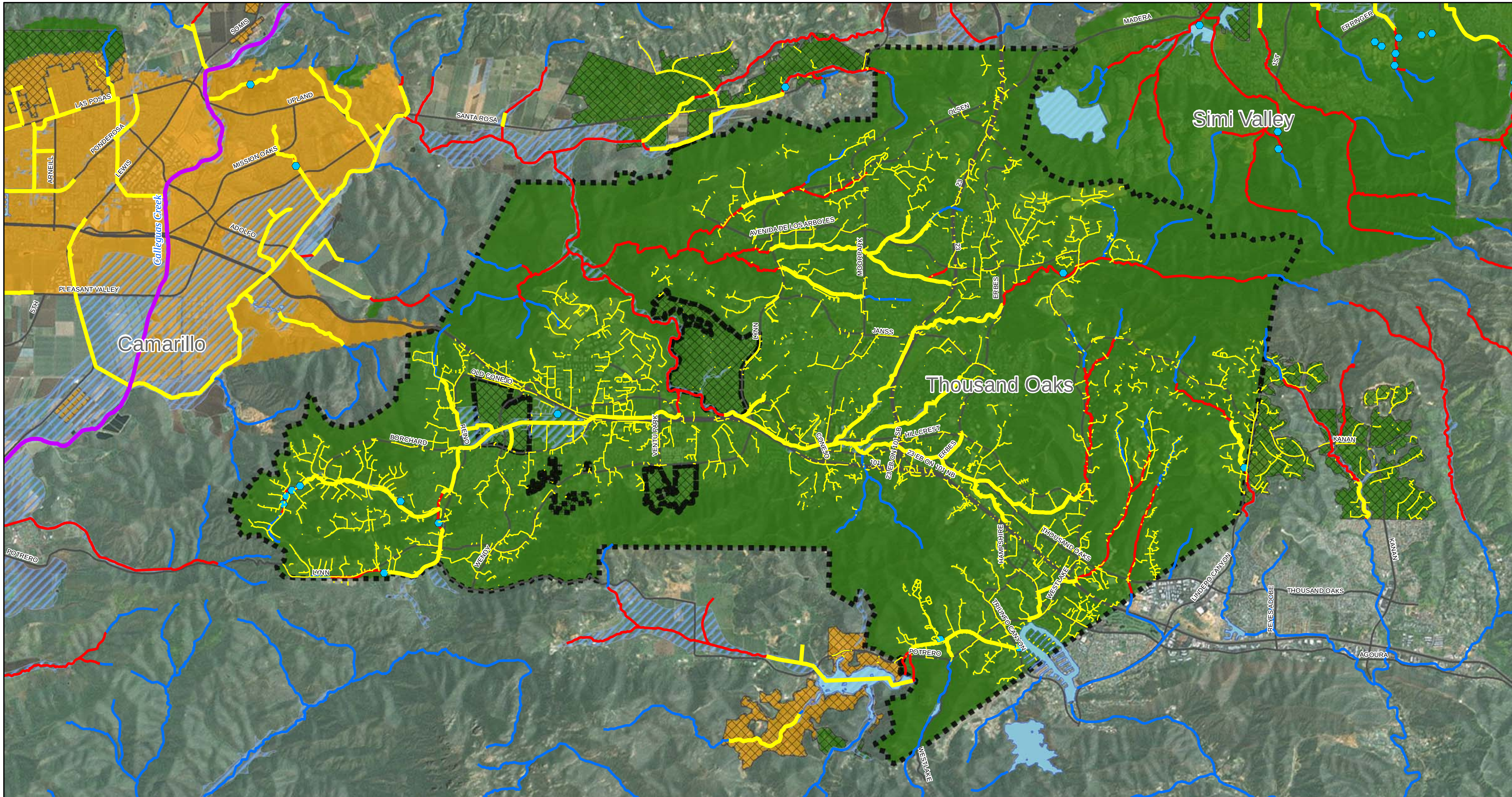
Simi Valley, CA

Geosyntec consultants

WW1717 | July 2013

Figure 3-10

P:\GIS\Ventura_County_HCP\Projects\Cities\Figure3-10SimiValley.mxd



Legend

- Large Channel (Q100>25,000 cfs) - Not Susceptible
- Modified Channel - Not Susceptible
- Storm Drain - Not Susceptible
- Tidal Channel - Not Susceptible
- Natural Redline Channel - Susceptible
- Natural Blueline Channel - Susceptible
- Lakes
- 100 Year Floodplain
- Urban County
- Street
- Basins

Hydromod Applicability

- Applicable
- Exempt
- Undetermined

Note: Applicability maps are provided for illustrative purposes. Determination of applicability is based on the requirements of the MS4 Permit and will be made by the land development permitting agency.

N

0 3,000 6,000 12,000 Feet

Basemap Source: ESRI

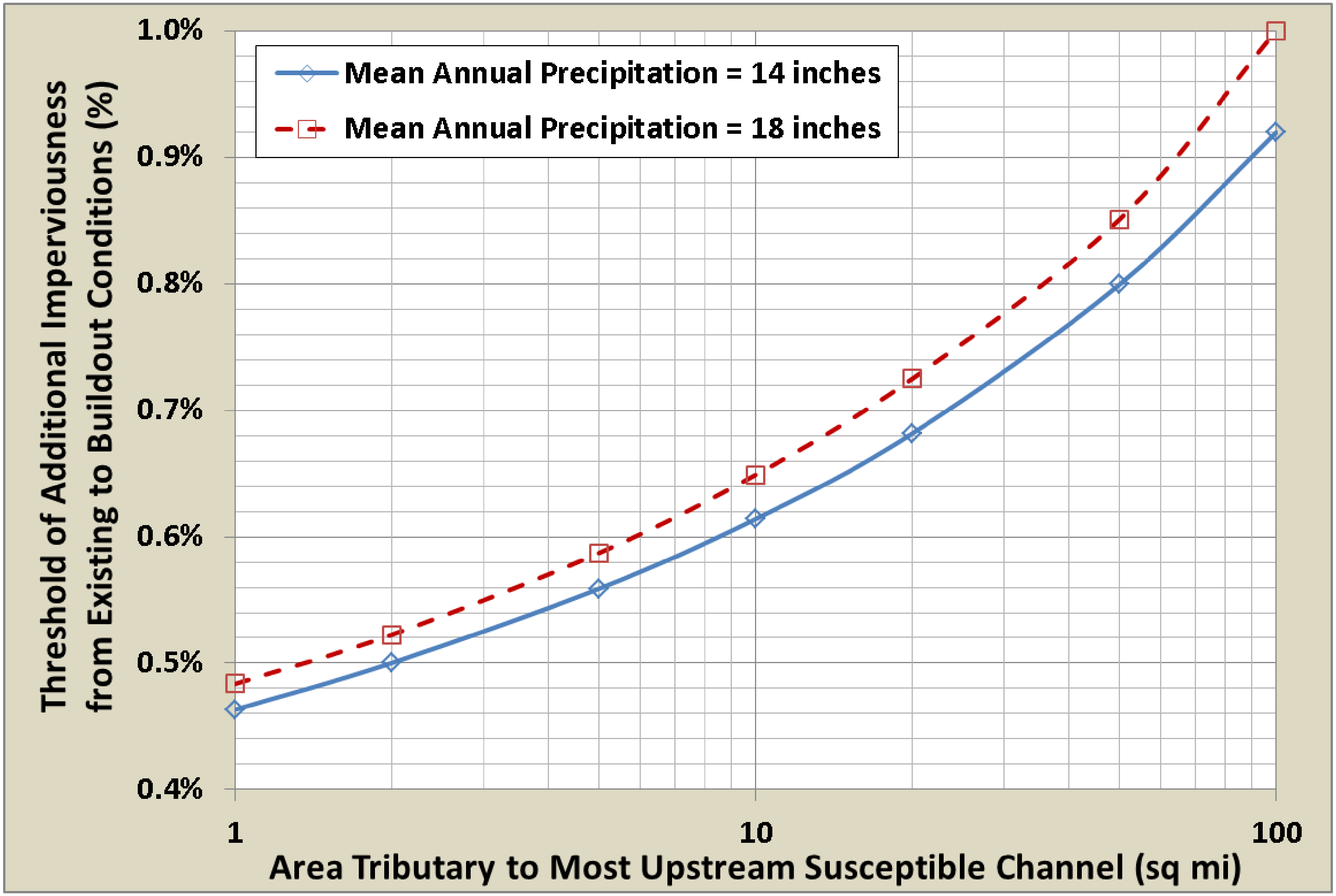
Hydromodification Control Applicability Map

Thousand Oaks, CA

Geosyntec consultants

WW1717	July 2013	Figure 3-11

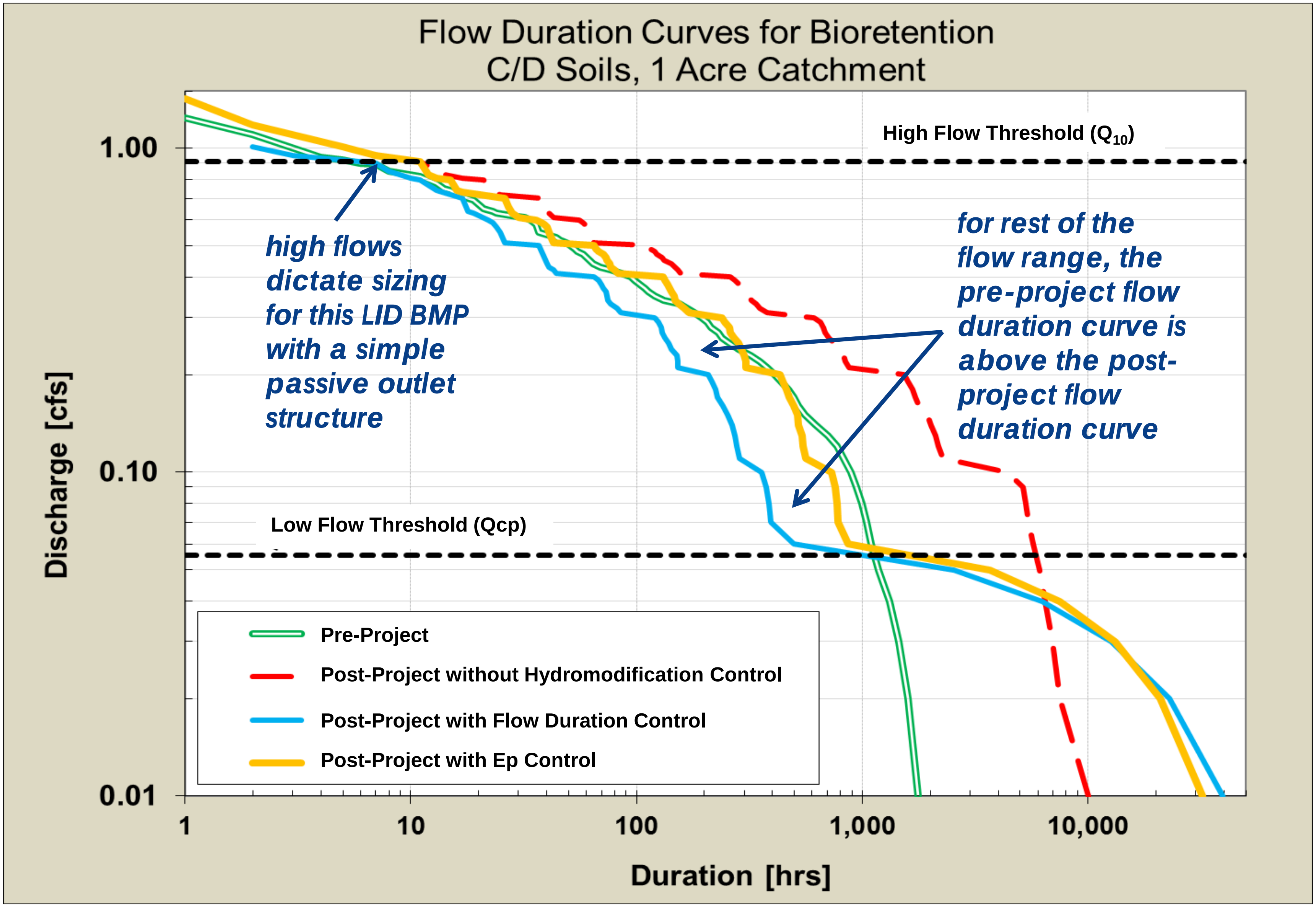
P:\GIS\Ventura_County_HCP\Projects\Cities\Figure3-11ThousandOaks.mxd



internal info: path, date revised, author

Geosyntec consultants

Threshold of Additional Imperviousness Below Which the Risk of Cumulative Hydromodification Impact is Negligible		Figure **3-12**
Oakland	July 2013	

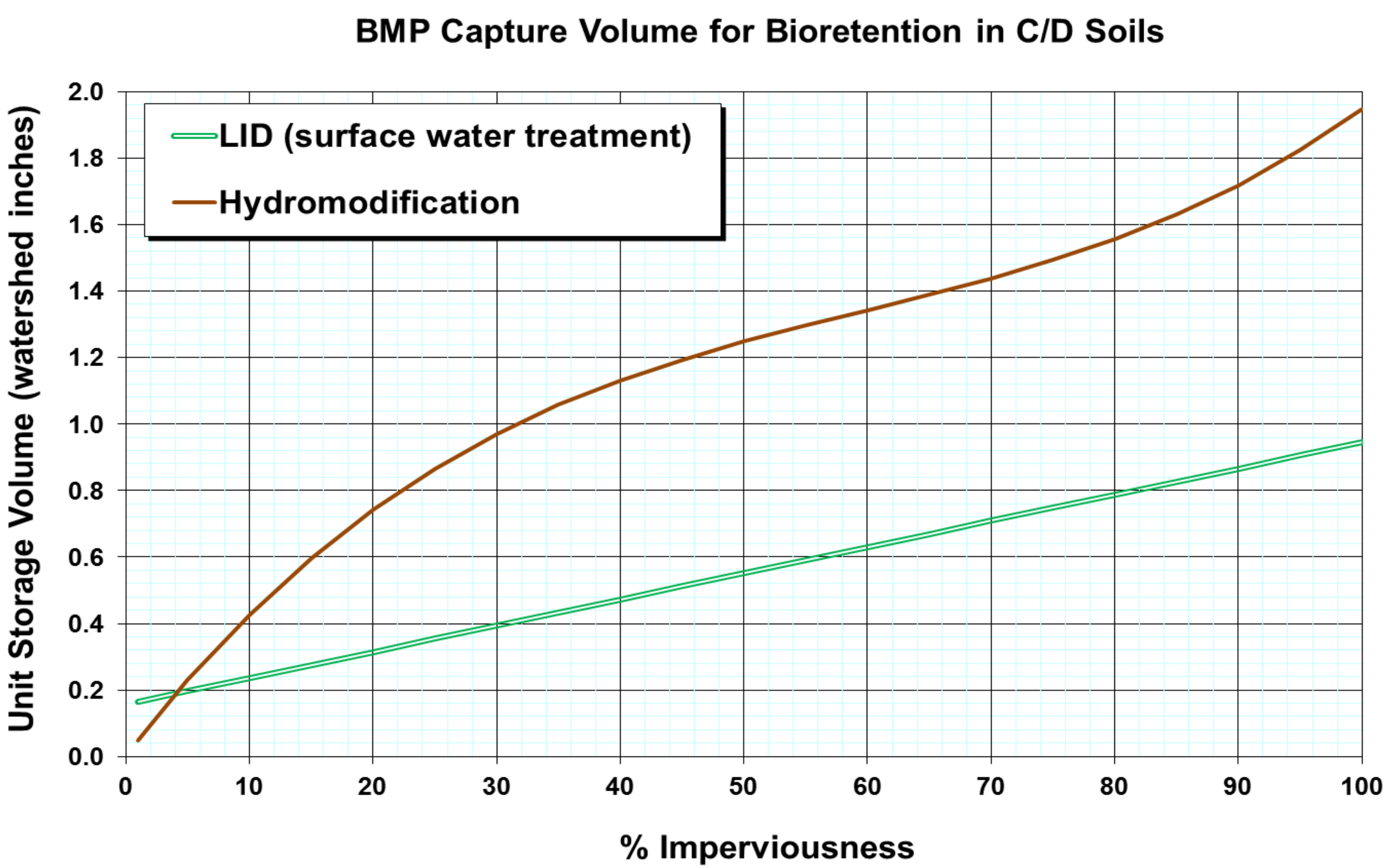


Geosyntec consultants

Example Flow Duration Curve Comparison for Flow Duration Control and Erosion Potential Control

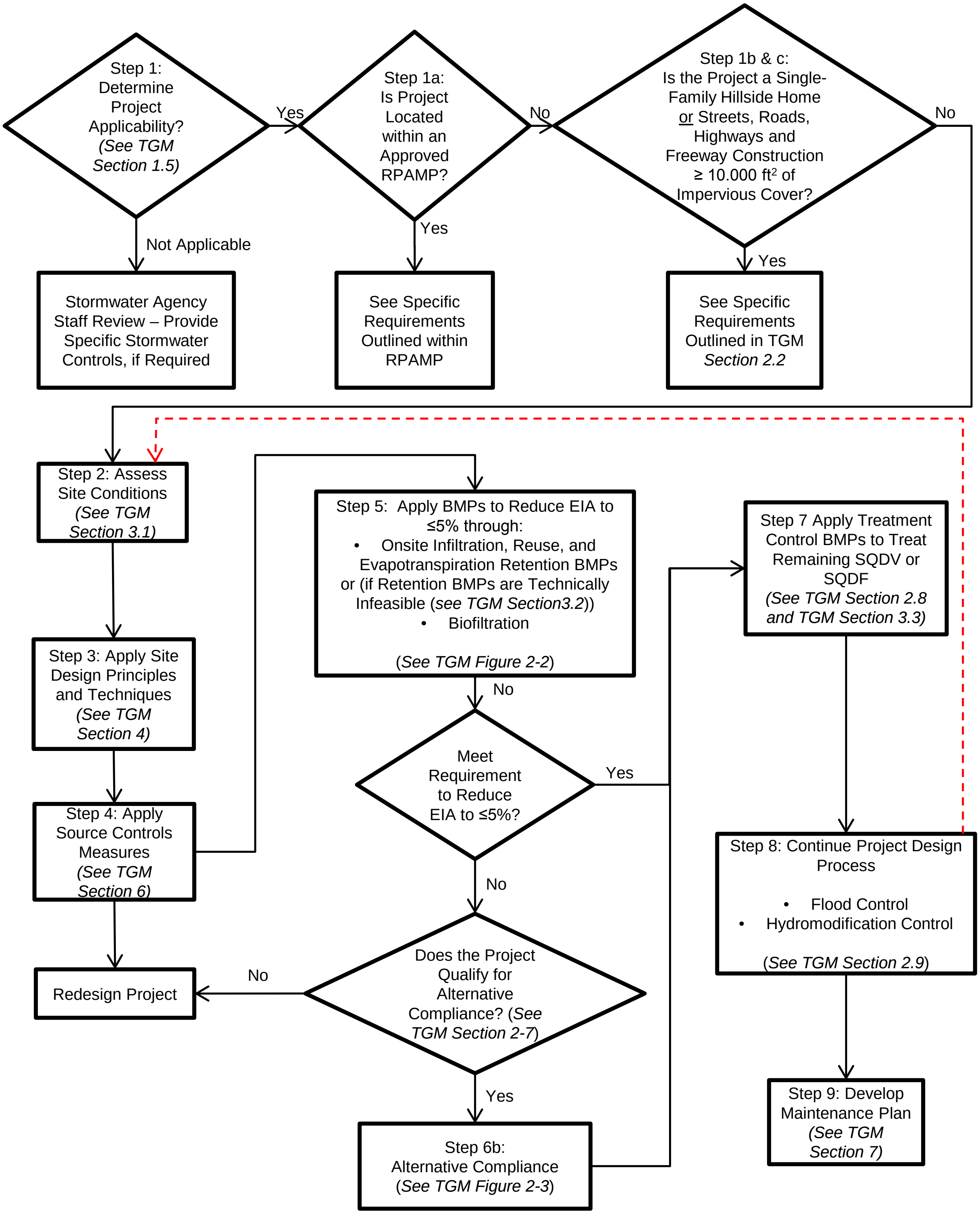
Oakland	July 2013

Figure
4-1



Geosyntec consultants

Example BMP Sizing Nomograph		Figure 4-2
Oakland	July 2013	



*If after several iterations, a new development project is still unable to meet 5% EIA, then the applicant may have to examine other options such as redesigning the site.

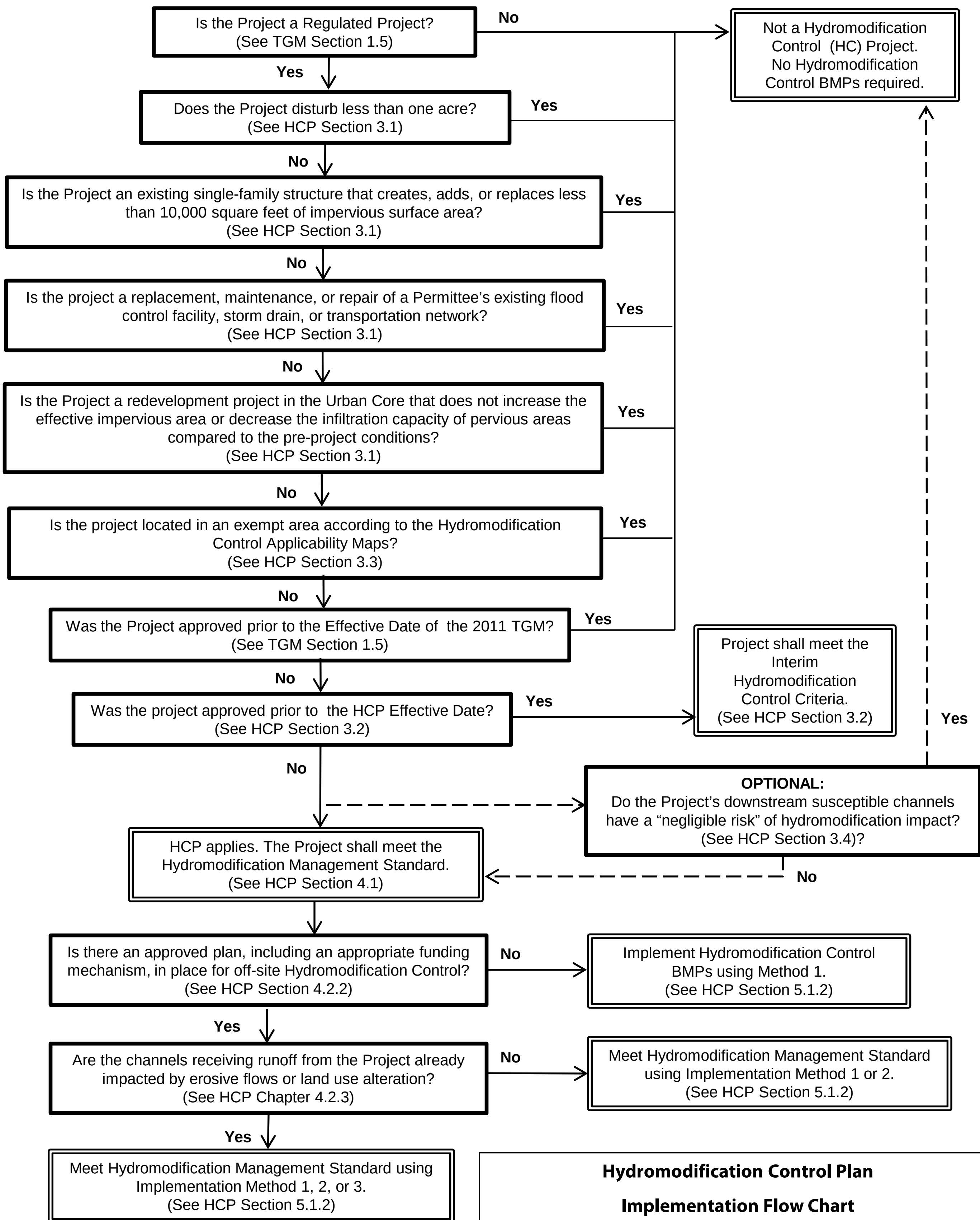
Stormwater Management Control Measures Design Decision Flow Chart

Geosyntec consultants

Oakland | July 2013

Figure **5-1**

internal info: path, date revised, author



Hydromodification Control Plan

Implementation Flow Chart

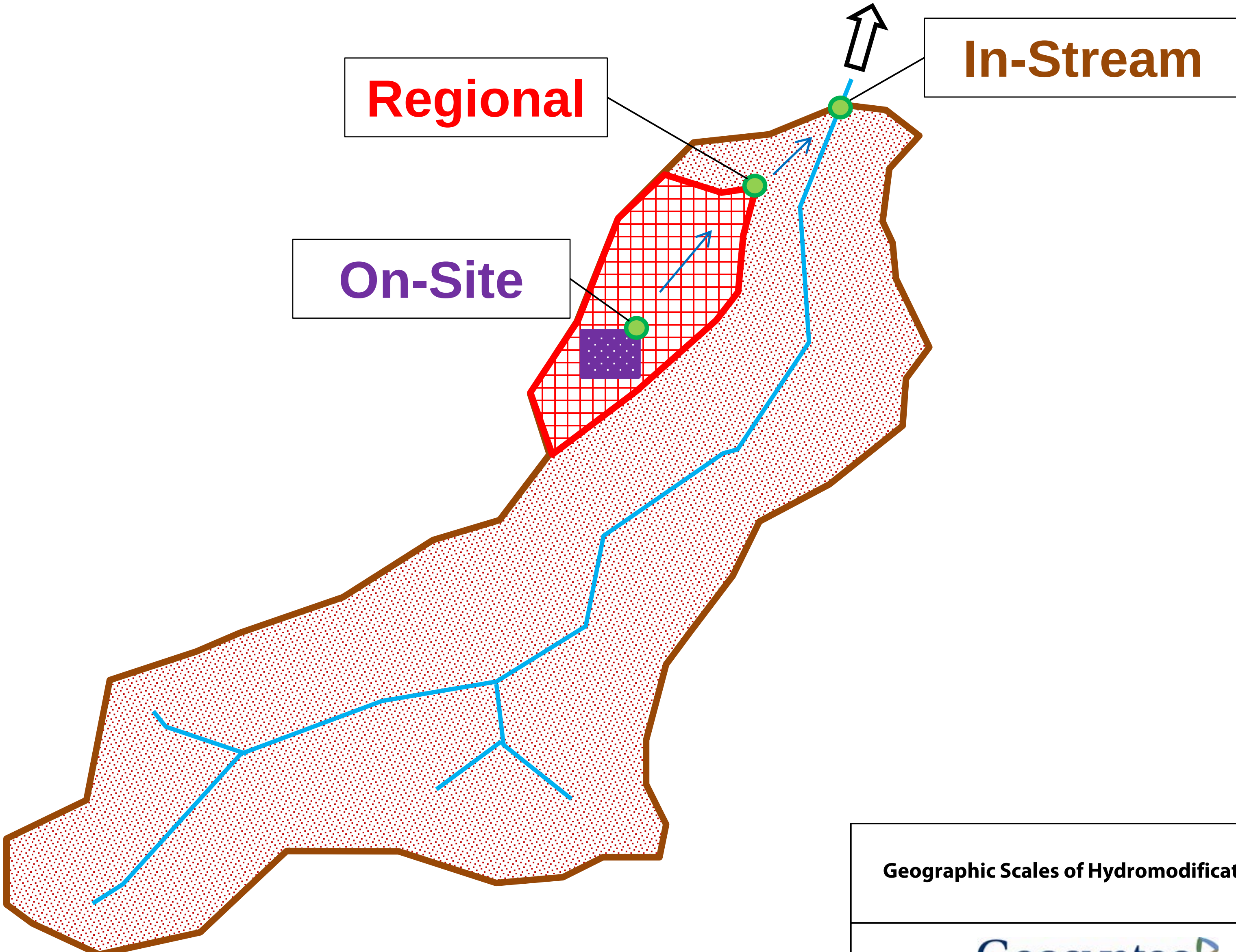
Geosyntec consultants

Figure

5-2

Oakland | July 2013

internal info: path, date revised, author

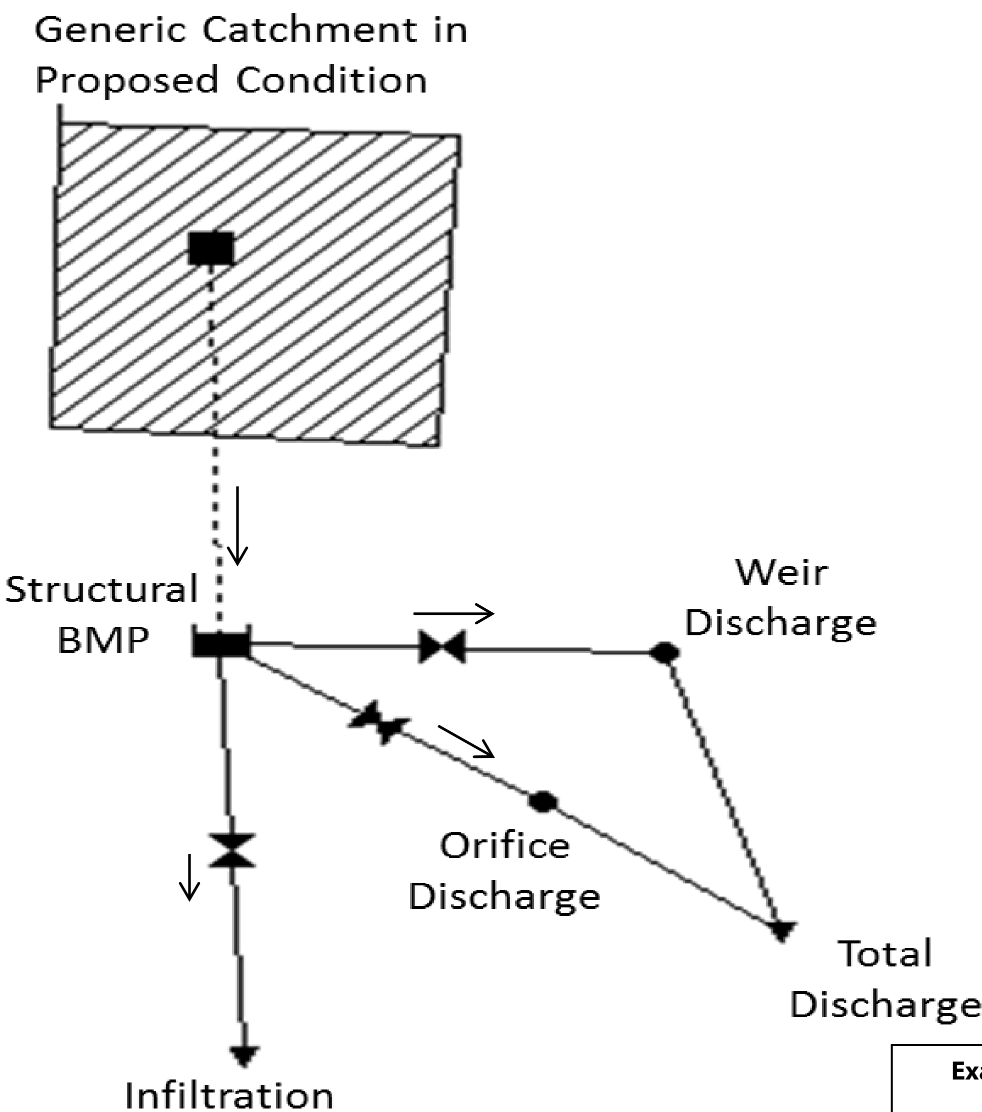


Geographic Scales of Hydromodification Control BMPs

Geosyntec consultants

Figure 5-3

Oakland | July 2013



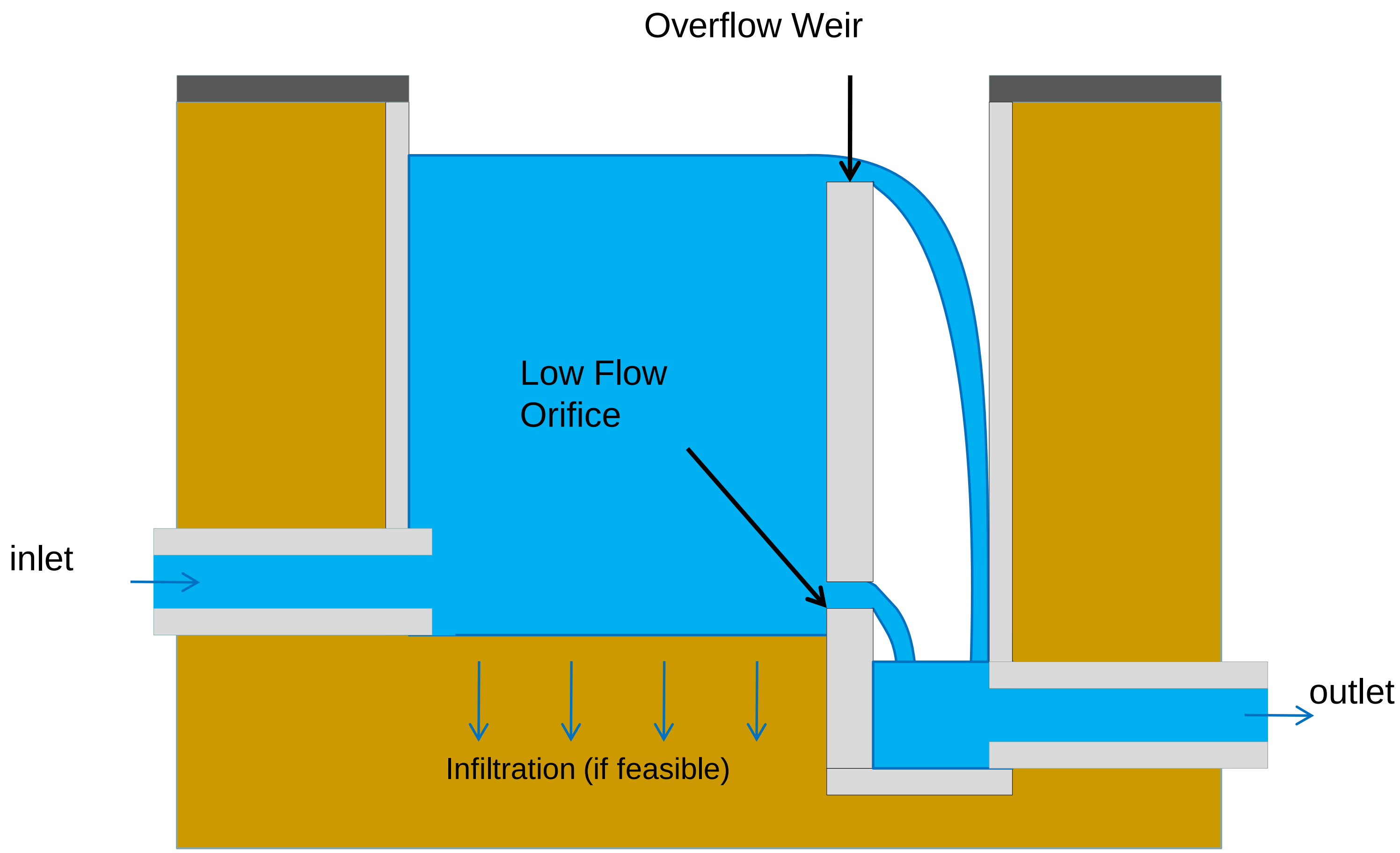
Example Modeling Configuration for a Post-Project Hydrologic Simulation

Geosyntec consultants

Figure **6-1**

Oakland	July 2013

internal info: path, date revised, author



Schematic of a Simple Hydraulic Outlet Configuration

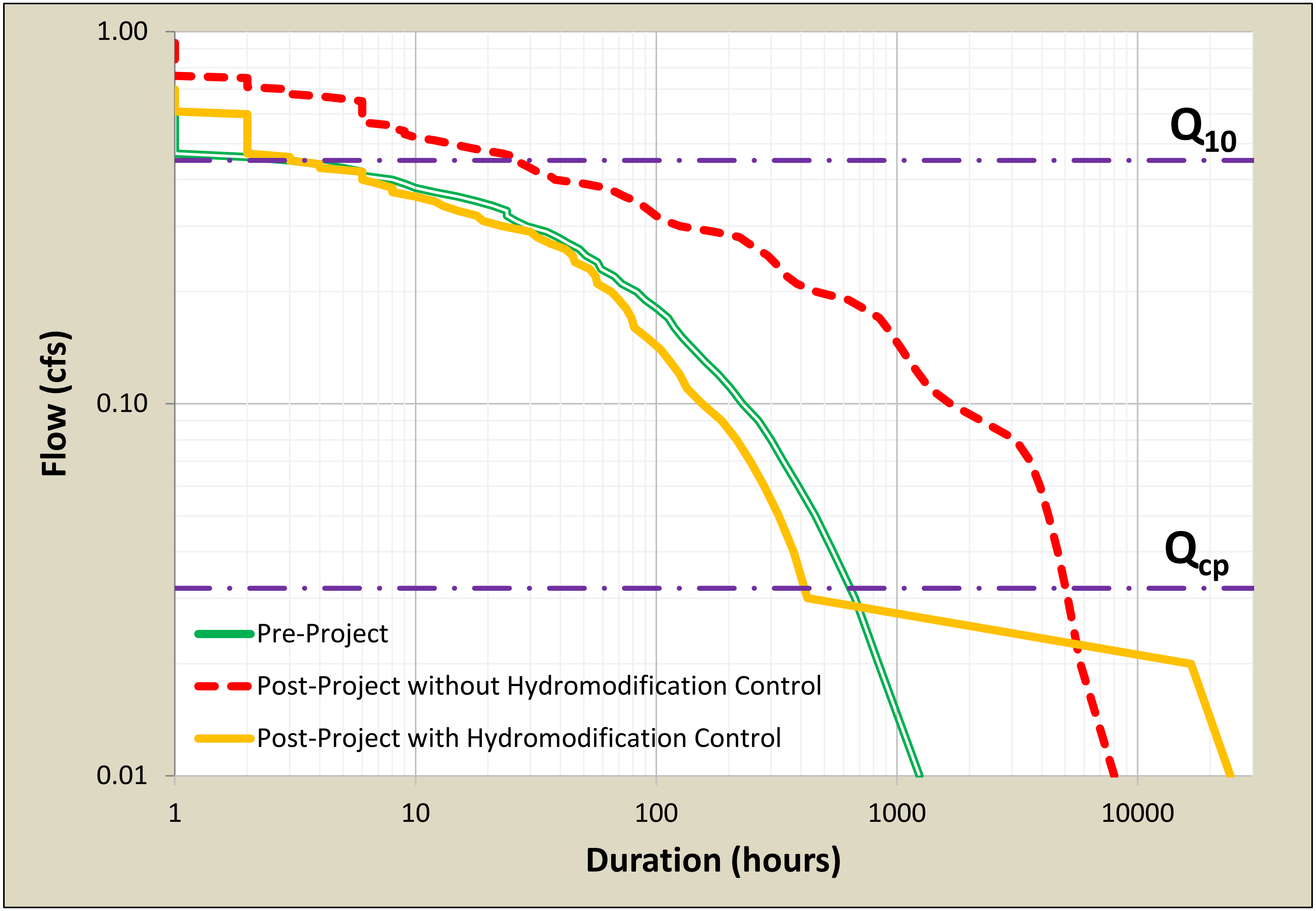
Geosyntec consultants

Figure

6-2

Oakland

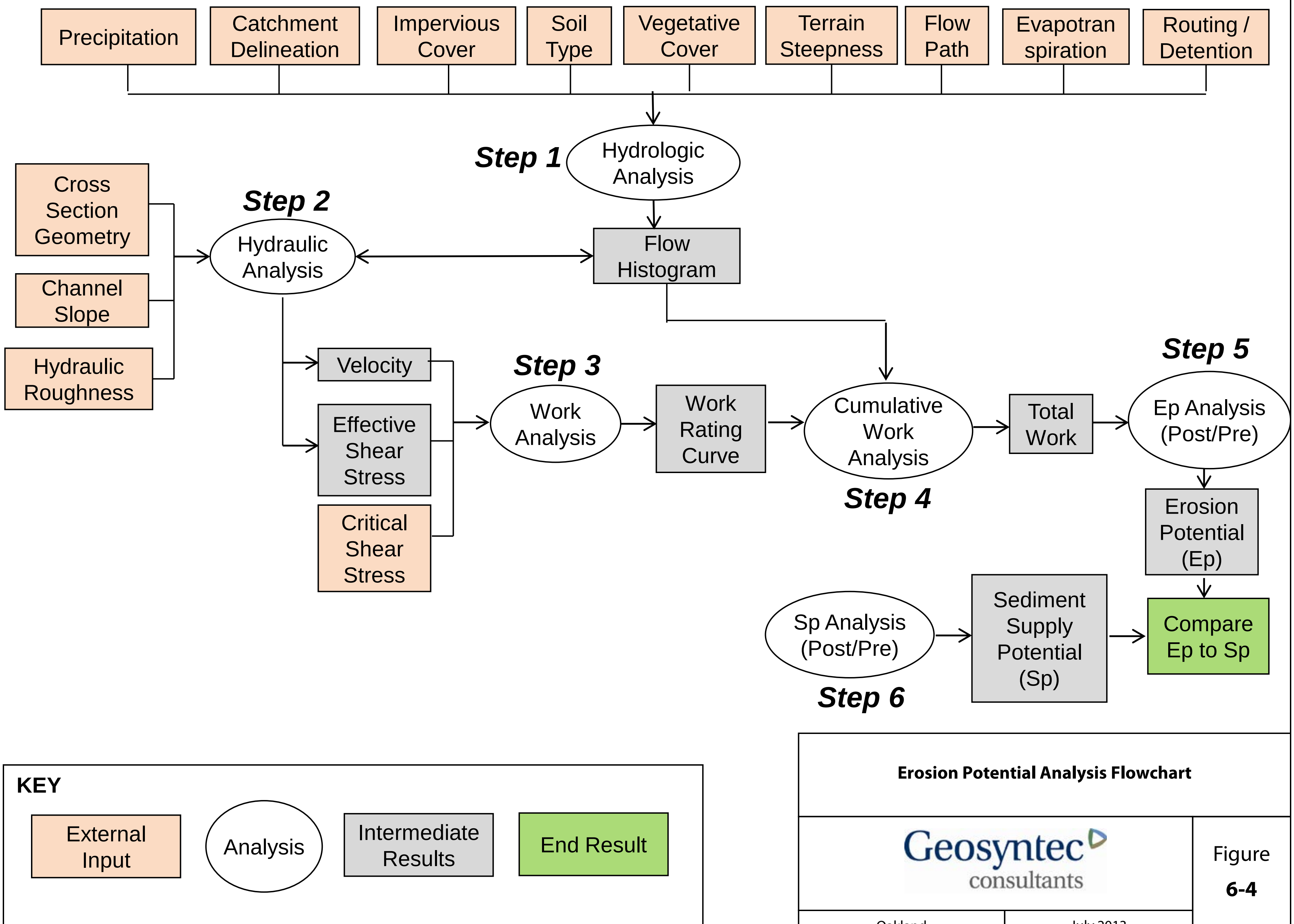
July 2013



internal info: path, date revised, author

Geosyntec consultants

Example Flow Duration Curve Comparison	Figure **6-3**
Oakland / July 2013	



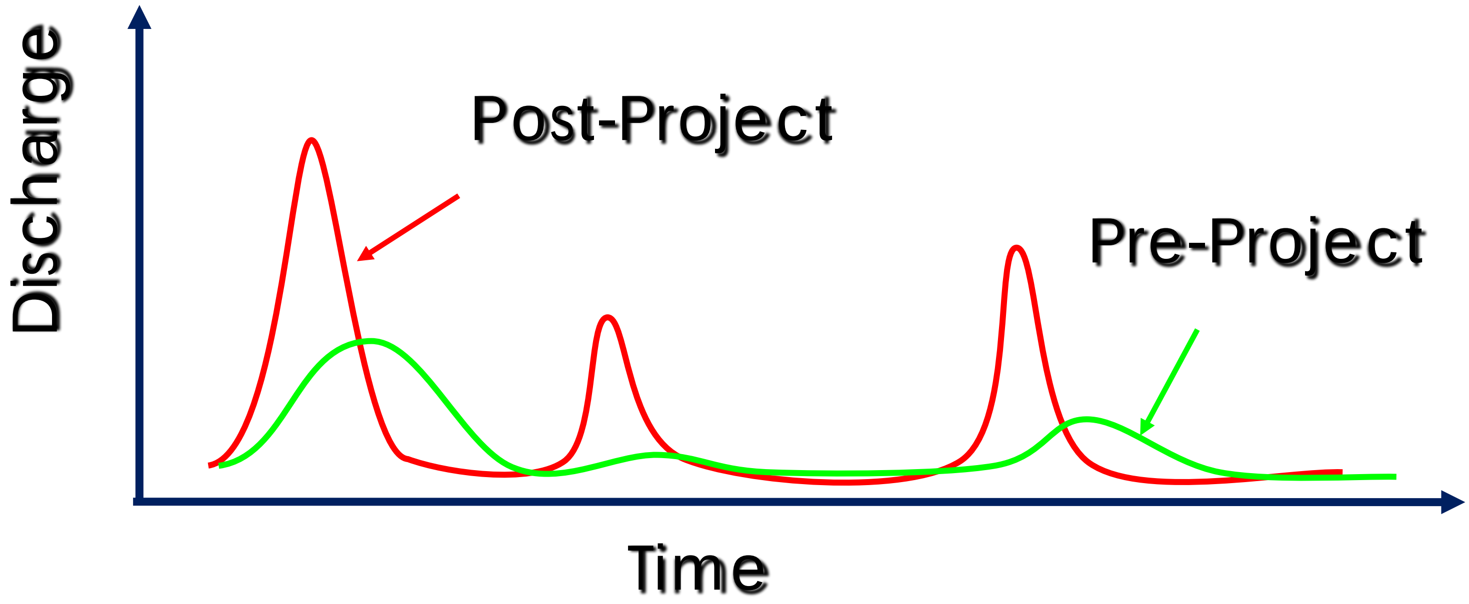
Erosion Potential Analysis Flowchart

Geosyntec consultants

Oakland | July 2013

Figure **6-4**

internal info: path, date revised, author



Example Hydrograph Comparison

Geosyntec consultants

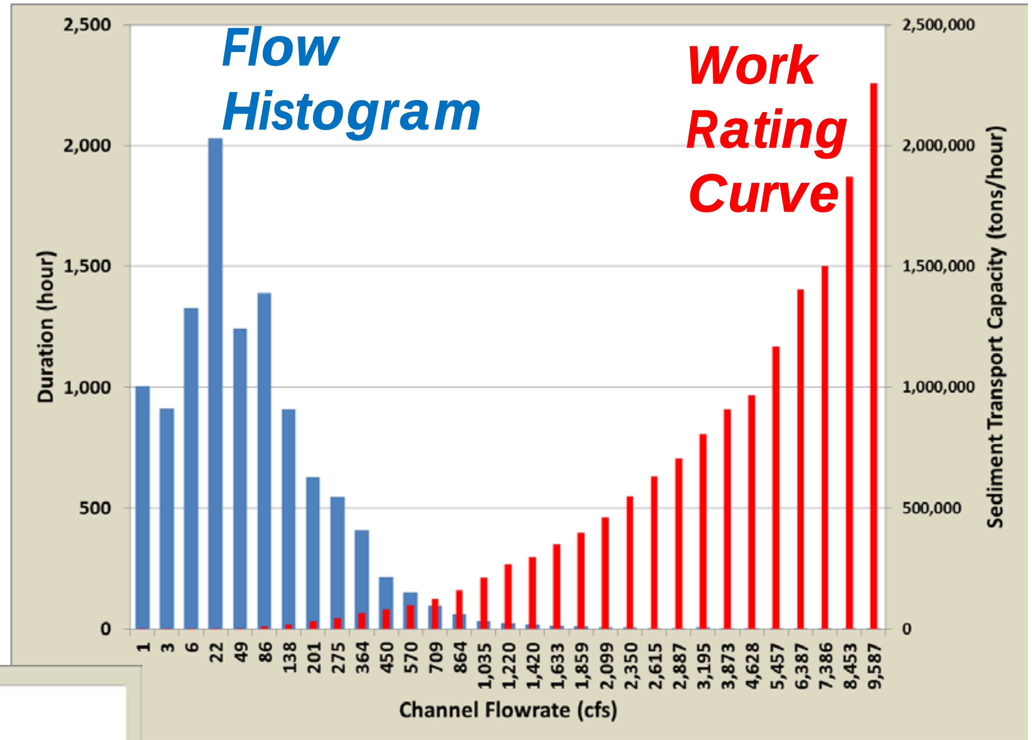
Figure **6-5**

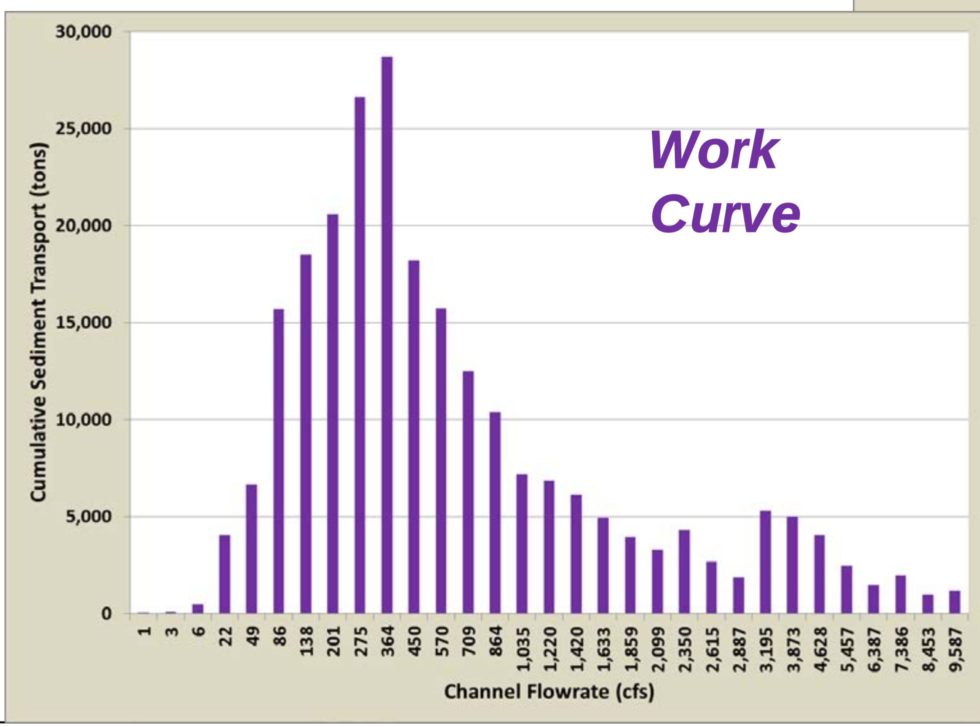
Oakland

July 2013

internal info: path, date revised, author

Σ (Duration x Work)
= Cumulative Work



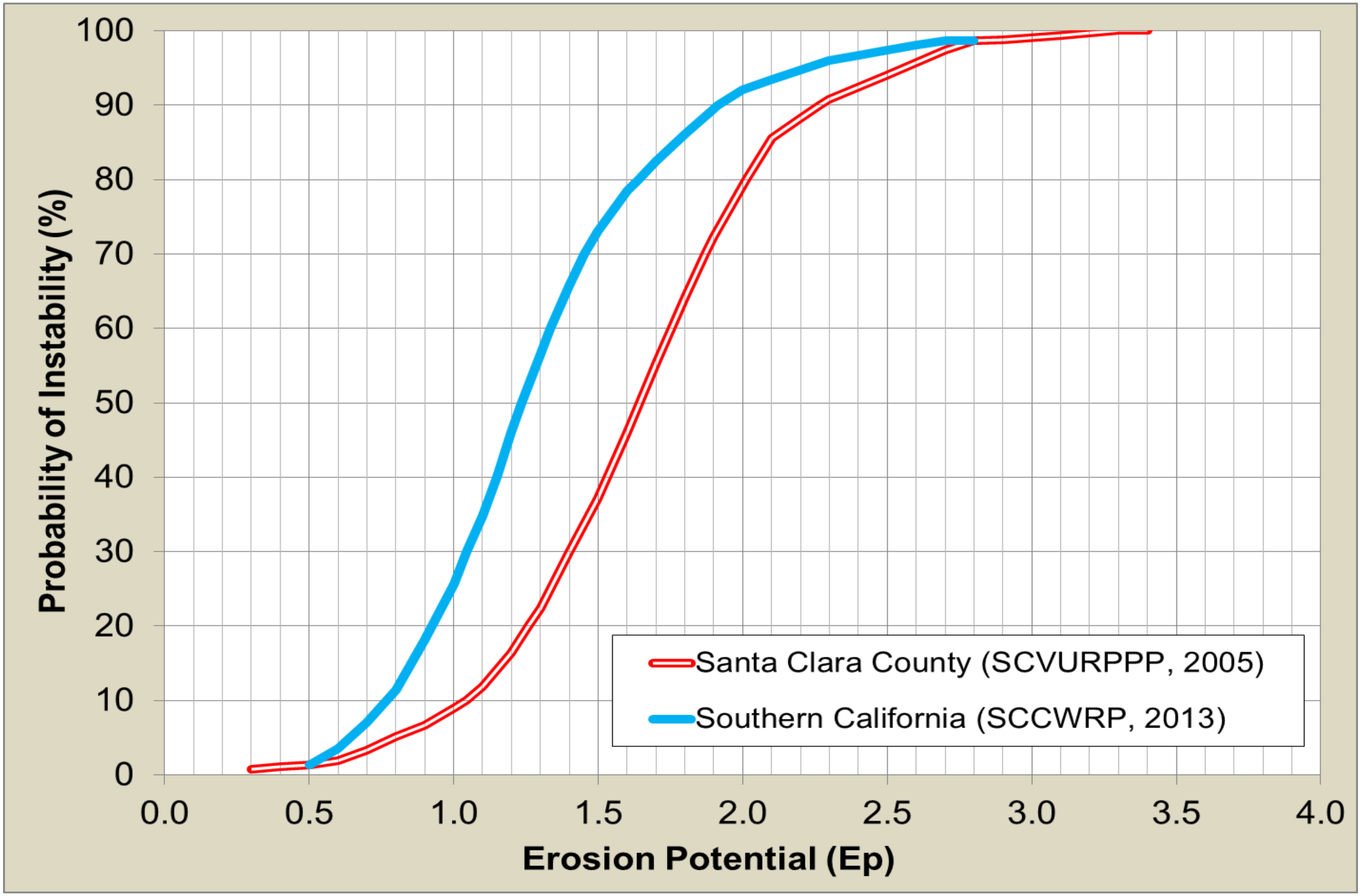


Example Hydrograph Comparison

Geosyntec consultants

Figure 6-6

Oakland | July 2013



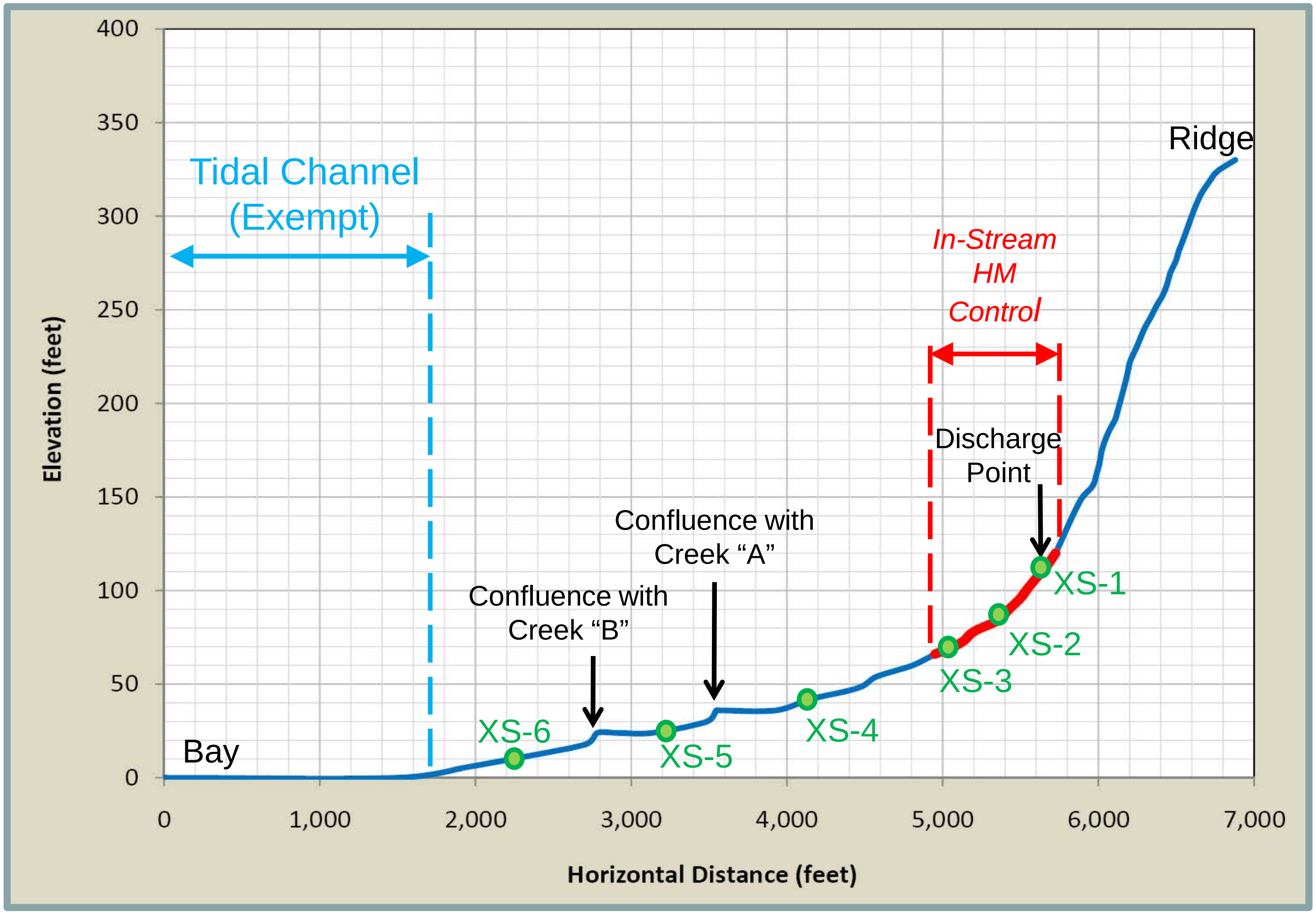
internal info: path, date revised, author

Geosyntec consultants

Comparison of Logistic Regression Models of Ep and Probability of Instability for Santa Clara County (San Francisco Bay Area) and Southern California

Oakland	July 2013

Figure **6-7**



Example Watershed Scale Longitudinal Profile

Geosyntec consultants

Figure **6-8**

Oakland | July 2013

APPENDIX A

Ventura County MS4 Permit (Order No. R4-2010-0108) Subpart 4.E.III.3

transferred to the permittee (for public offsite mitigation projects) or to an escrow account (for private offsite mitigation projects) within one year of the initiation of construction.

(5) The project applicant must demonstrate that the EIA achieved on-site is as close to 5 percent EIA as technically feasible, given the site's constraints.

(d) Watershed equivalence. Regardless of the methods through which permittees allow project applicants to implement alternative compliance measures, the sub-watershed -wide (defined as draining to the same hydrologic area in the Basin Plan) result of all development must be at least the same level of water quality protection as would have been achieved if all projects utilizing these alternative compliance provisions had complied with subparts 4.E.III.1.(a)-(d) of the permit. The permittees shall provide in their annual report to the Regional Board a list of mitigation project descriptions and pollutant and flow reduction analyses (compiled from design specifications submitted by project applicants and approved by the permittee(s)) comparing the expected aggregate results of alternative compliance projects to the results that would otherwise have been achieved by meeting the 5 percent EIA requirement on-site.

3. Hydromodification (Flow/ Volume/ Duration) Control Criteria

(a) Each Permittee shall require all New Development and Redevelopment projects identified in subpart 4.E.II to implement hydrologic control measures, to prevent accelerated downstream erosion and to protect stream habitat in natural drainage systems. The purpose of the hydrologic controls is to minimize changes in post-development hydrologic storm water runoff discharge rates, velocities, and duration. This shall be achieved by maintaining the project's pre-project storm water runoff flow rates and durations.

(1) Description

(A) Hydromodification control in natural drainage systems shall be achieved by maintaining the Erosion Potential (E_p) in streams at a value of 1, unless an alternative value can be shown to be protective of the natural drainage systems from erosion, incision, and sedimentation that can occur as a result of flow increases from impervious surfaces and damage stream habitat (see Attachment "E" - Determination of Erosion Potential)

(B) Hydromodification control may include one, or a combination of on-site, regional subregional hydromodification control BMPs, LID strategies, or stream restoration measures, with preference given to LID strategies and hydromodification control BMPs. Any in-stream restoration measure shall not adversely affect the beneficial uses of the natural drainage systems

(C) Natural drainage systems, which include unlined or unimproved (not engineered) creeks, streams, rivers and their tributaries, are located in the following watersheds:

(i) Ventura River

(ii) Santa Clara River

(iii) Calleguas Creek
(iv) Malibu Creek
(v) Miscellaneous Ventura Coastal

(D) The Southern California Storm Water Monitoring Coalition (SMC) is developing a regional methodology to eliminate or mitigate the adverse impacts of hydromodification as a result of urbanization, including hydromodification assessment and management tools.

(i) The SMC has identified the following objectives for the Hydromodification Control Study (HCS):

(I) Establishment of a stream classification for Southern California streams

(II) Development of a deterministic or predictive relationship between changes in watershed impervious cover and stream-bed/ stream bank enlargement

(III) Development of a numeric model to predict stream-bed/ stream bank enlargement and evaluate the effectiveness of mitigation strategies

(E) The Permittees shall participate in the SMC HCS to develop:

(i) A regional stream classification system
(ii) A numerical model to predict the hydrological changes resulting from new development
(iii) A numerical model to identify effective mitigation strategies

(F) Until the completion of the SMC HCS, Permittees shall implement the Interim Hydromodification Control Criteria, described in subpart 4.E.III.3(a)(3)(A) below, to control the potential adverse impacts of changes in hydrology that may result from new development and redevelopment projects identified in subpart 4.E.II

(G) Existing single-family structures are exempt from the Hydromodification control requirements unless such projects disturb one acre or more of land or create, add, or replace 10,000 square feet or more of impervious surface area

(2) Exemptions to Hydromodification Controls. Permittees may exempt the following New Development and Redevelopment projects from implementation of Hydromodification controls where assessments of downstream channel conditions and proposed discharge hydrology indicate that adverse Hydromodification effects to present and future beneficial uses of Natural Drainage Systems are unlikely:

(A) All projects that disturb less than one acre.

(B) Projects that are replacement, maintenance or repair of a Permittee's existing flood control facility, storm drain, or transportation network.

(C) Redevelopment Projects in the Urban Core that do not increase the effective impervious area or decrease the infiltration capacity of pervious areas compared to the pre-project conditions.

(D) Projects that have any increased discharge go directly or via a storm drain to a sump, lake, area under tidal influence, into a waterway that has a 100-year peak flow (Q100) of 25,000 cfs or more, or other receiving water that is not susceptible to Hydromodification impacts;

(E) Projects that discharge directly or via a storm drain into concrete or improved (not natural) channels (e.g., rip rap, sackcrete, etc.), which, in turn, discharge into receiving water that is not susceptible to Hydromodification impacts (as in D above).

(3) Interim Hydromodification Control Criteria

(A) The Interim Hydromodification Control Criteria to protect natural drainage systems until Permittees complete Hydromodification Control Plans (HCPs), described in subpart 4.E.III.3(a)(4) below, are as follows:

(i) **Projects disturbing land area of less than fifty acres** will be subject to LID and/or source or treatment BMPs as addressed in this permit. The combined effects of LID and the treatment BMPs are considered adequate for Hydromodification control for projects that disturb less than 50 acres.

(ii) **Projects disturbing land areas of fifty acres or greater** Projects in this category shall develop and implement a Hydromodification Analysis Study (HAS) that demonstrates that post development conditions are expected to approximate the pre-project erosive effect of sediment transporting flows in receiving waters. The HAS must lead to the incorporation into the project design features intended to approximate, to the extent feasible, an Erosion Potential value of 1 or any alternative value that can be shown to be protective of the natural drainage systems from erosion, incision, and sedimentation that can occur as a result of flow increases from impervious surfaces and damage stream habitat in natural drainage systems, or

(I) Alternatively, project proponents in this category may elect to develop, in partnership with Permittees, an equivalent implementation method based on flow duration control in the form of nomographs relating planned impervious area and local soil type (infiltration rates) to determine hydromodification control BMP volume and land area requirements for the proposed project. The nomographs shall be derived from continuous simulation modeling using Ventura County specific rain gauge records and soil types, and calibrated using data from a local undeveloped watershed with similar conditions; or

(II) Alternatively, the Co-Permittees may revise the Ventura County Technical Guidance Manual for Stormwater

Quality Control Measures to address projects that disturb more than 50 acres.

(4) Final Criteria

(A) The Permittees shall develop and implement watershed specific HCPs no later than (180 days) after the completion of the SMC HCS.

(i) The HCP shall identify:

(I) Stream classifications

(II) Flow rate and duration control methods

(III) Sub-watershed mitigation strategies

(IV) Stream restoration measures, which will maintain the stream and tributary Erosion Potential at 1 unless an alternative value can be shown to be protective of the natural drainage systems from erosion, incision, and sedimentation that can occur as a result of flow increases from impervious surfaces and damage stream habitat in natural drainage system tributaries

(B) The HCP shall contain the following elements:

(i) Hydromodification Management Standards

(ii) Natural Drainage Areas and Hydromodification Management Control Areas

(iii) New Development and Redevelopment Projects subject to the HCP

(iv) Description of authorized Hydromodification Management Control BMPs

(v) Hydromodification Management Control BMP Design Criteria.

(vi) For flow duration control methods, the range of flows to control for, and goodness of fit criteria

(vii) Allowable low critical flow, Q_c, which initiates sediment transport

(viii) Description of the approved Hydromodification Model.

(ix) Any alternate Hydromodification Management Model and Design

(x) Stream Restoration Measures Design Criteria

(xi) Monitoring and Effectiveness Assessment

(xii) Record Keeping

(C) The HCP shall be deemed in effect upon Executive Officer approval.

4. Water Quality Mitigation Criteria

(a) Each Permittee shall require all New Development and Redevelopment projects identified in subpart 4.E.II to implement post-construction storm water treatment BMPs and control measures to mitigate storm water pollution as follows:

(1) Projects disturbing land areas less than 50 acres

(A) Volumetric Treatment Control BMP

(i) The 85th percentile 24-hour runoff event determined as the maximized capture storm water volume for the area using a 48 to

ATTACHMENT E
Determination of Erosion Potential

E_p is determined as follows- The *total effective work* done on the channel boundary is derived and used as a metric to predict the likelihood of channel adjustment given watershed and stream hydrologic and geomorphic variables. The index under urbanized conditions is compared to the index under pre-urban conditions expressed as a ratio (E_p). The effective work index (*W*) is computed as the excess shear stress that exceeds a critical value for streambed mobility or bank material erosion integrated over time and represents the total work done on the channel boundary:

$$W = \sum_{i=1}^{n} (\tau_i - \tau_c)^{1.5} \cdot V \cdot \Delta t_i \qquad (1)$$

Where τ_c = critical shear stress that initiates bed mobility or erodes the weakest bank layer, τ_i = applied hydraulic shear stress, Δt = duration of flows (in hours), and n = length of flow record. The effective work index for presumed stable stream channels under pre-urban conditions is compared to stable and unstable channels under current urbanized conditions. The comparison, expressed as a ratio, is defined as the Erosion Potential (Ep)[1] (McRae (1992, 1996).

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

where:

W_{post} = work index estimated for the post-urban condition
W_{pre} = work index estimated for the pre-urban condition

[1] MacRae, C.R. 1992. The Role of Moderate Flow Events and Bank Structure in the Determination of Channel Response to Urbanization. Resolving conflicts and uncertainty in water management: Proceedings of the 45th Annual Conference of the Canadian Water Resources Association. Shrubsole, D, ed. 1992, pg. 12.1-12.21; MacRae, C.R. 1996. Experience from Morphological Research on Canadian Streams: Is Control of the Two-Year Frequency Runoff Event the Best Basis for Stream Channel Protection. Effects of Watershed Development and Management on Aquatic Ecosystems, ASCE Engineering Foundation Conference, Snowbird, Utah, pg. 144-162

APPENDIX B

Land Use Description and Impervious Cover Assumptions

APPENDIX B

LAND USE DESCRIPTION AND IMPERVIOUS COVER ASSUMPTIONS

Table B-1. County Land Use Descriptions, Bins, and Categories

County Land Use Description	Land Use Bin	County Land Use Category
COLD STORAGE	Commercial & Business	INDUSTRIAL
CONDOMINIUM - INDUSTRIAL - ANY SIZE	Industrial Parks Paved Parking	INDUSTRIAL
MAJOR MANUFACTURING	Industrial Parks Paved Parking	INDUSTRIAL
MINI-WAREHOUSE	Industrial Parks Paved Parking	INDUSTRIAL
MULTI-TENANT INDUSTRIAL BUILDING (PRIMARILY FOR SMA	Industrial Parks Paved Parking	INDUSTRIAL
OTHER - INDUSTRIAL IMPROVEMENTS NOT OTHERWISE CLASS	Industrial Parks Paved Parking	INDUSTRIAL
PACKINGHOUSES, CITRUS AND AVACADOS	Industrial Parks Paved Parking	INDUSTRIAL
PACKINGHOUSES, OTHER THAN CITRUS AND AVACADOS	Industrial Parks Paved Parking	INDUSTRIAL
SINGLE TENANT INDUSTRIAL, OTHER THAN MAJOR MANUFACT	Industrial Parks Paved Parking	INDUSTRIAL
VACANT INDUSTRIAL LAND OVER 5 ACRES	Industrial Unpaved Yards	INDUSTRIAL
VACANT INDUSTRIAL LAND TO 5 ACRES	Industrial Unpaved Yards	INDUSTRIAL
WAREHOUSING AND STORAGE, EXCEPT COLD STORAGE	Industrial Parks Paved Parking	INDUSTRIAL
BOWLING ALLEYS	Commercial & Business	RECREATION
CAMPS, RESORTS, PRIVATE PARKS, NOT SUBJECT TO EXEMP	Commercial & Business	RECREATION
GOLF COURSES	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RECREATION
GREENBELT AREAS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RECREATION
MOTION PICTURE THEATRES, INDOOR	Commercial & Business	RECREATION
MOTION PICTURE THEATRES, OUTDOOR	Commercial & Business	RECREATION
NONTAXABLE - LIBRARY DISTRICT, SANTA PAULA UNION HI	Commercial & Business	RECREATION
NONTAXABLE - MARINAS	Commercial & Business	RECREATION
NONTAXABLE - PARKS AND RECREATION AREAS, UNDEVELOPE	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RECREATION
NONTAXABLE - PARKS, INCLUDING PLAY FIELDS, DEVELOPE	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RECREATION
SPORT FACILITIES, EXCEPT GOLF COURSES AND BOWLING A	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RECREATION
10 OR MORE LIVING UNITS - APARTMENT TYPE CONSTRUCTI	Res Condos	RESIDENTIAL
2 COMPLETE SINGLE FAMILY DWELLINGS ON A PARCEL WHIC	Res 1/6 Acre Lot	RESIDENTIAL
2 FAMILY DWELLING - DUPLEX	Res 1/6 Acre Lot	RESIDENTIAL
3 FAMILY DWELLING - TRIPLEX	Res 1/8 Acre Lot	RESIDENTIAL

County Land Use Description	Land Use Bin	County Land Use Category
3 FAMILY DWELLING - TRIPLEX AND A SINGLE	Res 1/8 Acre Lot	RESIDENTIAL
3 INDIVIDUAL FAMILY DWELLINGS	Res 1/8 Acre Lot	RESIDENTIAL
4 FAMILY DWELLING - 2 DUPLEX	Res Condos	RESIDENTIAL
4 FAMILY DWELLING - DUPLEX AND 2 SINGLES	Res Condos	RESIDENTIAL
4 FAMILY DWELLING - QUADPLEX	Res Condos	RESIDENTIAL
4 FAMILY DWELLING - TRIPLEX AND A SINGLE	Res Condos	RESIDENTIAL
4 INDIVIDUAL FAMILY DWELLINGS	Res Condos	RESIDENTIAL
5 TO 9 LIVING UNITS - APARTMENT TYPE CONSTURCTION -	Res Condos	RESIDENTIAL
CONDOMINIUM, TOWNHOUSE, AND PLANNED DEVELOPMENT	Res Condos	RESIDENTIAL
CUSTOM SINGLE FAMILY DWELLING; SINGLE FAMILY DWELLI	Res 1/4 Acre Lot	RESIDENTIAL
GROUP QUARTERS, RETIREMENT, ETC.	Commercial & Business	RESIDENTIAL
HOTEL (TRANSIENT LODGING)	Commercial & Business	RESIDENTIAL
MIXED RESIDENTIAL IMPROVEMENTS NOT OTHERWISE CLASSI	Commercial & Business	RESIDENTIAL
MOBILE HOME IN MOBILE HOME PARK	Res 1/6 Acre Lot	RESIDENTIAL
MOBILE HOME ON OWNER'S LOT (NOT IN MOBILE HOME PARK	Res 1/6 Acre Lot	RESIDENTIAL
MOBILE HOME ON OWNER'S LOT IN MOBILE HOME CONDO	Res 1/6 Acre Lot	RESIDENTIAL
MOBILE HOME PARK	Res 1/6 Acre Lot	RESIDENTIAL
MOTEL (TRANSIENT LODGING)	Commercial & Business	RESIDENTIAL
RESIDENTIAL AND APARTMENT HOTELS (PERMANENT GUEST T	Commercial & Business	RESIDENTIAL
SINGLE FAMILY DWELLING ON A PARCEL 5 ACRES OR LARGE	Res 1 Acre Lot	RESIDENTIAL
TIMESHARE CONDOMINIUM	Res Condos	RESIDENTIAL
TRACT SINGLE FAMILY DWELLING; SINGLE FAMILY DWELLIN	Res 1/5 Acre Lot	RESIDENTIAL
VACANT LAND OVER 5 ACRES (NOT ZONED FOR MULTI-FAMIL	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESIDENTIAL
VACANT LAND TO 5 ACRES (NOT ZONED FOR MULTI-FAMILY	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESIDENTIAL
VACANT LAND TO 5 ACRES, RESIDENTIAL TRACT ONLY (NOT	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESIDENTIAL
VACANT LAND ZONED FOR MULTI-FAMILY, R-2 AND UP	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESIDENTIAL
AGRICULTURAL RELATED ACTIVITIES	Industrial Unpaved Yards	RESOURCE PROD
ANIMAL SPECIALTIES (EGG PRODUCTION, POULTRY, ETC.)	Industrial Unpaved Yards	RESOURCE PROD
AVOCADOS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
COVERED OR OPEN FIELD, NURSERY CROPS, AND SEEDS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD

County Land Use Description	Land Use Bin	County Land Use Category
DECIDUOUS (APRICOTS, WALNUTS, KIWIS, ETC.)	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
FIELD AND SEED CROPS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
FIELD FLOWERS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
GRAPEFRUIT	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
GREENHOUSES, INCLUDING HYDROPONIC FARMING	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
LCA AVOCADOS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
LCA COVERED OR OPEN FIELD, NURSERY CROPS, AND SEEDS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
LCA DECIDUOUS (APRICOTS, WALNUTS, KIWIS, ETC.)	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
LCA FIELD AND SEED CROPS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
LCA FIELD FLOWERS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
LCA GREENHOUSES, INCLUDING HYDROPONIC FARMING	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
LCA LEMONS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
LCA LIVESTOCK OPERATIONS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
LCA MIXED (ORCHARD - ROW CROPS)	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
LCA ORANGES	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
LCA ORCHARDS (MIXED)	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
LCA PASTURE AND RANGE LAND	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
LCA SOD FARMS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
LCA TRUCK CROPS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
LCA VINEYARDS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
LEMONS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
LIVESTOCK OPERATIONS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
MINING; MINERALS, SAND, GRAVEL, CLAY, STONE (INCLUD	Industrial Unpaved Yards	RESOURCE PROD
MISC USES; TREE FARM, ETC.	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
MIXED (ORCHARD - ROW CROPS)	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
NATURAL GAS COMPRESSOR PLANTS	Industrial Unpaved Yards	RESOURCE PROD
NONPRODUCING MINERAL RIGHT - FEE	Industrial Unpaved Yards	RESOURCE PROD
NONTAXABLE - AGRICULTURAL DISTRICT,	Open Space, Lawns, Parks, Golf Courses,	RESOURCE PROD

County Land Use Description	Land Use Bin	County Land Use Category
31st (STATE OF	Cemeteries	
NONTAXABLE - SOUTH VENTURA COUNTY CONSERVATION DIST	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
ORANGES	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
ORCHARDS (MIXED) AND VINEYARDS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
PASTURE AND RANGE LAND	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
PETROLEUM TERMINAL	Industrial Unpaved Yards	RESOURCE PROD
PRODUCING OIL WELL	Industrial Unpaved Yards	RESOURCE PROD
SOD FARMS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
TRUCK CROPS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
VINEYARDS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	RESOURCE PROD
AUTOMOBILE OTHER (LUBE AND OIL, SMOG STATION, TUNE-	Commercial & Business	SERVICES
AUTOMOBILE REPAIR SHOP	Commercial & Business	SERVICES
CAR WASH	Commercial & Business	SERVICES
CAR WASH (SELF-SERVE)	Commercial & Business	SERVICES
CEMETARY	Open Space, Lawns, Parks, Golf Courses, Cemeteries	SERVICES
CONVALESCENT HOSPITALS AND REST HOMES	Commercial & Business	SERVICES
FINANCIAL INSTITUTIONS (BANKS, SAVINGS AND LOANS)	Commercial & Business	SERVICES
FRATERNAL ORGANIZATIONS, VETERAN ORGANIZATIONS ETC.	Commercial & Business	SERVICES
FUNERAL PARLOR (MORTUARY)	Commercial & Business	SERVICES
GENERAL OFFICE, CONDOMINIUM	Commercial & Business	SERVICES
HIGH SCHOOLS, COLLEGES, AND UNIVERSITIES	Commercial & Business	SERVICES
HOSPITALS, FULL CARE	Commercial & Business	SERVICES
MAJOR OFFICE BUILDING, CONDOMINIUM (OVER 10,000 SQ	Commercial & Business	SERVICES
MAJOR OFFICE BUILDING, NOT CONDOMINIUM (OVER 10,000	Commercial & Business	SERVICES
MEDICAL CLINIC	Commercial & Business	SERVICES
MEDICAL-DENTAL OFFICES, CONDOMINIUM	Commercial & Business	SERVICES
MEDICAL-DENTAL OFFICES, NOT CONDOMINIUM	Commercial & Business	SERVICES
MID-SIZE OFFICE BUILDINGS (3000 SQ FT TO 10,000 SQ	Commercial & Business	SERVICES
NONTAXABLE - AIR FORCE AND COAST GUARD BASES, INCLU	Industrial Unpaved Yards	SERVICES
NONTAXABLE - CITY PROPERTY	Commercial & Business	SERVICES

County Land Use Description	Land Use Bin	County Land Use Category
NONTAXABLE - COMMUNITY AND JUNIOR COLLEGES	Commercial & Business	SERVICES
NONTAXABLE - COUNTY PROPERTY	Commercial & Business	SERVICES
NONTAXABLE - FEDERAL PROPERTY NOT OTHERWISE CLASSIF	Commercial & Business	SERVICES
NONTAXABLE - HOUSING AUTHORITY	Commercial & Business	SERVICES
NONTAXABLE - POSTAL PROPERTY	Commercial & Business	SERVICES
NONTAXABLE - PUBLIC HIGH SCHOOL	Commercial & Business	SERVICES
NONTAXABLE - PUBLIC KINDERGARTEN, ELEMENTARY AND JU	Commercial & Business	SERVICES
NONTAXABLE - REDEVELOPMENT AGENCY	Commercial & Business	SERVICES
NONTAXABLE - STATE PROPERTY	Commercial & Business	SERVICES
NONTAXABLE - UNDEVELOPED PUBLIC HIGHER EDUCATION SI	Open Space, Lawns, Parks, Golf Courses, Cemeteries	SERVICES
NONTAXABLE - UNDEVELOPED PUBLIC PRIMARY SCHOOL SITE	Open Space, Lawns, Parks, Golf Courses, Cemeteries	SERVICES
NONTAXABLE - UNDEVELOPED PUBLIC SECONDARY SCHOOL SI	Open Space, Lawns, Parks, Golf Courses, Cemeteries	SERVICES
NURSERY SCHOOLS, PRIMARY AND CHILD CARE, NOT SUBJEC	Commercial & Business	SERVICES
OTHER	Commercial & Business	SERVICES
RELIGIOUS, CHARITABLE QUALIFYING FOR EXEMPTION	Commercial & Business	SERVICES
SMALL OFFICE BUILDING (TO 3000 SP FT)	Commercial & Business	SERVICES
VACANT LAND (C-O, P-O, ETC.)	Open Space, Lawns, Parks, Golf Courses, Cemeteries	SERVICES
VEHICLE REPAIR AND SALES	Commercial & Business	SERVICES
AUTO WRECKING/DISMANTLING	Commercial & Business	TRADE
AUTOMOBILE REPAIR, SALES (NEW AND USED)	Commercial & Business	TRADE
AUTOMOBILE REPAIR, SALES (USED ONLY)	Commercial & Business	TRADE
BAR, NIGHTCLUB	Commercial & Business	TRADE
COMMERCIAL CONDOMINIUMS	Commercial & Business	TRADE
FAST-FOOD OR SHORT ORDER	Commercial & Business	TRADE
LARGE (OVER 3000 SQ FT) 1 TENANT/OCCUPANT, NOT IN A	Commercial & Business	TRADE
MAJOR DEPARTMENT STORES	Commercial & Business	TRADE
MAJOR SHOPPING CENTER AND MALLS, COMMUNITY, REGIONA	Commercial & Business	TRADE
MULTI-TENANT STORES, NEIGHBORHOOD SHOPPING CENTERS	Commercial & Business	TRADE
OTHER - COMMERCIAL IMPROVEMENTS NOT OTHERWISE CLASS	Commercial & Business	TRADE
RESTAURANTS OR COFFEE SHOPS (DESIGNED AND USED AS S	Commercial & Business	TRADE
SERVICE STATIONS	Commercial & Business	TRADE

County Land Use Description	Land Use Bin	County Land Use Category
SMALL (TO 3000 SQ FT) 1 TENANT/OCCUPANT, NOT IN ANY	Commercial & Business	TRADE
VACANT COMMERCIAL LAND OVER 5 ACRES	Commercial & Business	TRADE
VACANT COMMERCIAL LAND TO 5 ACRES	Commercial & Business	TRADE
COMMUNICATIONS	Industrial Unpaved Yards	TRANS/COMM/UTIL
NONTAXABLE - COUNTY WATER DISTRICTS	Industrial Unpaved Yards	TRANS/COMM/UTIL
NONTAXABLE - DRAINAGE DISTRICT, OXNARD	Industrial Unpaved Yards	TRANS/COMM/UTIL
NONTAXABLE - ELECTRIC UTILITY COMPANY (EDISON)	Industrial Unpaved Yards	TRANS/COMM/UTIL
NONTAXABLE - ELECTRIC UTILITY COMPANY (OTHER)	Industrial Unpaved Yards	TRANS/COMM/UTIL
NONTAXABLE - FLOOD CONTROL BASINS AND CHANNELS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	TRANS/COMM/UTIL
NONTAXABLE - GAS UTILITY COMPANY	Industrial Unpaved Yards	TRANS/COMM/UTIL
NONTAXABLE - HIGHWAY PARCEL	Industrial Parks Paved Parking	TRANS/COMM/UTIL
NONTAXABLE - MUNICIPAL WATER DISTRICT	Industrial Unpaved Yards	TRANS/COMM/UTIL
NONTAXABLE - PORTS AND HARBORS	Industrial Unpaved Yards	TRANS/COMM/UTIL
NONTAXABLE - RAILWAYS	Industrial Unpaved Yards	TRANS/COMM/UTIL
NONTAXABLE - RESERVOIRS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	TRANS/COMM/UTIL
NONTAXABLE - SANITARY AND SANITATION DISTRICTS	Industrial Parks Paved Parking	TRANS/COMM/UTIL
NONTAXABLE - STATE BOARD OF EQUALIZATION	Industrial Unpaved Yards	TRANS/COMM/UTIL
NONTAXABLE - STORM DRAINAGE MAINTENANCE DISTRICT, V	Industrial Unpaved Yards	TRANS/COMM/UTIL
NONTAXABLE - TELEPHONE COMPANY	Industrial Unpaved Yards	TRANS/COMM/UTIL
NONTAXABLE - VENTURA COUNTY WATER WORKS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	TRANS/COMM/UTIL
NONTAXABLE - WATER CONSERVATION DISTRICT	Open Space, Lawns, Parks, Golf Courses, Cemeteries	TRANS/COMM/UTIL
NONTAXABLE - WATER DISTRICT OFFICES	Industrial Unpaved Yards	TRANS/COMM/UTIL
PARKING LOTS AND PARKING GARAGES	Industrial Parks Paved Parking	TRANS/COMM/UTIL
PIPELINES, PETROLEUM	Industrial Unpaved Yards	TRANS/COMM/UTIL
TRANSPORTATION (TRUCK DEPOT, TERMINAL AND YARD, AIR	Industrial Unpaved Yards	TRANS/COMM/UTIL
UNDEDICATED OR PRIVATE STREETS, ROADS AND WALKWAYS	Industrial Parks Paved Parking	TRANS/COMM/UTIL
WATER COMPANIES, MUTUAL, PRIVATE AND UTILITY; SANIT	Industrial Unpaved Yards	TRANS/COMM/UTIL
WATER WELL SITE (PRIVATE)	Open Space, Lawns, Parks, Golf Courses, Cemeteries	TRANS/COMM/UTIL
NONCOMMERCIAL FOREST	Open Space, Lawns, Parks, Golf Courses, Cemeteries	UNDEVELOPED
NONTAXABLE - NATIONAL FOREST	Open Space, Lawns, Parks, Golf Courses, Cemeteries	UNDEVELOPED

County Land Use Description	Land Use Bin	County Land Use Category
SPITE STRIPS	Open Space, Lawns, Parks, Golf Courses, Cemeteries	UNDEVELOPED
UNDEVELOPED AND UNUSED LAND (BRUSH HILLS, DRY RIVER	Open Space, Lawns, Parks, Golf Courses, Cemeteries	UNDEVELOPED
WATER AREAS; RIVERS, LAKES, RESERVOIRS, OCEAN, HARB	Open Space, Lawns, Parks, Golf Courses, Cemeteries	UNDEVELOPED
NO DESIGNATION	Open Space, Lawns, Parks, Golf Courses, Cemeteries	NONE

Table B-2. Assumed imperviousness by Land Use Category

Land Use Bin	Effective Percent Imperviousness
Open Space, Lawns, Parks, Golf Courses, Cemeteries	0
Res 1 Acre Lot	10
Res 1/2 Acre Lot	13
Res 1/3 Acre Lot	15
Res 1/4 Acre Lot	19
Res 1/5 Acre Lot	23
Res 1/6 Acre Lot	28
Res 1/8 Acre Lot	32
Res Condos	37
Industrial Unpaved Yards	36
Commercial & Business	50
Industrial Parks Paved Parking	70
Parking Lots, Roofs, Driveways, Paved Streets	90
Grassland	0
Open Brush	0
Big Brush	0
Chamis Narrow Leaf Chapparal	0
Oak Savanna	0
Orchard	0
Woodland	0
Pinon and Juniper	0
Forest	0

APPENDIX C

Technical Memorandum – Development of Hydromodification Control Applicability Maps

Geosyntec consultants

1111 Broadway, 6th Floor
Oakland, California 94607
PH 510.836.3034
FAX 510.836.3036
www.geosyntec.com

Memorandum

Date: 31 December 2012

To: Arne Anselm, Ventura County Watershed Protection District

Copies to: Ventura County Permittees

From: Judd Goodman P.E., Lisa Austin P.E., and Matthew Freiberg, Geosyntec Consultants

Subject: Development of Hydromodification Control Applicability Maps
Geosyntec Project Number: WW1631

1. INTRODUCTION

Subpart 4.E.III.3 of the Ventura County MS4 Permit (Order No. R4-2010-0108) contains Hydromodification Control Criteria applicable to new development and redevelopment projects in Ventura County and requires the Permittees[1] to develop and implement watershed specific Hydromodification Control Plans (HCPs). One helpful element of an HCP is a map showing those areas subject to the Hydromodification Control Criteria and those areas that are exempt.

This technical memorandum provides guidance on how to map areas where the Hydromodification Control Criteria apply. Hydromodification Control Applicability Maps (Applicability Maps) will be developed by each Permittee for inclusion in an HCP consistent with the following requirements in the MS4 permit:

> *(2) Exemptions to Hydromodification Controls. Permittees may exempt the following New Development and Redevelopment projects from implementation of Hydromodification controls where assessments of downstream channel conditions and proposed discharge hydrology indicate that adverse Hydromodification effects to present and future beneficial uses of Natural Drainage Systems are unlikely:*
>
> *(A) All projects that disturb less than one acre.*

[1] The MS4 Permittees include the County of Ventura and the cities of Camarillo, Fillmore, Moorpark, Ojai, Oxnard, Port Hueneme, San Buenaventura (Ventura), Santa Paula, Simi Valley and Thousand Oaks.

(B) Projects that are replacement, maintenance or repair of a Permittee's existing flood control facility, storm drain, or transportation network.

(C) Redevelopment Projects in the Urban Core that do not increase the effective impervious area or decrease the infiltration capacity of pervious areas compared to the pre-project conditions.

(D) Projects that have any increased discharge go directly or via a storm drain to a sump, lake, area under tidal influence, into a waterway that has a 100-year peak flow (Q100) of 25,000 cfs or more, or other receiving water that is not susceptible to Hydromodification impacts.

(E) Projects that discharge directly or via a storm drain into concrete or improved (not natural) channels (e.g., rip rap, sackcrete, etc.), which, in turn, discharge into receiving water that is not susceptible to Hydromodification impacts (as in D above).

While subparts 4.E.III.3.(a)(2)(A), (B), and (C) are project-specific, subparts (D) and (E) can be assessed based on existing drainage infrastructure and thus form the basis for developing the Applicability Maps.

This technical memorandum is organized according to the steps necessary to create the Applicability Maps, as follows:

- Section 2 defines the boundaries of the Applicability Maps.
- Section 3 describes how to identify which water bodies are and are not susceptible to accelerated downstream erosion (i.e., hydromodification impacts) per the MS4 Permit and includes preliminary Receiving Water Susceptibility Maps developed by Geosyntec.
- Section 4 provides instructions to create the Applicability Maps and includes one example Applicability Map for the County's Unincorporated Urban Centers located within the Ventura River Watershed.

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

2. MAP BOUNDARIES

The first step to creating an Applicability Map is to define the map boundary. The map boundary is where new and redevelopment is anticipated to occur. Development is planned to occur within the existing urban areas which are delineated using the City Urban Restriction Boundaries (CURB) and, in the case of unincorporated Ventura County, the Unincorporated Urban Centers. These boundaries are provided in Figure 1. For reference, the city and County boundaries are included in Figure 1 as well.

3. SUSCEPTIBILITY OF RECEIVING WATERS TO HYDROMODIFICATION

The second step to creating an Applicability Map is to identify water bodies within and downstream of the jurisdictional boundaries that are and are not susceptible to hydromodification impacts. Per the MS4 Permit, non-susceptible water bodies include: lakes, sumps, tidally influenced water bodies, large rivers, and modified conveyances. Water bodies that are considered susceptible to hydromodification impacts are the remaining natural stream channels. Geosyntec, with assistance from the Permittees, created Receiving Water Susceptibility Maps (Susceptibility Maps) using the GIS data sets listed in Table 1 and the following steps:

1. The existing drainage network was mapped using the Redline and Blueline jurisdictional channel lines provided by the County[2].
2. Geosyntec initially identified non-susceptible lakes, tidally influenced water bodies, large rivers, and improved channels using aerial imagery and supporting information provided by Ventura County Watershed Protection District staff.
3. Redline and Blueline channels that were not overlapped by a lake, tidally influenced water body, large river, or modified conveyance were designated as natural channels susceptible to hydromodification impacts.
4. The Permittees reviewed Geosyntec's initial water body Susceptibility Maps to best reflect conditions within their respective jurisdictions[3].
5. Geosyntec incorporated the Permittee comments into revised Susceptibility Maps.

The resulting Susceptibility Maps are provided in Figures 2 through 12. These maps should be considered as living documents that can be updated by the Permittees if more accurate information on drainage infrastructure is obtained. The methodology used to map each type of non-susceptible receiving water is provided in the following sections. Although not mentioned

[2] Geosyntec used Redline and Blueline jurisdictional channels based on available data. If additional channels are available, then the Permittees should add them to the Susceptibility Maps.
[3] The cities of Port Hueneme and Santa Paula did not provide comment on the Susceptibility Maps.

in the MS4 Permit, a section describing the 100-year floodplain and its significance to the Susceptibility Maps is included as well.

3.1 Lakes

Permanent lakes, including manmade reservoirs, are not considered susceptible to accelerated stream erosion since fluvial processes do not apply in these receiving waters. It is assumed that the lakes mapped are large enough to sufficiently dampen the hydrologic effects of increased runoff discharge, volume, and duration caused by development. Thus, areas which drain to a lake without first flowing through a natural channel are considered exempt from the Hydromodification Control Criteria, even if natural channels exist downstream of the lake. The County's lakes were simply mapped by adding the Ventura Lakes shapefile provided by the County.

Light Blue areas in the Susceptibility Maps, Figures 2 to 12, represent open water associated with lakes.

3.2 Sumps

For the purposes of evaluating receiving water susceptibility, a sump is considered to be a low space that collects runoff which does not discharge without pumping. Areas which drain to a sump without first flowing through a natural channel are considered exempt from the Hydromodification Control Criteria. Sump locations within the County were not provided for this mapping effort. However, detention basins were provided by the County and are included in the Susceptibility Maps. Unlike lakes or sumps, areas that drain directly to detention basins should not automatically be considered exempt from the Hydromodification Control Criteria unless there is sufficient evidence that the detention facilities maintain the project's pre-project stormwater runoff flow rates and durations. Because the existing detention facilities were not designed and constructed to account for hydromodification control per the latest MS4 requirements, it is likely that these facilities do not meet the Hydromodification Control Criteria as currently constructed without retrofit. No hydrologic analysis has been conducted to demonstrate this, however.

Light Blue points in the Susceptibility Maps represent detention basins.

3.3 Tidally Influenced Waterways

It is assumed that tidally influenced waterways are not susceptible to accelerated downstream erosion because the backwater effects of such channels dampen the hydrologic effects of increased runoff discharge, volume, and duration caused by development. Waterways which are tidally connected to the Pacific Ocean were first identified using firsthand accounts from Ventura County staff. The County provided a list of channels and landmarks that mark the inland extent of tidal influence. These landmarks were identified using GIS and the channel segments traced to the ocean. This set of tidally influenced waterways was reviewed by the coastal Permittees[4] and Geosyntec modified the shapefiles according to the comments received. In situations where it is not clear whether a waterway is tidally influenced, one rule of thumb is to compare the channel invert or thalweg elevation with the mean higher-high water (MHHW) elevation. If the invert is lower than the MHHW, the channel is considered tidally influenced. For Ventura County, the MHHW elevation is assumed to be 5.27-ft NAVD 88 according to NOAA tide gage station 9411340 in Santa Barbara.

Bright Green lines in the Susceptibility Maps represent tidally influenced waterways.

3.4 Large Rivers

According to the MS4 Permit, waterways that have a 100-year peak flow (Q100) of 25,000 cfs or more are not susceptible to hydromodification impacts. The reasoning behind this criterion is that rivers this large are resilient to the proportionately smaller cumulative effect of project-related increases in runoff discharge, volume, and duration. The extent of the large rivers that meet the criterion were determined using 100-year peak flow data provided by Ventura County Watershed Protection District for Calleguas Creek, the Santa Clara River, the Ventura River, and tributaries to Malibu Creek. Channel segments downstream of a computation point with a 100-year flow rate of 25,000 cfs or greater were traced in GIS and exported as their own shapefile.

Purple lines in the Susceptibility Maps represent the large rivers with a Q100 greater than or equal to 25,000 cfs.

3.5 Modified Conveyances

According to the MS4 Permit, storm drains, concrete channels, and improved (not natural) channels (e.g., rip rap, sackcrete, etc.) are not susceptible to hydromodification impacts. Considering that the MS4 Permit glossary defines natural drainage systems as “unlined or unimproved (not engineered) creeks, streams, rivers or similar waterways,” it is the interpretation of the Permittees that any modified conveyance with engineered improvements should be

[4] Permittees located along the Pacific Ocean include Ventura County and the Cities of Oxnard, Port Hueneme, and Ventura.

considered non-susceptible. This includes earthen channels that have rip rap, sackcrete, or compacted earth along either the bed or one of the banks.

Geosyntec identified modified conveyances by superimposing the Redline and Blueline layers over areal images and drainage facilities provided by the County. Geosyntec visually scanned the layered images starting at the mouth of each river or creek and followed the flow path upstream, inspecting each tributary for signs of modifications. Google Maps Street View was used to provide higher resolution inspection of creeks near roads. Modified segments were traced using GIS to produce a new shapefile. A map of these modified conveyances was reviewed by the Permittees and comments received were incorporated into the shapefile. The detailed storm drain networks were not readily available for all Permittees, but the larger modified conveyances were mapped in the Susceptibility Maps. The storm drain networks for Unincorporated Ventura County (including both publicly and privately owned conveyances) and Thousand Oaks were provided and are included in the Susceptibility Maps. It is recommended that the Permittees update the Susceptibility Maps to include their storm drain networks prior to completing the Applicability Maps.

Yellow lines in the Susceptibility Maps represent the modified conveyances, which includes improved channels and storm drain pipes.

3.6 Floodplains

Although floodplains are not directly mentioned in the MS4 Permit exemption criteria, they are essential for evaluating whether a modified conveyance discharges directly to a large river. Along intermittent rivers such as Calleguas Creek, Santa Clara River, and Ventura River, storm drain outfalls tend to be located above the creek's water surface elevation and outside of the water's edge for most of the year. Thus, there is an un-inundated riparian area between the outfall and the main stream course even though the outfall is considered directly connected to the river. When considering whether an outfall discharges directly to a receiving stream, the river corridor should be viewed as an area and not a linear feature. Geosyntec has included the 100-year floodplain, provided by the County, to evaluate connectivity of storm drain outfalls to large rivers. If the outfall is located within the 100-year floodplain of the river, then the modified conveyance that terminates at the outfall is considered to "discharge directly" to that receiving stream in accordance with Subpart 4.E.III.3.(a)(2)(E).

The diagonal hatched areas in the Susceptibility Maps represent the 100-year floodplain.

4. HYDROMODIFICATION CONTROL APPLICABILITY MAPS

The third and final step for developing an Applicability Map is to use the Susceptibility Map to identify areas within the jurisdictional boundary where the Hydromodification Control Criteria apply and where they are exempt. These two categories are defined as follows:

- Applicable areas drain to one or more channels susceptible to hydromodification impacts (i.e., blue or red lines on the Susceptibility Maps or other unmapped natural streams) prior to entering a lake, sump, or the Pacific Ocean.
- Exempt areas drain directly or via a continuously non-susceptible flow path (i.e., green, purple, and yellow lines on the Susceptibility Maps) to a lake, sump, or the Pacific Ocean.

The Permittees will create the Applicability Maps using the following steps. Included, in italics, with each step is a description of the datasets and methods used to develop the example Applicability Map for the County's Unincorporated Urban Centers located within the Ventura River Watershed (Figure 13).

1. The jurisdictional boundary will overlay delineated subcatchment areas to isolate the subcatchments of interest.

   In GIS the jurisdictional area (Unincorporated_Urban_Infill_Areas.shp) was combined with available subcatchment delineations (Zone1_Ventura_River_Watershed.shp and V_subwatershed.shp) to isolate the subcatchments of interest.

2. Receiving waters mapped in the Susceptibility Maps will be added to evaluate whether each subcatchment of interest is entirely applicable, entirely exempt, or has a mix of both categories.

   The jurisdictional channels (Redline_Channel.shp and Blueline_Streams.shp), lakes (VentLakes.shp), detention basins (Basins.shp), tidally influenced waterways (Tidally_influenced.shp), large rivers (Large_River.shp), modified conveyances (Modified_Channel.shp, StormDrains_Co.shp), and the 100-year floodplain (01-20-10_100_Yr_Flood_nad27.shp) were added to the map. Then the subcatchments of interest were identified as "applicable", "exempt", or "mixed" according to the definitions provided above for applicable and exempt areas.

3. Those subcatchments that contain a mix of both applicable and exempt area will be further subdivided using available topography data (e.g. elevation contours) such that the new subcatchments of interest are entirely applicable or entirely exempt.

   LiDAR data (LIDARxyzi_2_PointToRaster.tif), a street map (Street.shp), and a USGS topographic map (USA Topo Maps) were added to the GIS project file so that additional drainage divides could be drawn within the subcatchments of interest designated as "mixed". New subcatchments of interest were then delineated using the drainage divides and each was identified as being either "applicable" or "exempt".

4. Subcatchments of interest will be color coded on the Applicability Map according to whether they are applicable or exempt areas.

   In the example Applicability Map, green subcatchments of interest represent areas within the jurisdictional boundary where the Hydromodification Control Criteria applies. Orange subcatchments of interest represent areas that are exempt from the Hydromodification Control Criteria.

The Applicability Maps should be considered as living documents that can be updated by the Permittees if more accurate information on drainage infrastructure and subcatchment delineations is obtained.

5. REFERENCES

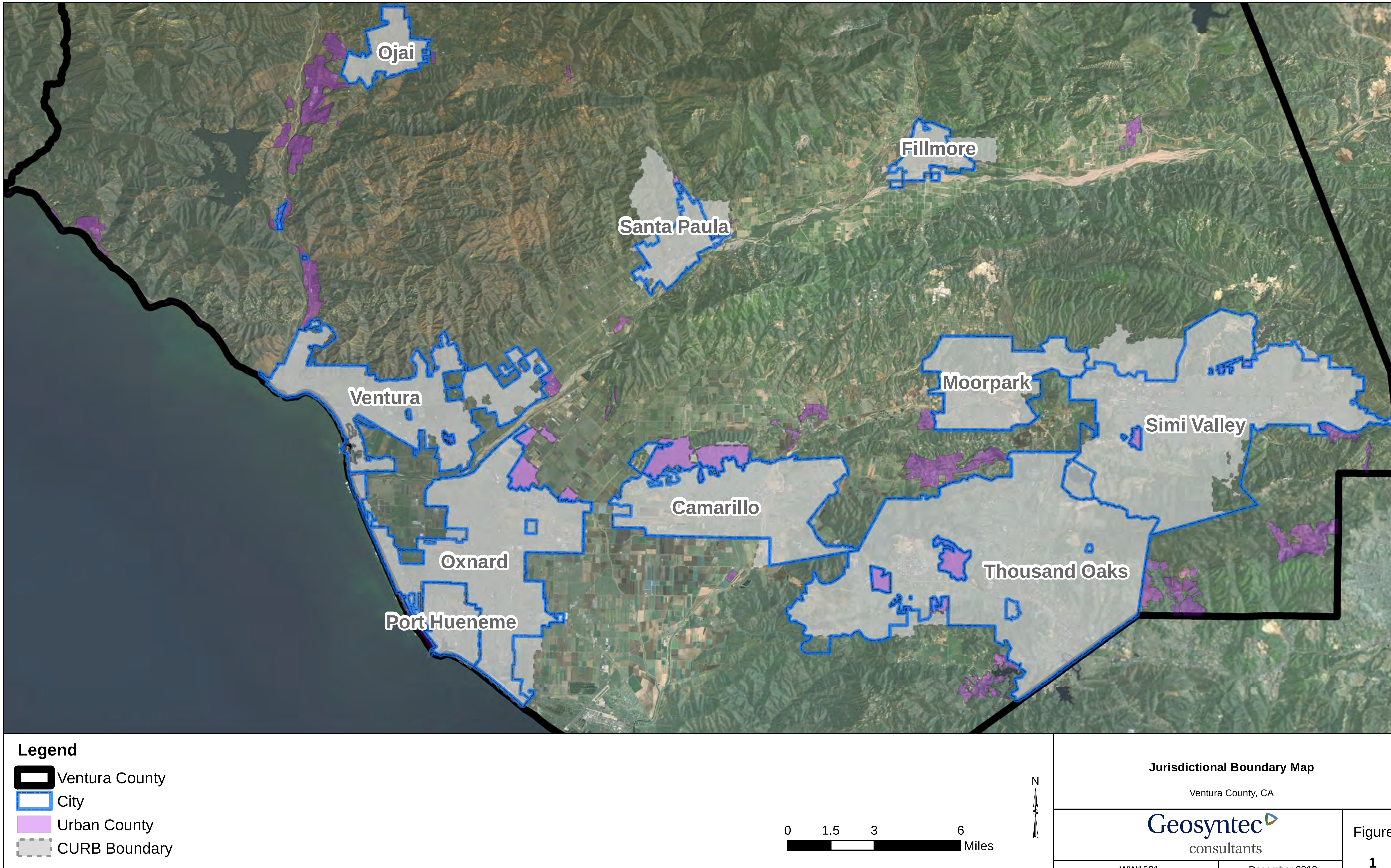
Los Angeles Regional Water Quality Control Board (LARWQCB). 2010. Ventura County Municipal Separate Storm Sewer System Permit. Order R4-2010-0108. NPDES Permit No. CAS004002.

Table 1. Spatial Datasets Used to Create the Susceptibility and Applicability Maps

Description	Dataset Name	Feature Class	Source
City Urban Restriction Boundaries (CURB)	Countywide_CURB.shp	Polygon	Ventura County
Unincorporated Urban Centers boundary	Unincorporated_Urban_Infill_Areas.shp	Polygon	Ventura County
City boundaries	city.shp	Polygon	Ventura County
County boundary	Ventura_County.shp	Polygon	Ventura County
Red Line jurisdictional channels	Redline_Channel.shp	Line	Ventura County
Blue Line jurisdictional channels	Blueline_Streams.shp	Line	Ventura County
Major Lakes	Ventlakes.shp	Polygon	Ventura County
Detention Basins	Basins.shp	Point	Ventura County
Waterways tidally connected to the Pacific Ocean	Tidally_Influenced.shp	Line	Geosyntec, Permittees
Q100 calculation points on Calleguas Creek	CC_Q100.shp	Point	Ventura County
Q100 calculation points on Santa Clara River	SCR_Q100.shp	Point	Ventura County
Q100 calculation points on Ventura River	VR_Q100.shp	Point	Ventura County
Q100 calculation points on tributaries of Malibu Creek	Zone_4_Q100.shp	Point	Ventura County
Large Rivers with Q100 $\geq$ 25,000 cfs	Large_River.shp	Line	Geosyntec
Aerial Imagery and Transportation network	Bing Maps Hybrid	Basemap, Raster	Microsoft Corporation, ESRI Inc.
Images taken from roadways	Google Maps - Street View	Website, Raster	Google Inc.

Description	Dataset Name	Feature Class	Source
Modified Conveyances including storm drains, concrete channels, and improved channels	Modified_Channel.shp	Line	Geosyntec, Permittees
Storm drain Conveyances in Ventura County	StormDrains_Co.shp	Line	Ventura County
Storm drain Conveyances in Thousand Oaks	StormDrains_TO.shp	Line	Thousand Oaks
100-Year Floodplain	01-20-10_100_Yr_Flood_nad27.shp	Polygon	Ventura County
Major subwatershed delineations within the Ventura River Watershed	Zone1_Ventura_River_Watershed.shp	Polygon	Ventura County
Major subwatershed delineations within the Santa Clara River Watershed	Zone2_Santa_Clara_River_Watershed.shp	Polygon	Ventura County
Major subwatershed delineations within the Calleguas Creek Watershed	Zone3_Calleguas_Creek_Watershed.shp	Polygon	Ventura County
Subcatchment delineations within the Ventura River Watershed	V_Subwatershed.shp	Polygon	Ventura County
LiDAR elevation data	Ventura River Wshed.zip (containing multiple .xyzi files)	3-D Point	Ventura County
LiDAR elevation data	LIDARxyzi_2_PointToRaster.tif	Raster	Geosyntec
Street centerlines	Street.shp	Line	Ventura County
USGS Topographic Maps	USA Topo Maps	Basemap, Raster	USGS, National Geographic Society, ESRI Inc.

* * * * *



Jurisdictional Boundary Map

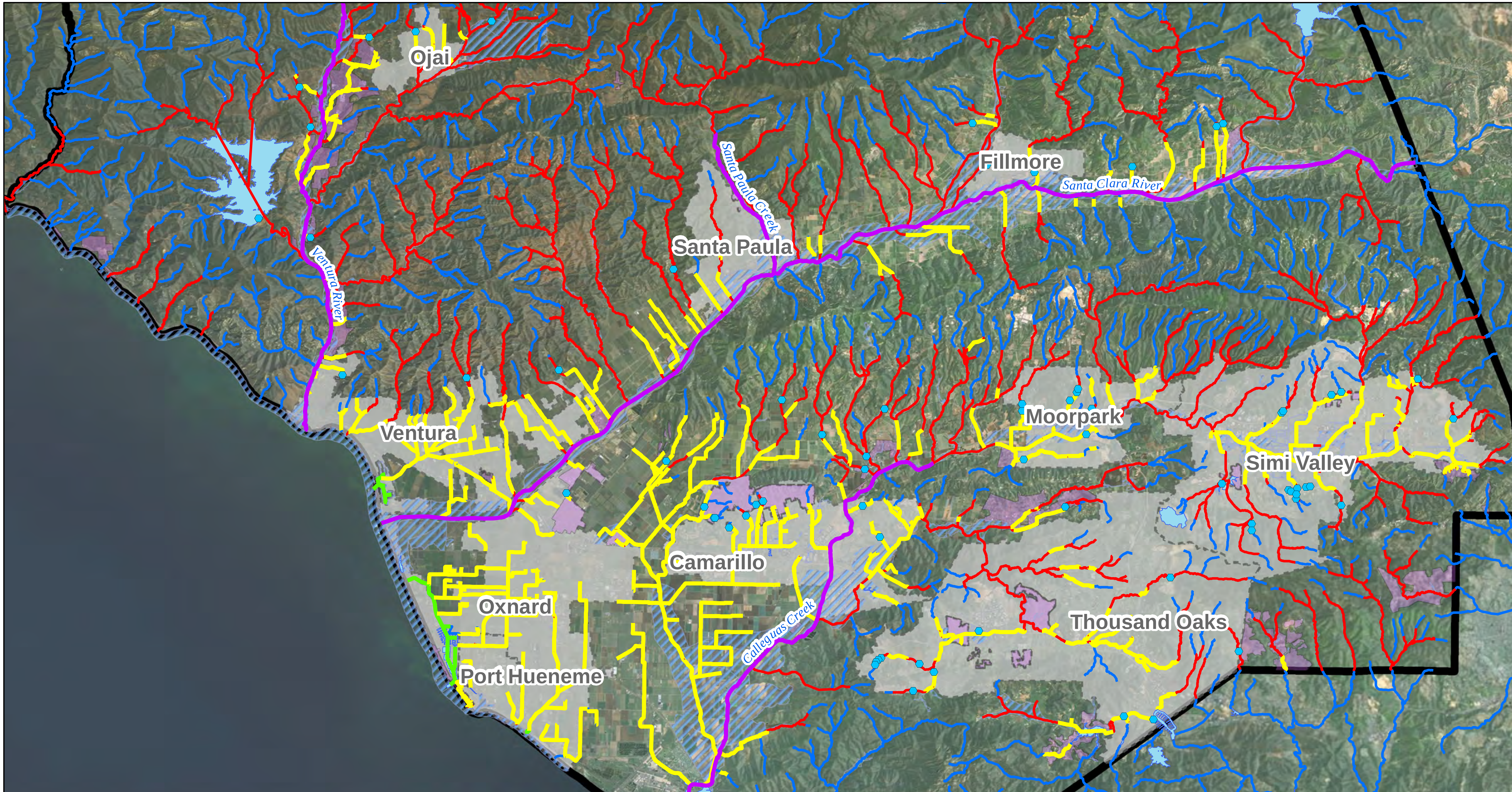
Ventura County, CA

Geosyntec consultants

Figure 1

WW1631 | December 2012

P:\GIS\Ventura County Hydromod Mapping\Zone123 Project\Cities\JursidictionalBoundaries.mxd



Legend

- Large Channel (Q100>25,000 cfs) - Not Susceptible
- Modified Channel - Not Susceptible
- TidalChannel - Not Susceptible
- Natural Redline Channel - Susceptible
- Natural Blueline Channel - Susceptible
- CURB Boundary
- Urban County
- Ventura Lakes
- 100 Year Floodplain
- Basins

0 1.5 3 6 Miles

N

Basemap Source: ESRI

Susceptibility of Water Bodies to Hydromodification

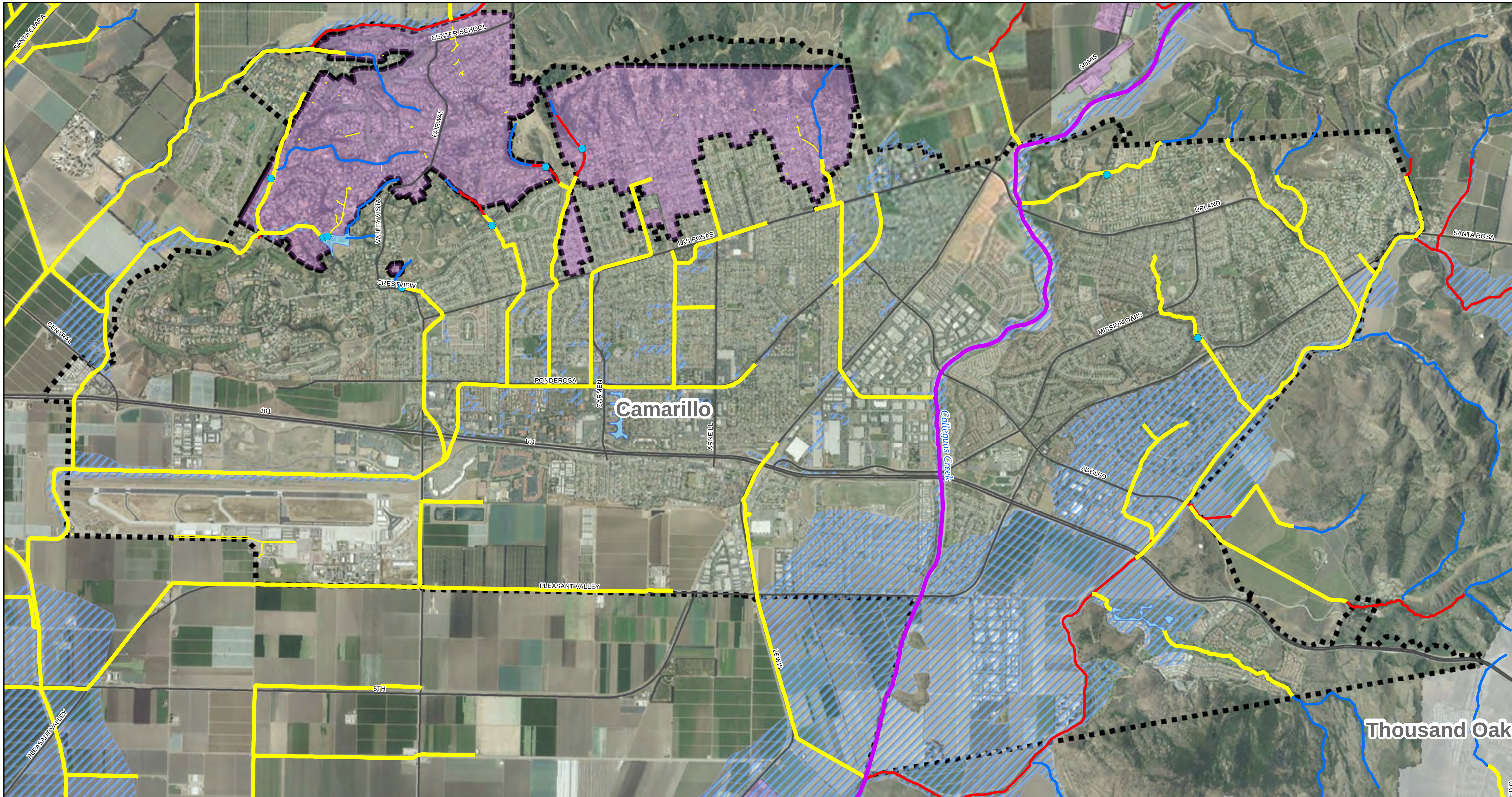
Ventura County, CA

Geosyntec consultants

Figure 2

WW1631 | December 2012

P:\GIS\Ventura County Hydromod Mapping\Zone123 Project\Zone123_HydromodMap_0628121 (Arc 10).mxd



Legend

- Large Channel (Q100>25,000 cfs) - Not Susceptible
- Modified Channel - Not Susceptible
- Storm Drain - Not Susceptible
- Tidal Channel - Not Susceptible
- Natural Redline Channel - Susceptible
- Natural Blueline Channel - Susceptible
- Camarillo CURB
- CURB Boundary
- Urban County
- Ventura Lakes
- 100 Year Floodplain
- Street
- Basins

0 1,500 3,000 6,000 Feet

N

Basemap Source: ESRI

Susceptibility of Water Bodies to Hydromodification

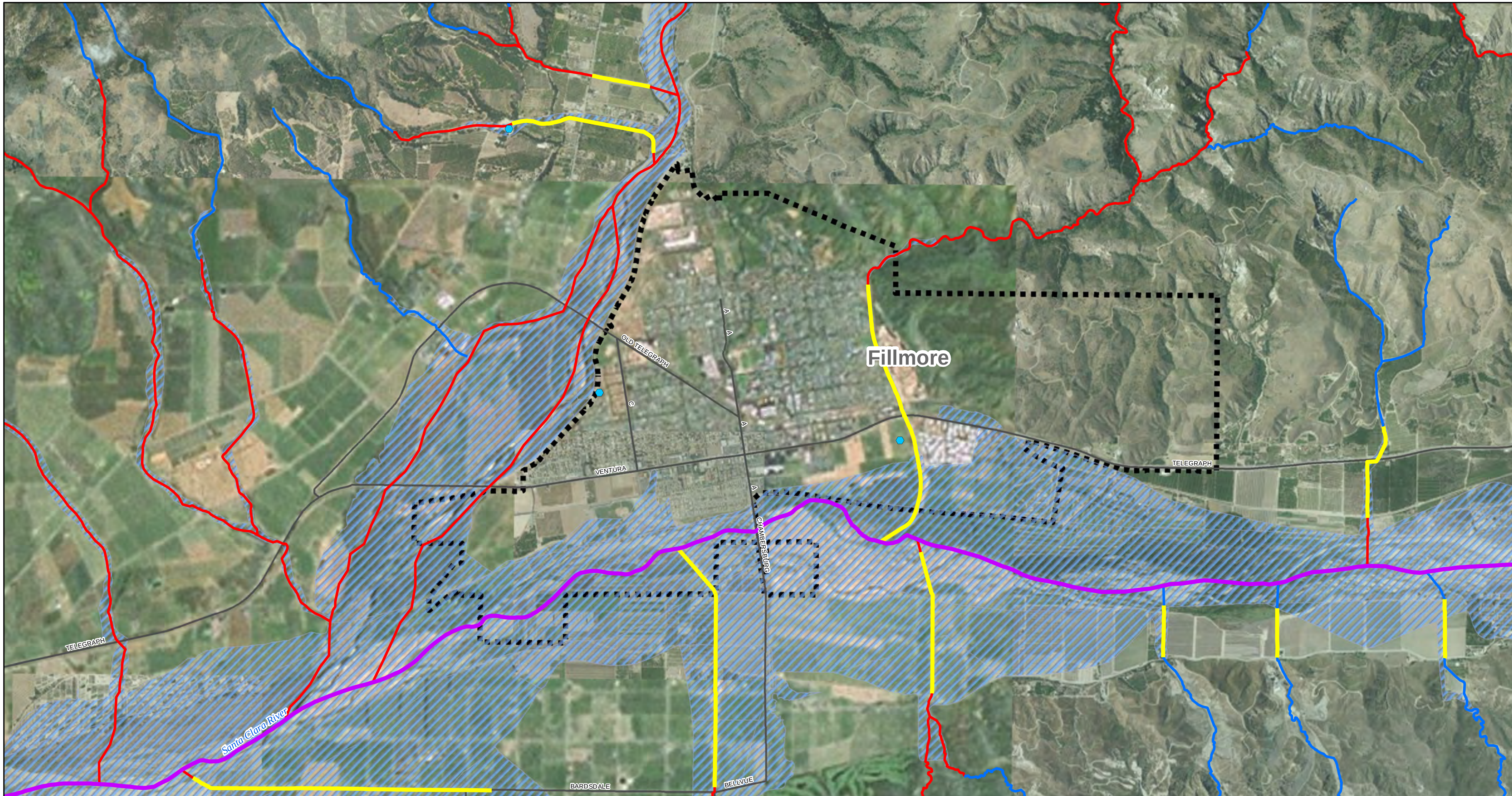
Camarillo, CA

Geosyntec consultants

Figure 3

WW1631 | December 2012

P:\GIS\Ventura County Hydromod Mapping\Zone123 Project\Cities\Camarillo_zoom.mxd



Legend

- Large Channel (Q100>25,000 cfs) - Not Susceptible
- Modified Channel - Not Susceptible
- Storm Drain - Not Susceptible
- Tidal Channel - Not Susceptible
- Natural Redline Channel - Susceptible
- Natural Blueline Channel - Susceptible
- Fillmore CURB
- CURB Boundary
- Urban County
- Ventura Lakes
- 100 Year Floodplain
- Street
- Basins

0 1,250 2,500 5,000 Feet

Basemap Source: ESRI

N

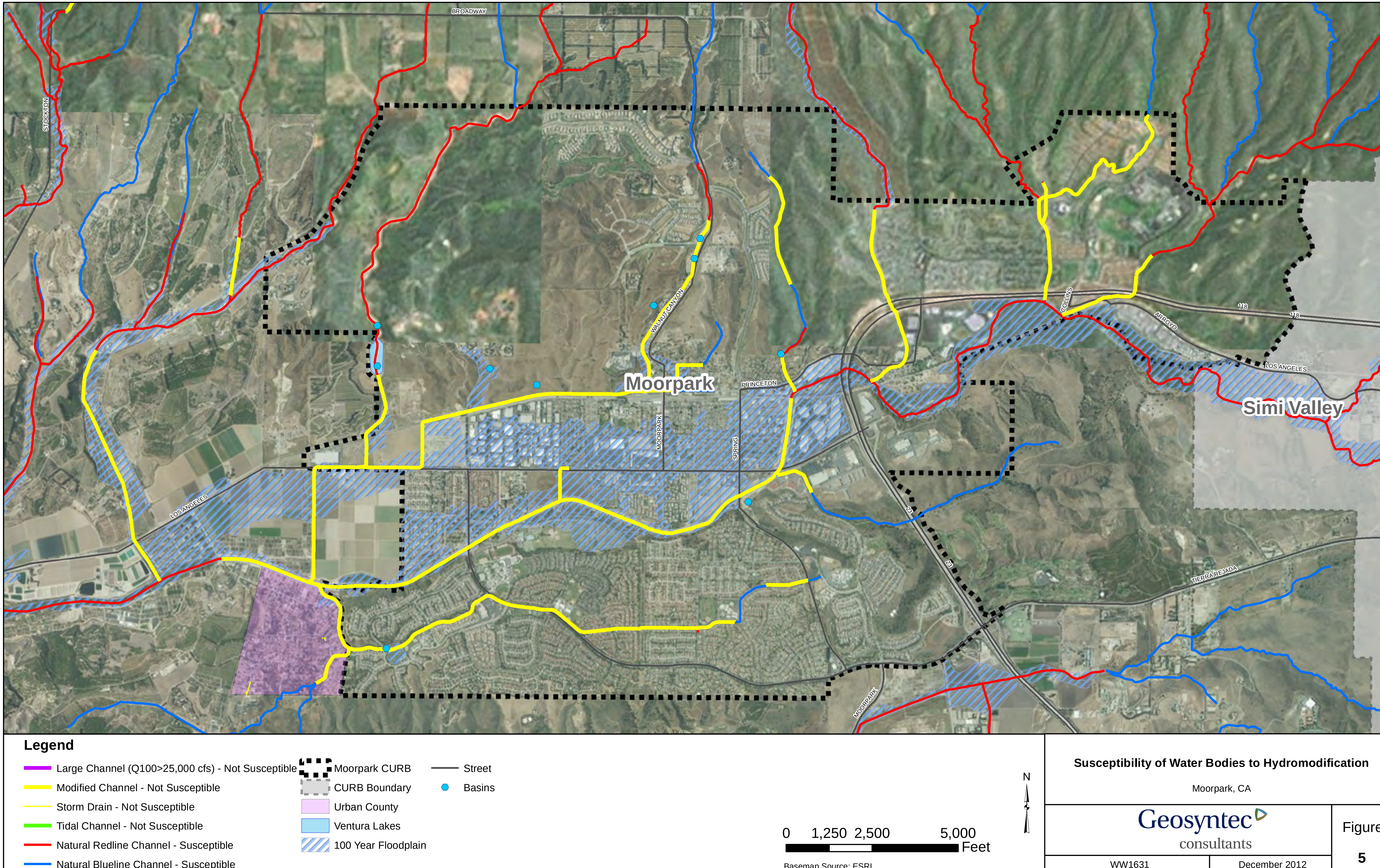
Susceptibility of Water Bodies to Hydromodification

Fillmore, CA

Geosyntec consultants

WW1631	December 2012	Figure 4

P:\GIS\Ventura County Hydromod Mapping\Zone123 Project\Cities\Filmore_zoom.mxd



Susceptibility of Water Bodies to Hydromodification

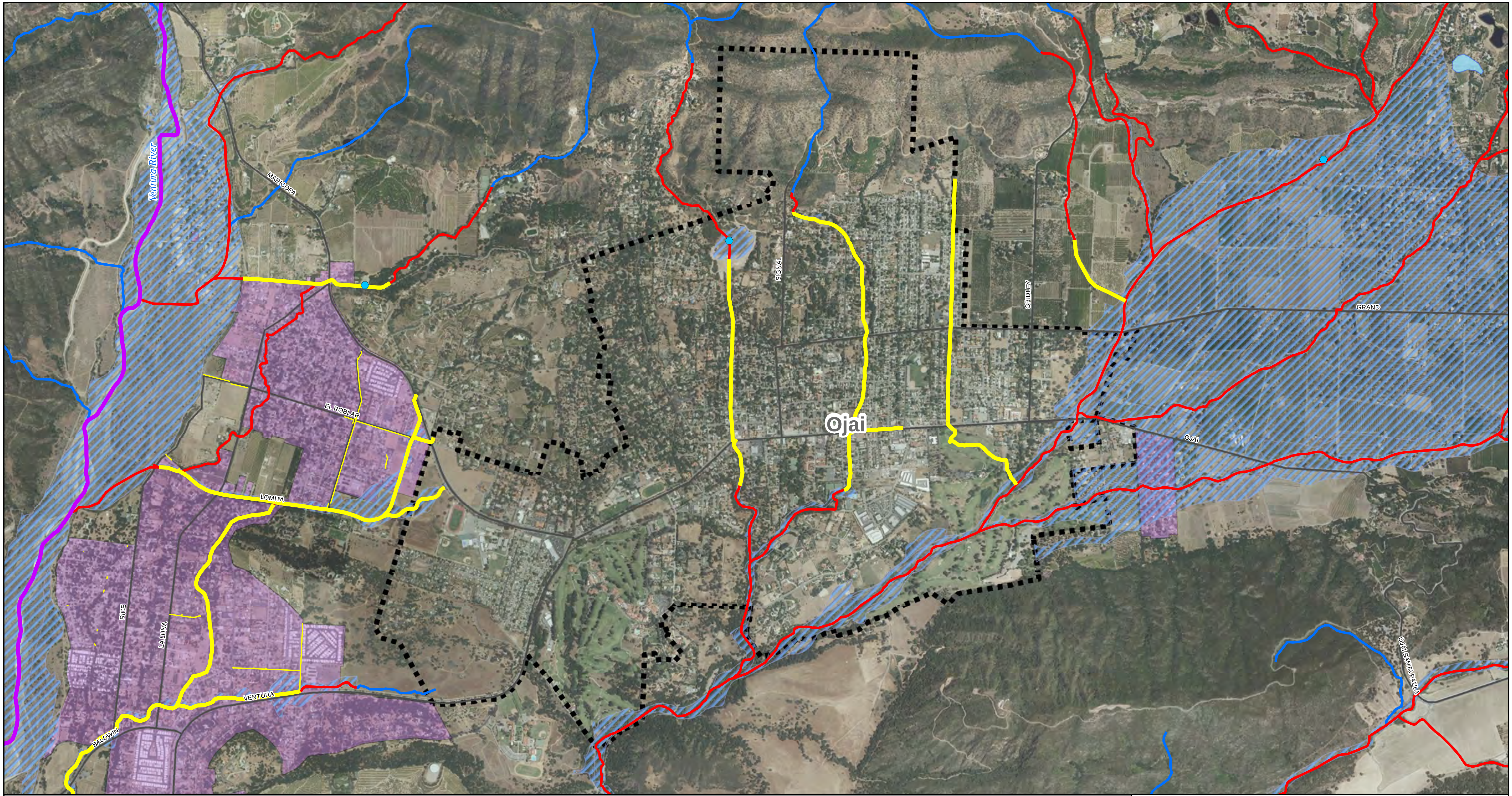
Moorpark, CA

Geosyntec consultants

WW1631 | December 2012

Figure 5

P:\GIS\Ventura County Hydromod Mapping\Zone123 Project\Cities\Moorepark_zoom.mxd



Legend

- Large Channel (Q100>25,000 cfs) - Not Susceptible
- Modified Channel - Not Susceptible
- Storm Drain - Not Susceptible
- Tidal Channel - Not Susceptible
- Natural Redline Channel - Susceptible
- Natural Blueline Channel - Susceptible
- Ojai CURB
- CURB Boundary
- Urban County
- Ventura Lakes
- 100 Year Floodplain
- Street
- Basins

N

0 1,000 2,000 4,000 Feet

Basemap Source: ESRI

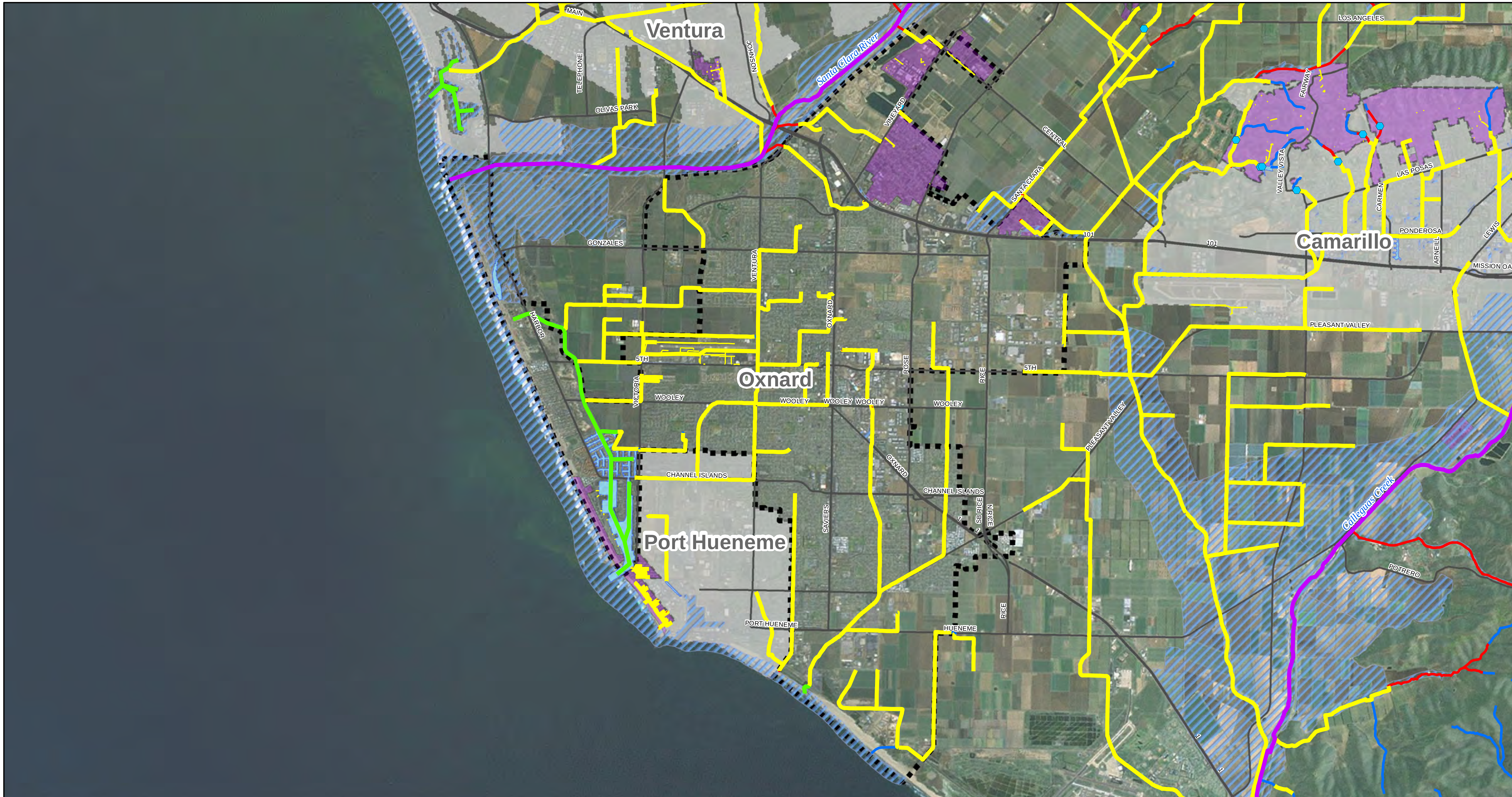
Susceptibility of Water Bodies to Hydromodification

Ojai, CA

Geosyntec consultants

WW1631	December 2012	Figure 6

P:\GIS\Ventura County Hydromod Mapping\Zone123 Project\Cities\Ojai_zoom.mxd



Legend

	Large Channel (Q100>25,000 cfs) - Not Susceptible		Oxnard CURB		Street
	Modified Channel - Not Susceptible		CURB Boundary		Basins
	Storm Drain - Not Susceptible		Urban County		
	Tidal Channel - Not Susceptible		Ventura Lakes		
	Natural Redline Channel - Susceptible		100 Year Floodplain		
	Natural Blueline Channel - Susceptible				

N

0 3,250 6,500 13,000 Feet

Basemap Source: ESRI

Susceptibility of Water Bodies to Hydromodification

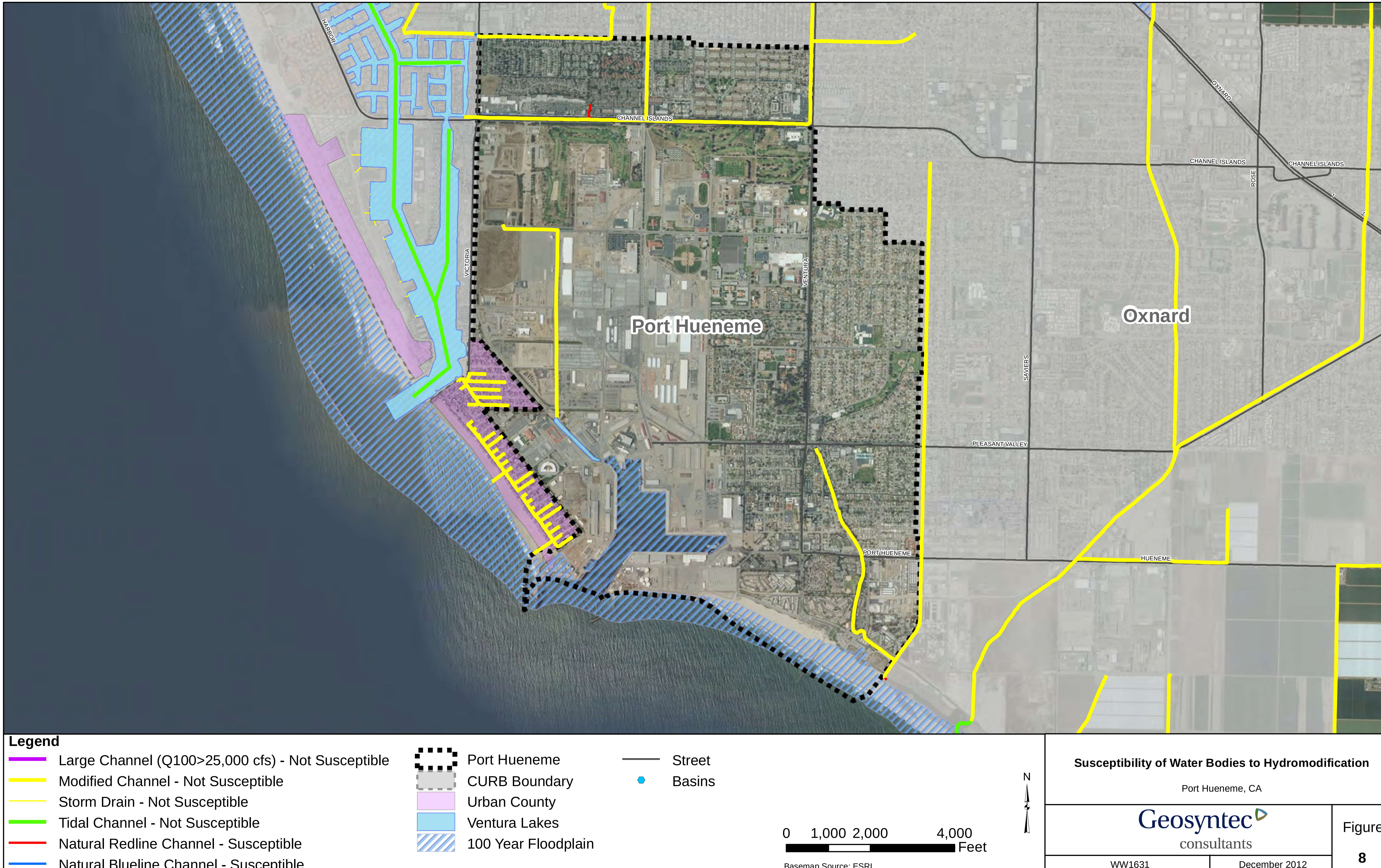
Oxnard, CA

Geosyntec consultants

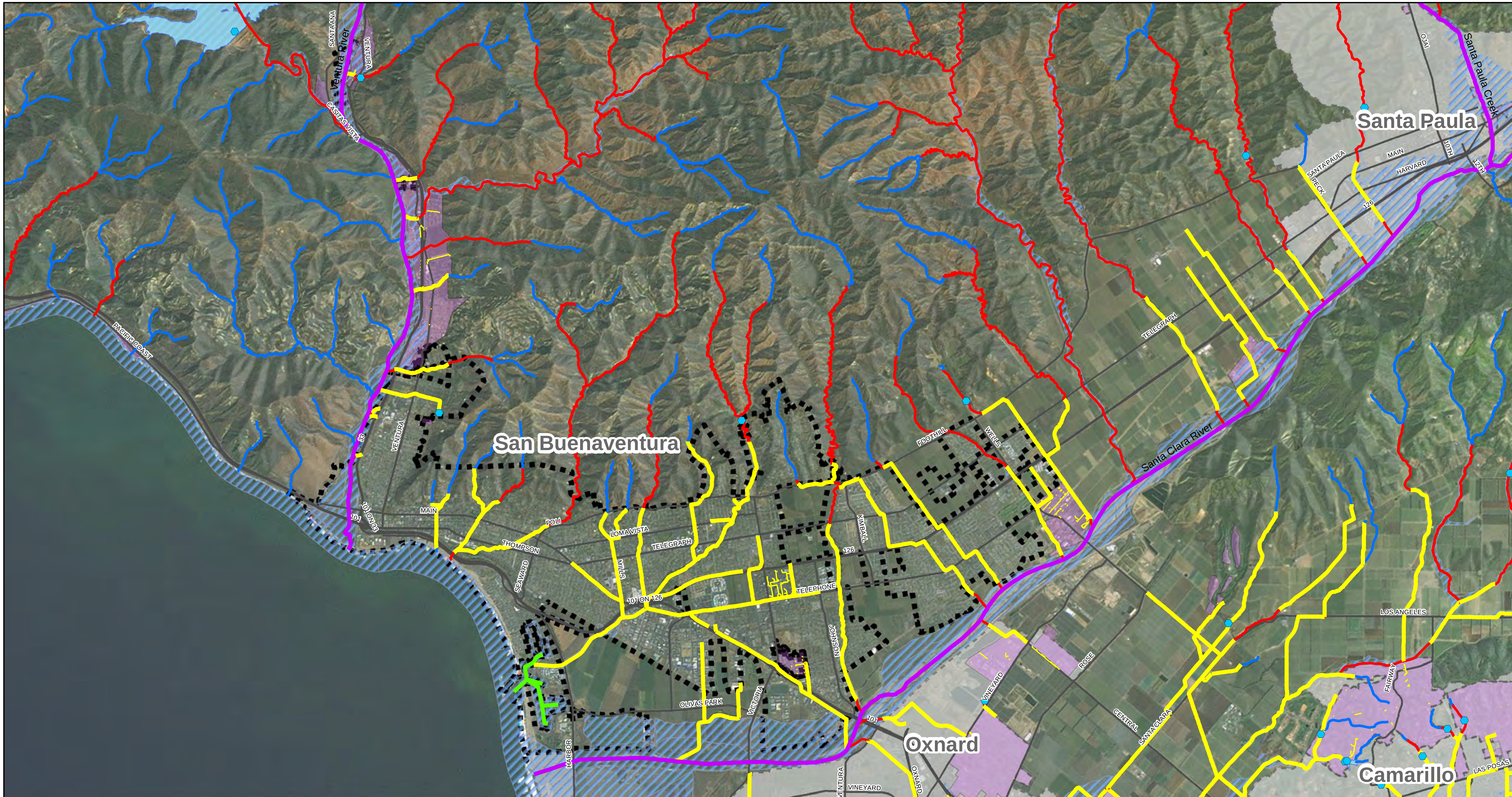
WW1631 | December 2012

Figure 7

P:\GIS\Ventura County Hydromod Mapping\Zone123 Project\Cities\Oxnard_zoom.mxd



P:\GIS\Ventura County Hydromod Mapping\Zone123 Project\Cities\PortHueneme_zoom.mxd



Legend

- Large Channel (Q100>25,000 cfs) - Not Susceptible
- Modified Channel - Not Susceptible
- Storm Drain - Not Susceptible
- Tidal Channel - Not Susceptible
- Natural Redline Channel - Susceptible
- Natural Blueline Channel - Susceptible
- Ventura CURB
- CURB Boundary
- Urban County
- Ventura Lakes
- 100 Year Floodplain
- Street
- Basins

N

0 3,250 6,500 13,000 Feet

Basemap Source: ESRI

Susceptibility of Water Bodies to Hydromodification

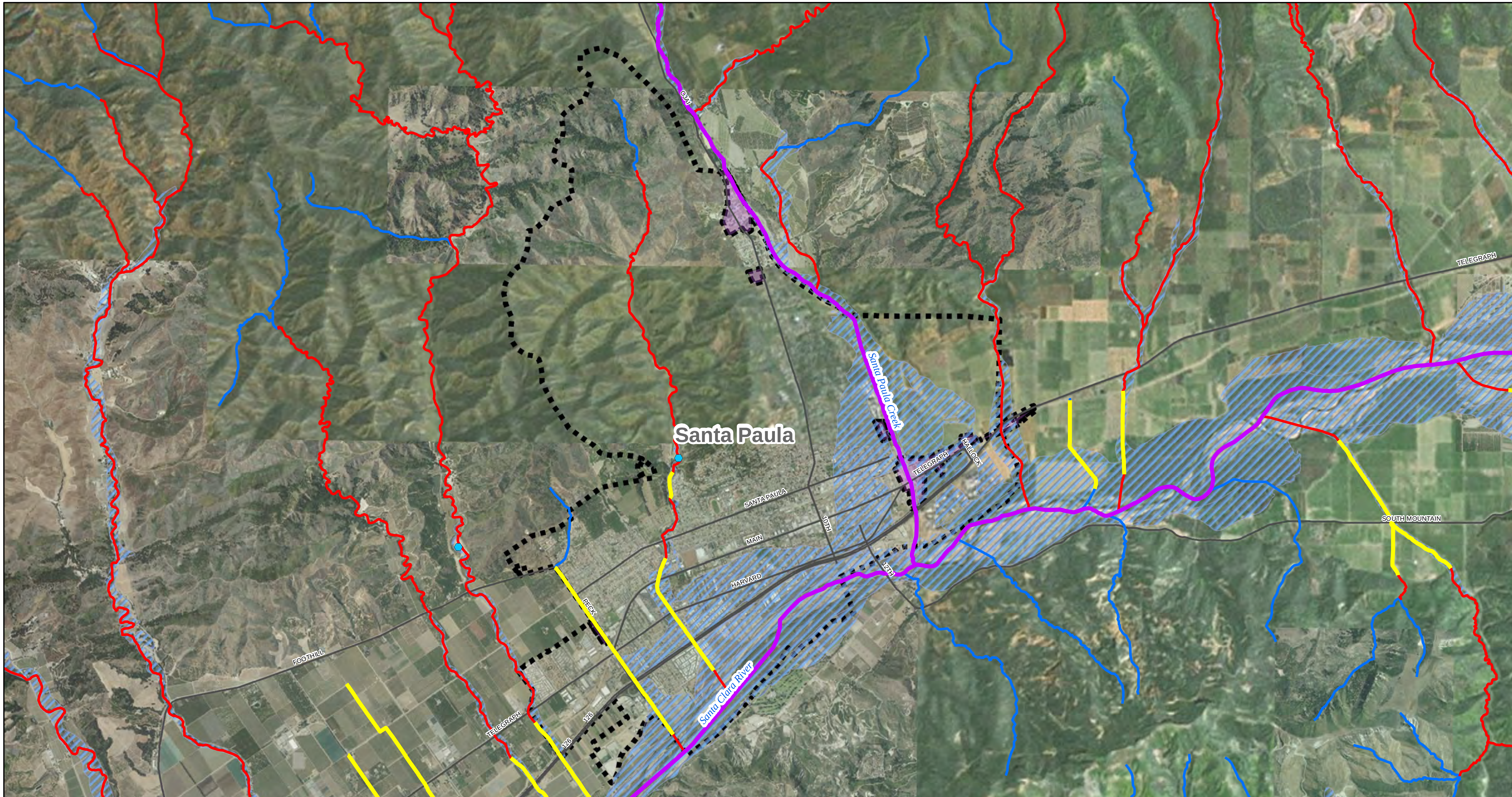
San Buenaventura, CA

Geosyntec consultants

Figure 9

WW1631 | December 2012

P:\GIS\Ventura County Hydromod Mapping\Zone123 Project\Cities\San_Buenaventura(Arc10).mxd



Legend

- Large Channel (Q100>25,000 cfs) - Not Susceptible
- Modified Channel - Not Susceptible
- Storm Drain - Not Susceptible
- Tidal Channel - Not Susceptible
- Natural Redline Channel - Susceptible
- Natural Blueline Channel - Susceptible
- Santa Paula CURB
- CURB Boundary
- Urban County
- Ventura Lakes
- 100 Year Floodplain
- Street
- Basins

0 1,750 3,500 7,000 Feet

N

Basemap Source: ESRI

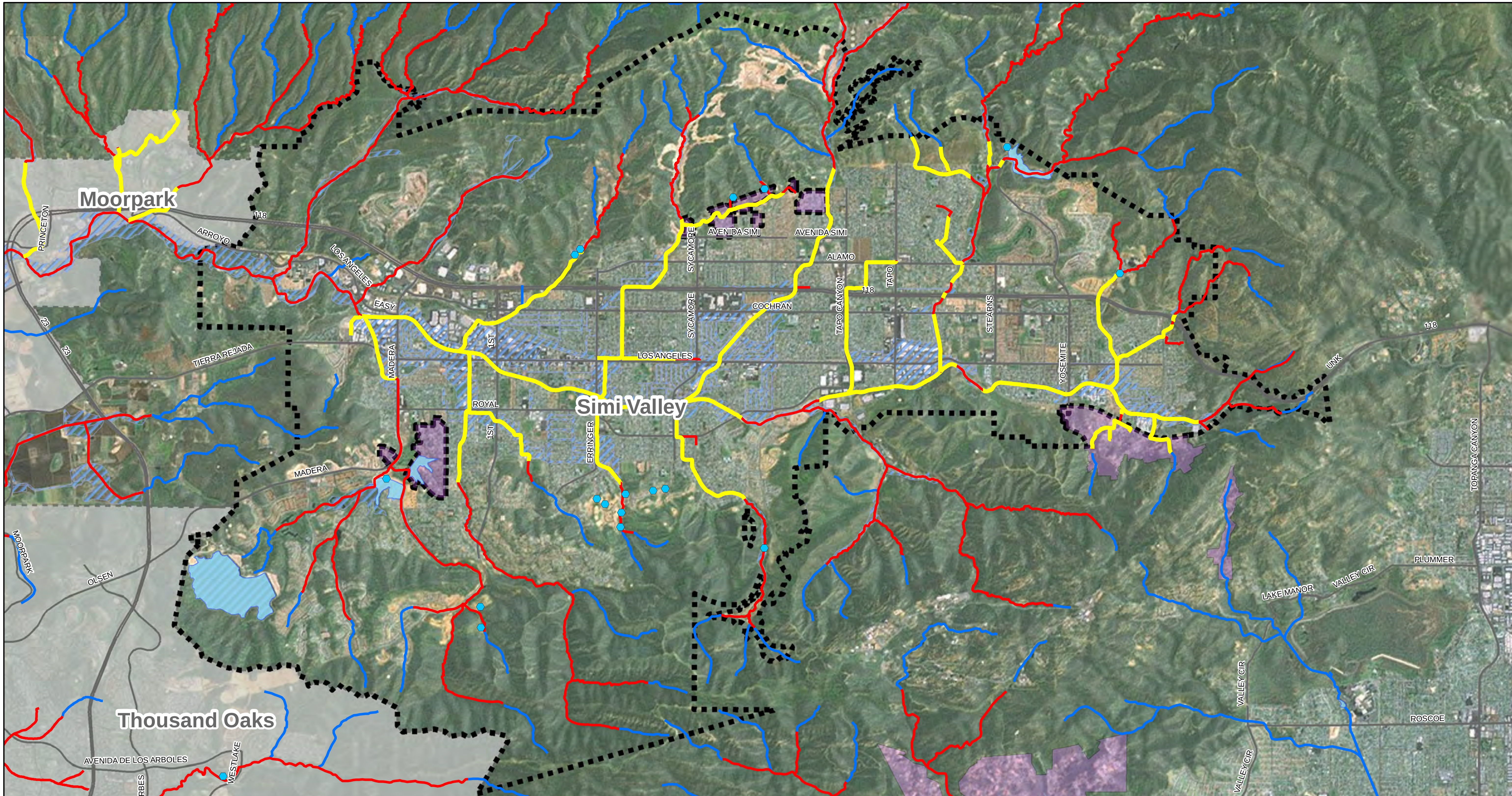
Susceptibility of Water Bodies to Hydromodification

Santa Paula, CA

Geosyntec consultants

WW1631	December 2012	Figure 10

P:\GIS\Ventura County Hydromod Mapping\Zone123 Project\Cities\SantaPaula_Zoom(Arc10).mxd



Legend

- Large Channel (Q100>25,000 cfs) - Not Susceptible
- Modified Channel - Not Susceptible
- Storm Drain - Not Susceptible
- Tidal Channel - Not Susceptible
- Natural Redline Channel - Susceptible
- Natural Blueline Channel - Susceptible
- Simi Valley CURB
- CURB Boundary
- Urban County
- Ventura Lakes
- 100 Year Floodplain
- Street
- Basins

N

0 2,500 5,000 10,000 Feet

Basemap Source: ESRI

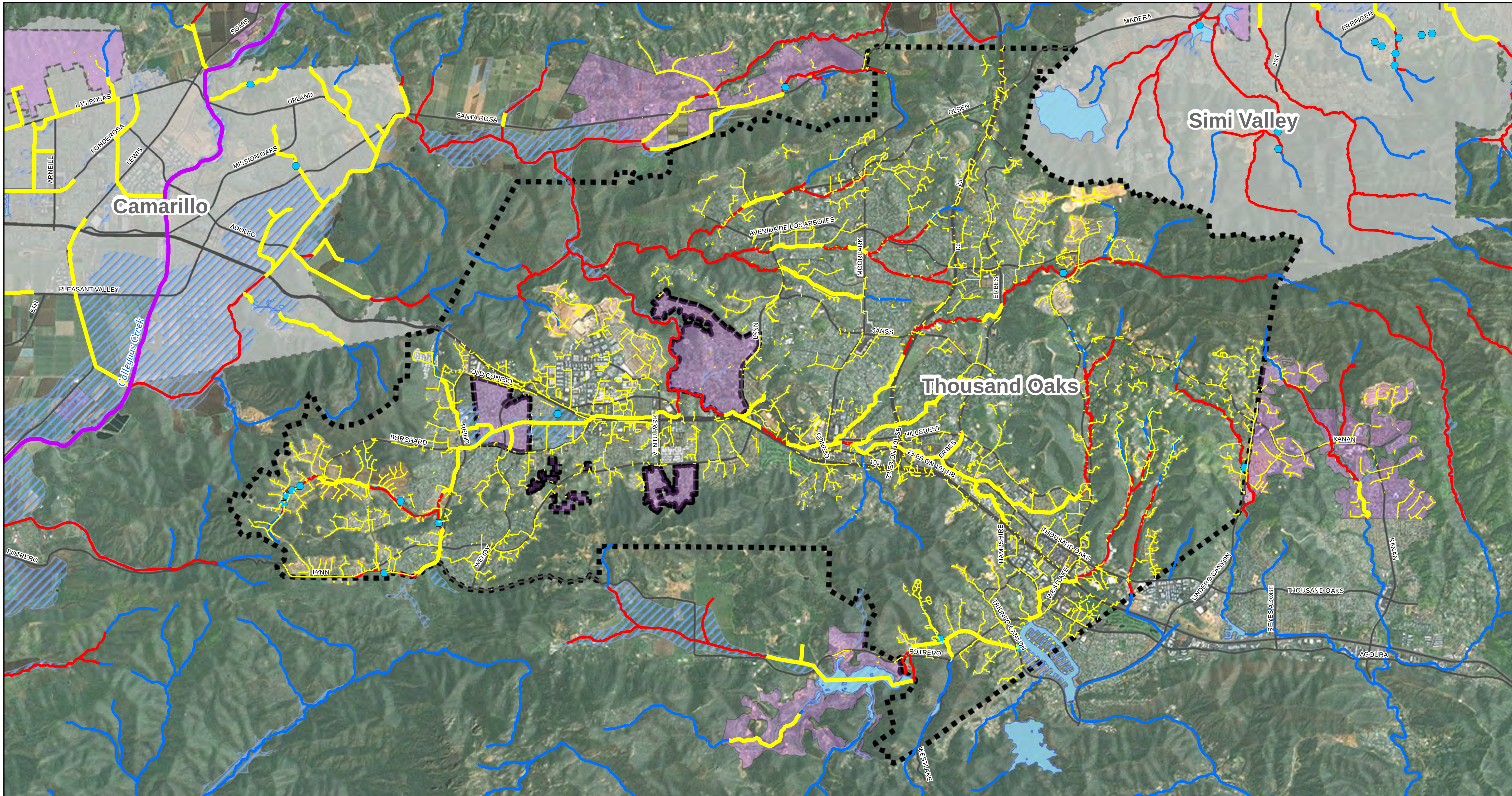
Susceptibility of Water Bodies to Hydromodification

Simi Valley, CA

Geosyntec consultants

WW1631	December 2012	Figure 11

P:\GIS\Ventura County Hydromod Mapping\Zone123 Project\Cities\SimiValley_Zoom(Arc10)1.mxd



Legend

- Large Channel (Q100>25,000 cfs) - Not Susceptible
- Modified Channel - Not Susceptible
- Storm Drain - Not Susceptible
- Tidal Channel - Not Susceptible
- Natural Redline Channel - Susceptible
- Natural Blueline Channel - Susceptible
- Thousand Oaks CURB
- CURB Boundary
- Urban County
- Ventura Lakes
- 100 Year Floodplain
- Street
- Basins

0 3,000 6,000 12,000 Feet

N

Basemap Source: ESRI

Susceptibility of Water Bodies to Hydromodification

Thousand Oaks, CA

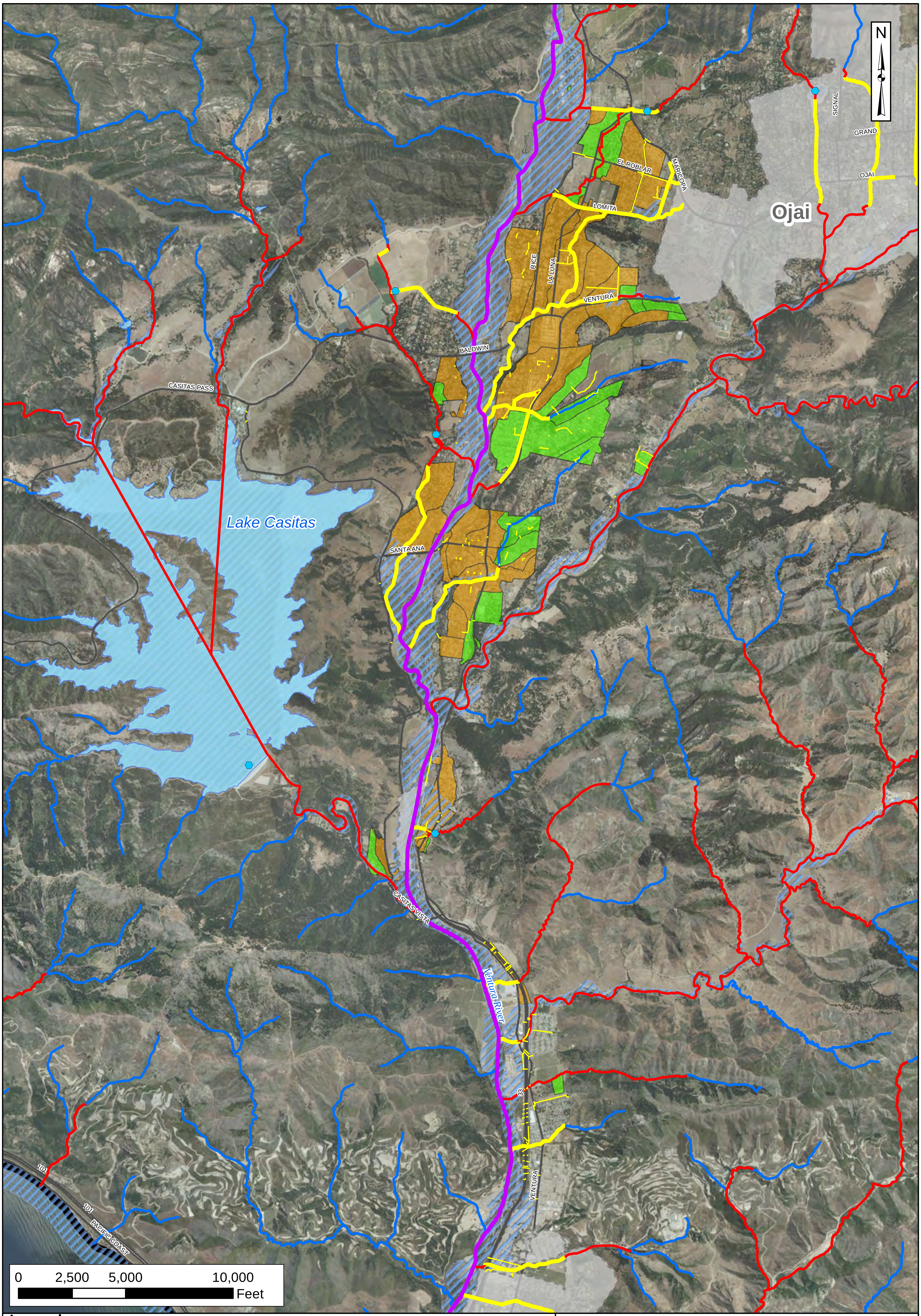
Geosyntec consultants

Figure 12

WW1631

December 2012

P:\GIS\Ventura County Hydromod Mapping\Zone123 Project\Cities\ThousandOaks_Zoom(Arc10).mxd



Legend

- Large Channel (Q100>25,000 cfs) - Not Susceptible
- Modified Channel - Not Susceptible
- Storm Drain - Not Susceptible
- Tidal Channel - Not Susceptible
- Natural Redline Channel - Susceptible
- Natural Blueline Channel - Susceptible
- Street
- CURB Boundary
- Ventura Lakes
- 100 Year Floodplain
- Basins

Hydromod Status

- Applicable
- Exempt

Basemap Source: ESRI

Example Hydromodification Control Applicability Map - County Unincorporated Urban Centers within the Ventura River Watershed

Geosyntec consultants

Figure 13

WW1631

December 2012

P:\GIS\Ventura County Hydromod Mapping\Zone123 Project\VenturaCountyInfillApplicability.mxd

APPENDIX D

Basis for Designating Negligible Risk Based on Cumulative Future Buildout

APPENDIX D

BASIS FOR DESIGNATING NEGLIGIBLE RISK BASED ON CUMULATIVE FUTURE BUILDOUT

1. BACKGROUND

Hydromodification impacts are typically most severe just downstream of development and tend to decrease if more undeveloped watershed area contributes to the channel in the downstream direction. Analyses were performed to evaluate thresholds for additional impervious cover, from existing conditions (at the time of the HCP effective date) to buildout conditions, for the area tributary to a susceptible receiving water below which the risk of hydromodification impacts is considered negligible for that channel.

The following results are provided as a function of a susceptible channel's tributary area (A) and median grain size (D_{50}):

- If A $\geq$ 1 square mile and D_{50} $\leq$ 16 mm, then the threshold of additional imperviousness is evaluated using the nomograph in Figure 3-12.

  Figure 3-12 is based on empirical flow duration equations (Hawley and Bledsoe, 2011), empirical channel geometry relationships (Coleman et al, 2005 and County of San Diego, 2009), and Erosion Potential analyses (see HCP Section 6.3 for a discussion on the Erosion Potential analysis method). The results range from 0.46% to 1.00% additional imperviousness, depending on watershed size and mean annual precipitation (MAP).

- If A < 1 square mile and D_{50} $\leq$ 16 mm, then the threshold of additional imperviousness is 0.44%. (See Section 6.2 below.)
- If D_{50} $\geq$ 16 mm, then the threshold of additional imperviousness is 1.65%. (See Section 6.2 below.)

The analyses used to establish these thresholds are described below.

2. HYDROLOGIC ANALYSIS

2.1 Identify the Typical Range of Rainfall Conditions

For the purposes of this analysis, the typical range of mean annual precipitation (MAP) is assumed to be 14 inches to 18 inches per year because most of the developed regions within Ventura County fall within this range on the isohyetal map (Figure 2-5) and this range is consistent with Ventura County's long-term precipitation gage records

(VCWPD 2007). It is anticipated that future development will impact the most miles of susceptible channel in the Calleguas Watershed within and downstream of the Cities of Thousand Oaks, Simi Valley, and Moorpark. The long-term precipitation records in these areas are all within the 14 inch to 18 inch range and thus these two MAPs were used in this analysis.

Table D-1. Long-Term Precipitation Gage Records in Ventura County

Precipitation Gage ID	Period of Record	Mean Annual Precipitation (inches)
Camarillo #219	1965-2006	13.45
Port Hueneme #17	1891-2006	13.62
Moorpark #141	1949-2006	14.45
Ventura #66	1873-2006	14.71
Simi Valley #154	1948-2006	14.89
Thousand Oaks #128	1943 -2006	15.6
Santa Paula #245	1961-2006	17.35
Piru #36	1927-2006	17.39
Fillmore #199	1959-2006	18.44
Ojai #30	1906-2006	21.32

2.2 Identify the Range of Watershed Areas

The range of typical watershed areas used in the sensitivity analysis were established based on an inventory of a subset of natural drainage channels that have significant urban development in their tributary areas. While there are a few susceptible drainage channels with watershed areas over 100 square miles or less than 1 square mile, most of the susceptible channels downstream of development are lower order with watershed areas ranging from about 2 to 10 square miles. Seven categories of watershed area (1-, 2-, 5-, 10-, 20-, 50-, and 100-square miles) were used in this analysis.

2.3 Identify Length of Daily Flow Record

A 30-year length of daily flow record was assumed in this analysis. During preliminary runs it was found that the threshold of additional impervious cover was not sensitive to changes in the assumed length of daily flow record.

2.4 Calculate Necessary Peak Flow Inputs (Q_2, Q_5, Q_{10})

Empirical peak flow equations used to estimate the 2-, 5-, and 10-year recurrence interval flows (Hawley and Bledsoe, 2011). The general form of the equation is:

$$Q_i = e^{(Incpt)} * A^a * P^p * e^{(impmax*Impmax)}$$

Where:

Q_i	=	the instantaneous peak flow at return interval i years (cfs)
Incpt	=	the vertical axis intercept of the log-transformed linear regression model
A	=	total drainage area (mi^2)
P	=	average annual precipitation (in)
Impmax	=	the maximum spatial extent of the total impervious area during the gage record as a fraction of the total drainage area (mi^2/mi^2)

a, p, and impmax = regression parameters specific to each return period

Table D-2 provides the regression parameters for each return period of interest.

Table D-2. Regression parameters for the 2-, 5-, and 10-year peak flows

Return Period (yrs)	Incpt (-)	a (mi^2)	p (in)	Impmax (-)
2	-0.644	0.667	1.29	8.61
5	2.137	0.838	0.773	3.23
10	2.90	0.868	0.767	0

Table D-3 presents the resulting flowrates for each combination of tributary area and mean annual precipitation analyzed (14 total) assuming no imperviousness.

Table D-3. Peak Flow (Q_2, Q_5, Q_{10}) Results

Tributary Area	Mean Annual Precipitation	Q2	Q5	Q10
A	MAP			
sq mi	in/yr	cfs	cfs	cfs
1	14	15.8	65.2	138
2	14	25.1	116	251
5	14	46.2	251	556
10	14	73.4	449	1015
20	14	117	802	1853
50	14	215	1729	4104
100	14	341	3091	7491
1	18	21.9	79.1	167
2	18	34.7	141	304
5	18	63.9	305	674
10	18	102	545	1231
20	18	161	974	2247
50	18	297	2100	4977
100	18	472	3753	9083

2.5 Calculate Inputs for Long-Term Cumulative Durations (Q_{max}, Q_{min}, day1, day2, N_B, $H_{B\text{-}log}$)

In order to represent the mean daily flows with cumulative duration curves, logarithmic histogram bins were created to represent flow frequencies without any discontinuities following the Hawley and Bledsoe (2011) methodology. The bin size of the logarithmically-spaced histogram bins ($H_{B\text{-}log}$) is represented as follows:

$$H_{B\text{-}log} = \{\ln(Q_{max})-\ln(Q_{min})\}/(N_B-1)$$

Where:

Q_{max}	=	the maximum flow of record (cfs)
Q_{min}	=	the minimum flow of record (cfs)
N_B	=	the number of bins

The minimum flow (Q_{min}) was set equal to 0.01 cfs, which represents the lowest non-zero mean daily flow reported at any gage used in the Hawley and Bledsoe (2011) analysis. The number of bins (N_B) was set at 25 to provide a balance between using small enough bin sizes for adequate resolution and ensuring that the flow-record data would be capable of populating each of the bins. The maximum flow of record (Q_{max}) is equivalent to the maximum mean 24-hour flow and is estimated using the following equation:

$$Q_{max}=e^{(-2.24)}*A^{0.979}*P^{1.79}*Yr^{0.341}$$

Where:

A	=	total drainage area (mi^2)
P	=	average annual precipitation (in)
Yr	=	the length of the mean daily flow record (30 years)

Q_{max} is also the scaling factor for the duration density function (DDF), or conditional probability density function, used to predict the cumulative durations of the binned geomorphically-effective flows. A power function is used to represent the duration in days, with the following form:

$$days = day1*Q^{day2}$$

The parameter 'day1' represents the magnitude of the power function calibrated in 'days' and 'cfs' and is estimated using the following relationship:

$$day1 = e^{(-12.9)}*A^{0.676}*P^{3.71}*Yr^{1.85}*e^{(13.8*Impav)}$$

Where:

A	=	total drainage area (mi^2)

P	=	average annual precipitation (in)
Yr	=	the length of the mean daily flow record (30 years)
Impav	=	the average spatial extent of the total impervious area expressed as a fraction of the total drainage area (mi^2/mi^2)

The parameter 'day2' represents the shape of the power function and is calibrated in 'days' and 'cfs' through the following relationship:

$$day2 = -1.60+0.166*\ln(Q_{10})-0.138*\ln(day1)+0.129*\ln(Yr)+0.720*Impav$$

Where:

Q_{10}	=	the instantaneous 10-year peak flow
Yr	=	the length of the mean daily flow record (30 years)
Impav	=	the average spatial extent of the total impervious area expressed as a fraction of the total drainage area (mi^2/mi^2)

2.6 Calculate Long-Term Cumulative Durations for Each Flow Bin (B, $B_{lwr-log}$, $B_{upr-log}$, Q, days)

Using the bin size estimated above (H_{B-log}), the lower and upper bounds of each logarithmically-spaced bin (B) can be calculated as follows:

$$B_{lwr-log} = e^{\{\ln(Qmin)+(B-2)*HB-log\}}$$

$$B_{upr-log} = e^{\{\ln(Qmin)+(B-1)*HB-log\}}$$

The average flow within each of the bins was used in the power function to calculate the cumulative duration for the histogram.

$$Q = (B_{lwr-log}+B_{upr-log})/2$$

$$days= day1*Q^{day2}$$

3. HYDRAULIC ANALYSIS

3.1 Identify a Range of Typical Receiving Channel Geometry Dimensions

An empirical relationship developed by Coleman et al (2005), modified by Stein (County of San Diego, 2009) was used to express channel dimensions (width, depth, and, to a lesser extent, gradient) as a function of dominant discharge (Q_{bf}, in cfs). The Stein and Coleman relationship was used because it: (1) produced more consistent and conservative results than the Hey-Thorne (1986) relationship; (2) resulted in Qcrit results within the range of values suggested for implementation in the San Diego HMP (0.1Q2, 0.3Q2, 0.5Q2); (3) was general in that it did not require an assumption of D50; and (4) is applicable to the most sensitive sand bedded channels, which the Parker (2007) relationship is not. The geometry relationships are as follows:

$$\text{Width (ft)} = 0.6012 * Q_{bf}^{0.6875}$$

$$\text{Depth (ft)} = 0.3854 * Q_{bf}^{0.3652}$$

Q_{bf}, assumed to be approximately the 5-year peak discharge (Q_5), was estimated using the empirical equation from Hawley and Bledsoe (2011) provided in Section 2.4 of this Appendix. This equation calculates Q_5 (cfs) as a function of watershed area (sq. mi.), mean annual precipitation (MAP, in/yr), and percent impervious cover (%) based on empirical observations of USGS gages.

Manning's equation was used to iteratively find the slope for each channel dimension, such that the wetted cross sectional area at bankfull conveys the Q_5. Manning's equation is expressed as:

$$Q = \frac{1.49 A R^{0.67} S^{0.5}}{n}$$

Where:

Q	=	Flowrate (cfs)
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)

The hydraulic analysis assumed a Manning Roughness value (n) of 0.035 for the main channel, corresponding to a non-vegetated, straight channel with no riffles and pools. This reflects the small, ephemeral receiving channels which are prevalent in Southern California. A relatively low 'n' value was used at the request of the San Diego Regional Water Board in the development of the San Diego HMP. A Manning's roughness of

0.07 was used for the over bank floodplain with an assumed side slope of 10 to 1 (Horizontal:Vertical). The overbank parameters were not as sensitive of parameters as longitudinal slope and channel geometry for the purpose of this analysis, therefore a range was not evaluated.

The receiving channel geometry dimensions used for hydraulic analysis of each model scenario are presented in Table D-4.

Table D-4. Receiving Channel Geometry Dimensions

Tributary Area	Mean Annual Precipitation	Longitudinal Slope	Bankfull Width	Bankfull Depth
A	***MAP***	***S***	***W***	***D***
sq mi	**in/yr**	**%**	**ft**	**ft**
1	14	0.45	10.6	1.8
2	14	0.30	15.8	2.2
5	14	0.18	26.8	2.9
10	14	0.12	40.0	3.6
20	14	0.08	59.7	4.4
50	14	0.05	101.2	5.9
100	14	0.04	150.8	7.3
1	18	0.40	12.1	1.9
2	18	0.27	18.1	2.4
5	18	0.16	30.7	3.1
10	18	0.11	45.7	3.8
20	18	0.07	68.2	4.8
50	18	0.05	115.6	6.3
100	18	0.03	172.4	7.8

3.2 Calculate Effective Shear Stress and Velocity for Each Flow Bin

The flow velocity was calculated after iterating for the slope to achieve $Q=Q_5$ as:

$$V = Q/A$$

Where:

V = Flow Velocity (ft/s)

Q = Flowrate (cfs)

A	=	Cross Section Flow Area (ft^2)

Average boundary shear stress was calculated 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	=	Longitudinal slope (ft/ft)

4. WORK ANALYSIS

4.1 Identify Critical Flowrate (10%Q_2)

The regional default critical flowrate of 10% Q_2, per Appendix E, was used for this analysis. Flow rates below this value were assumed to perform no work on the channel.

4.2 Calculate Work for Each Flow Bin

The simplified effective work equation used is specified in the Ventura County MS4 Permit (LARWQCB, 2010) and 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]

If the effective shear stress for a given flow bin is less than the critical shear stress, then the effective work is equal to zero.

5. 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 [unitless]
W_i	=	Work per flow bin [unitless]
Δt	=	Duration per flow bin [days]
n	=	number of flow bins

6. 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:

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]

6.1 <u>Iterate % Impervious Cover to Meet the Hydromodification Management Standard (Ep < 1.05)</u>

Considering that the Hydromodification Management Standard for Ventura County aims to “maintain the Ep in-stream at a value of 1.0”, it is assumed that an Ep value less than 5% of the target value meets the Management Standard (i.e., an Ep value of 1.04 rounds to 1.0). Additional basis for the use of a +/- 5% allowance on Ep is supported in Section 6.3.7 in the HCP. An iterative process was used to determine the percentage of impervious cover that meets the hydromodification management standard (Ep < 1.05). The percent imperviousness is an input for the DDF power function coefficient and exponent (day1 and day2, respectively) and modifies the duration of flows within each of the logarithmically-spaced flow bin. The new durations (days) for each flow bin are multiplied by the work per flow bin (W_i) and summed across all bins to arrive at a new value for total work associated with the post-project condition ($W_{t,post}$) and Erosion Potential (Ep). Percent impervious cover is subsequently adjusted until an E_p of 1.05 is converged upon.

In preliminary runs it was evaluated that the threshold additional impervious cover associated with Ep equal to 1.05 was not highly sensitive to the baseline pre-development (or existing condition) imperviousness. For example, an increase in imperviousness from 0% to 1% resulted in the same Ep as an increase from 10% to 11%. The resulting thresholds of additional imperviousness from existing (at the time of the HCP effective date) to buildout conditions are provided below in Table D-5 and in Figure 3-12. The results provided used an existing imperviousness of 0%.

Table D-5: Threshold Additional Imperviousness Results

Tributary Area	Mean Annual Precipitation	Threshold Additional Imperviousness	Pre-Project Total Cumulative Work	Post-Project Total Cumulative Work	Erosion Potential
A	***MAP***	***Impav***	***Wt, pre***	***Wt, post***	***Ep***
sq mi	**in/yr**	**%**	**--**	**--**	**--**
1	14	0.46	1.67	1.75	1.05
2	14	0.50	1.52	1.59	1.05
5	14	0.56	1.45	1.52	1.05
10	14	0.61	1.48	1.55	1.05
20	14	0.68	1.59	1.67	1.05
50	14	0.80	1.89	1.98	1.05
100	14	0.92	2.27	2.39	1.05
1	18	0.48	2.69	2.82	1.05
2	18	0.52	2.44	2.57	1.05
5	18	0.59	2.12	2.23	1.05
10	18	0.65	2.07	2.17	1.05
20	18	0.72	2.12	2.23	1.05
50	18	0.85	2.25	2.36	1.05
100	18	1.00	2.54	2.67	1.05

6.2 Thresholds of Additional Imperviousness Based on Hawley and Bledsoe (2013)

For susceptible channels with a tributary area less than one square mile, the threshold of additional imperviousness below which the risk of hydromodification impacts is considered negligible for that channel is 0.44%. This result is based on equating two of the channel enlargement equations listed in Hawley and Bledsoe (2013) and solving for an Ep of 1.05. The two enlargement functions are:

$$Ar = 1.18*Ep^{0.998}$$

and

$$Ar = 1.18*e^{(11.0*Imp)}$$

Where:

Ar = Enlargement expressed as the relative magnitude

Ep = Sediment-transport capacity load ratio between 25-yr post-developed and pre-developed DDF simulations

Imp = Total impervious area as a fraction of total drainage area

The following equation expresses Imp as a function of Ep:

$$Imp = (0.998/11) * \ln(Ep)$$

Assuming Ep is equal to 1.05, the resulting Imp is 0.44%.

For susceptible channels with a median grain size (D_{50}) greater than 16 mm, a +/- 20% allowance on Ep is supported in Section 6.3.7 in the HCP. Assuming an Ep of 1.20 and using the equation above, the threshold additional imperviousness, below which the risk of hydromodification impacts is considered negligible for that channel, is 1.65%.

7. REFERENCES

Coleman, D., MacRae, C., and Stein, E.D. 2005. Effect of Increases in Peak Flows and Impervious on the Morphology of Southern California Streams, Technical Report 450. Southern California Coastal Water Research Project.

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

Hawley, R.J., and Bledsoe, B.P. 2011. "How do flow peaks and durations change in suburbanizing semi-arid watersheds? A southern California Study," Journal of Hydrology, Elsevier, Vol 405, pp 69-82.

Hawley, R.J., and Bledsoe, B.P. 2013. "Channel enlargement in semiarid suburbanizing watersheds: A southern California case study," Journal of Hydrology, Elsevier, Vol 496, pp 17-30.

Hey, R.D., and Thorne, C.R. 1986. "Stable Channels with Mobile Gravel Beds," Journal of Hydraulic Engineering, American Society of Civil Engineers, Vol 112, No. 8, pp 671-689.

Los Angeles Regional Water Quality Control Board. 2010. Municipal Separate Storm Sewer Systems NPDES Permit. Order R4-2010-0108. NPDES Permit Number CAS004002.

Parker, G.P., P.R. Wilcock, C. Paola, W.E. Dietrich, J.C. Pitlick. 2007. "Physical basis for quasi-universal relationships describing bankfull hydraulic geometry of single-thread gravel bed rivers". Journal of Geophysical Research – Earth surface. vol. 112.

Ventura County Watershed Protection District. 2007. Precipitation Record Results as of 9/26/07.Website: http://portal.countyofventura.org/portal/page/portal/PUBLIC_WORKS/Watershed_Protection_District/About_Us/VCWPD_Divisions/Planning_and_Regulatory/Hydrology/Current%20Rainfall%20Information/Special%20Media%20Storm%20Statement.

APPENDIX E

Basis for Low and High Flow Thresholds

APPENDIX E

BASIS FOR LOW AND HIGH FLOW THRESHOLDS

1. LOW FLOW THRESHOLD REGIONAL ANALYSIS

As a conservative default, 10% of the pre-development 2-year peak flowrate ($0.1Q_2$) is considered to be an appropriate low flow threshold for Ventura County. This assumption is supported by a regional critical flow sensitivity analysis, consistent with the methodology used by PWA in Appendix A of the *San Diego HMP* (County of San Diego, 2009). This sensitivity analysis was performed as follows:

1.1 Step 1: Identify the Typical Range of Rainfall Conditions for the HCP Area

For the purposes of this analysis, the typical range of mean annual precipitation is assumed to be 14” to 18” per year because: most of the developed regions fall within this range on the isohyetal map (Figure 1); and this range is consistent with Ventura County’s long-term precipitation gage records (VCWPD, 2007). It is anticipated that future development will impact the most miles of susceptible channel in the Calleguas watershed within and downstream of the Thousand Oaks, Simi Valley, and Moorpark CURB boundaries. The long-term precipitation records in these areas are all within the 14” to 18” range.

Table E-1. Long-Term Precipitation Gage Records in Ventura County

Precipitation Gage ID	Period of Record	Mean Annual Precipitation (inches)
Camarillo #219	1965-2006	13.45
Port Hueneme #17	1891-2006	13.62
Moorpark #141	1949-2006	14.45
Ventura #66	1873-2006	14.71
Simi Valley #154	1948-2006	14.89
Thousand Oaks #128	1943 -2006	15.6
Santa Paula #245	1961-2006	17.35

Precipitation Gage ID	Period of Record	Mean Annual Precipitation (inches)
Piru #36	1927-2006	17.39
Fillmore #199	1959-2006	18.44
Ojai #30	1906-2006	21.32

1.2 Step 2: Identify the Range of Typical Watershed Areas Likely to be Developed

The range of typical watershed areas used in the sensitivity analysis were established based on taking inventory of a subset of natural drainage channels that have significant urban development in their tributary areas. While there are a few susceptible streams with watershed areas over 100 square miles, most of the susceptible streams downstream of development are lower order with watershed areas ranging from about 2 to 10 square miles. Three categories of watershed area (2-, 5-, and 10-square miles) were used in the sensitivity analysis.

1.3 Step 3: Identify a Range of Typical Receiving Channel Dimensions for Each Watershed Area

An empirical relationship developed by Coleman et al (2005), modified by Stein (County of San Diego, 2009) was used to express channel dimensions (width, depth, and, to a lesser extent, gradient) as a function of dominant discharge (Q_{bf}, in cfs). The Stein and Coleman relationship was used because it: (1) produced more consistent and conservative results than the Hey-Thorne (1986) relationship; (2) resulted in Qcrit results within the range of values suggested for implementation in the San Diego HMP (0.1Q2, 0.3Q2, 0.5Q2); (3) was general in that it did not require an assumption of D50; and (4) is applicable to the most sensitive sand bedded channels, which the Parker (2007) relationship is not. The geometry relationships are as follows:

$$\text{Width (ft)} = 0.6012 * Q_{bf}^{0.6875}$$

$$\text{Depth (ft)} = 0.3854 * Q_{bf}^{0.3652}$$

Q_{bf}, assumed to be approximately the 5-year peak discharge (Q_5), was estimated using the USGS regional regression for undeveloped watersheds in the South Coast region

(Waananen and Crippen, 1977). This equation calculates Q_5 (cfs) as a function of watershed area (sq. mi.) and mean annual precipitation (MAP, in/yr), based on empirical observations of USGS gages. The relationship is:

$$Q_5 = 0.4 * \text{Watershed Area}^{0.77} * \text{MAP}^{1.69}$$

Manning's equation was used to iteratively find the slope for each channel dimension, such that the wetted cross sectional area at bankfull conveys the Q_5. Manning's equation is expressed as:

$$Q = \frac{1.49 A R^{0.67} S^{0.5}}{n}$$

Where:

Q = Flowrate (cfs)

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)

The sensitivity analysis assumed a Manning Roughness value of 0.035, corresponding to a non-vegetated, straight channel with no riffles and pools. This reflects the small, ephemeral receiving channels which are prevalent in Southern California. A relatively low 'n' value was used at the request of the San Diego Regional Water Board in the development of the San Diego HMP.

1.4 Step 4: Identify a Range of Typical Channel Materials for Receiving Channels

A sand-bedded channel is the most sensitive channel type to sediment transport in the region. While Ventura County does have gravel and cobble bedded streams, analysis of a sand-bedded channel is considered appropriately conservative when considering a default value. The range of critical shear stress assumed to initiate mobilization of a sand-bed is between 0.025 lb/ft^2 and 0.05 lb/ft^2. While 0.025 lb/ft^2 is the value assumed by PWA in the San Diego HMP sensitivity analysis (County of San Diego, 2009), 0.05

lb/ft^2 is the recommended value of permissible shear stress per ASCE Manual No. 77 (1992) for sand-bedded channels containing a low content of fine sediment in the water. This range of values does not account for the effects of vegetation density on banks and channel irregularities, which would effectively increase the critical shear stress.

1.5 Step 5: Identify the Flow Rate at Which Boundary Shear Stress Exceeds Critical Shear Stress for the Channel and Material

Using Manning's equation for the established channel cross section, roughness, and gradient (from Step 3), the flow depth was iterated until the average boundary shear stress equaled the critical value (from Step 4). Average boundary shear stress was calculated 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 = Longitudinal slope (ft/ft)

The resulting flowrate from this iterative process is Q_{crit}, or the flow rate at which boundary shear stress equals critical shear stress.

1.6 Step 6: Express the Flow Rate as a Function of Q_2

The 2-year peak discharge (Q_2) was calculated for each channel condition using the following USGS regional regression for the South Coast region (Waananen and Crippen, 1977):

$$Q_2 = 0.14 * \text{Watershed Area}^{0.72} * \text{MAP}^{1.62}$$

By dividing the calculated Q_{crit} (Step 5) by Q_2, the low flow threshold was calculated for each channel. The results are provided in Table 2 below.

1.7 Step 7: Group Critical Flowrates by Channel Material

The low-flow threshold for sand-bedded channels is approximately 5% Q_2 to 15% Q_2. As a regional default for sizing hydromodification control facilities in Ventura County, 10% Q_2 will be assumed. This value is consistent with the minimum low-flow threshold of other HMPs in California. Although channels with coarser bed material will have a greater low-flow threshold, 10% Q_2 will be used unless a stream-specific analysis is conducted.

Table E-2: Regional Critical Flow Analysis Results

Tributary Area	Mean Annual Precip	5-year Discharge	2-year Discharge	Critical Discharge	Low Flow Threshold	Bankfull Width	Bankfull Depth
A	*MAP*	Q_5	Q_2	Q_{crit}	Q_{crit}/Q_2	*W*	*D*
sq mi	in/yr	cfs	cfs	cfs	%	ft	ft
τ_{crit} = 0.025 lb/ft^2, sand bed (low end)							
2	14	59.0	16.6	0.4	**3%**	9.9	1.7
5	14	119.5	32.1	1.3	**4%**	16.1	2.2
10	14	203.7	52.8	2.8	**5%**	23.3	2.7
2	18	90.2	24.9	0.9	**4%**	13.3	2.0
5	18	182.7	48.2	2.5	**5%**	21.6	2.6
10	18	311.5	79.4	5.5	**7%**	31.1	3.1
τ_{crit} = 0.05 lb/ft^2, sand bed (high end)							
2	14	59.0	16.6	1.5	**9%**	9.9	1.7
5	14	119.5	32.1	4.3	**13%**	16.1	2.2
10	14	203.7	52.8	9.6	**18%**	23.3	2.7
2	18	90.2	24.9	2.8	**11%**	13.3	2.0
5	18	182.7	48.2	8.1	**17%**	21.6	2.6
10	18	311.5	79.4	17.8	**22%**	31.1	3.1

2. HIGH FLOW THRESHOLD

The pre-development 10-year peak flowrate (Q_{10}) is considered to be an appropriate high flow threshold for Ventura County for the following reasons:

- According to the report *Hydromodification Assessment and Management in California*, commissioned and sponsored by the California State Water Resources Control Board, "in large storms with return intervals of 10 or more years, the influence of urbanization is considered less pronounced" (SCCWRP, 2012).

- Less frequent, larger magnitude flows are less strongly affected by urbanization because during such infrequent storm events, the ground rapidly becomes saturated, and acts (for purposes of runoff generation) in a similar manner as impervious surfaces (County of Orange, 2012).

- Flows above the 10-year return period cause relatively little cumulative erosion in receiving waters due to their low recurrence (County of San Diego, 2009).

- The eight (8) HMPs developed to date in California (Alameda County, Contra Costa County, Fairfield Suisun Urban Runoff Management Program, Sacramento County, San Diego County, San Mateo County, Santa Clara County, and South Orange County) have all adopted the 10-year peak flowrate (Q_{10}) as the upper flow threshold.

3. 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.

Coleman, D., MacRae, C., and Stein, E.D. 2005. Effect of Increases in Peak Flows and Impervious on the Morphology of Southern California Streams, Technical Report 450. Southern California Coastal Water Research Project.

County of Orange. 2012. South Orange County Hydromodification Management Plan. October 2012.

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

Hey, R.D., and thorne, C.R. 1986. "Stable Channels with Mobile Fravel Beds," Journal of Hydraulic Engineering, American Society of civil engineers, Vol 112, No. 8, pp 671-689.

Parker, G.P., P.R. Wilcock, C. Paola, W.E. Dietrich, J.C. Pitlick. 2007. "Physical basis for quasi-universal relationships describing bankfull hydraulic geometry of single-thread gravel bed rivers". Journal of Geophysical Research – Earth surface. vol. 112.

Southern California Coastal Water Research Project. 2012. Hydromodification Assessment and Management in California. Technical Report 667. April 2012.

Ventura County Watershed Protection District. 2007. Precipitation Record Results as of 9/26/07.Website: http://portal.countyofventura.org/portal/page/portal/PUBLIC_WORKS/Watershed_Protection_District/About_Us/VCWPD_Divisions/Planning_and_Regulatory/Hydrology/Current%20Rainfall%20Information/Special%20Media%20Storm%20Statement

Waananen, A.A., and Crippen, J.R. 1977. Magnitude and frequency of floods in California: US Geological Survey Water-Resources Investigations Report 77-21, 96p

APPENDIX F

Hydromodification Control BMP Fact Sheets

HCP-1 Underground Detention

Underground detention can be provided in tanks and vaults. Detention tanks are underground storage facilities typically constructed with large diameter corrugated metal pipe, but could also be constructed of concrete or high density polyethylene (HDPE) pipe. Detention vaults are box-shaped underground storage facilities typically constructed with reinforced concrete. These flow control BMPs can be designed as standalone detention units or inline with water quality BMPs to increase detention where above ground space is limited.

Underground Detention Units

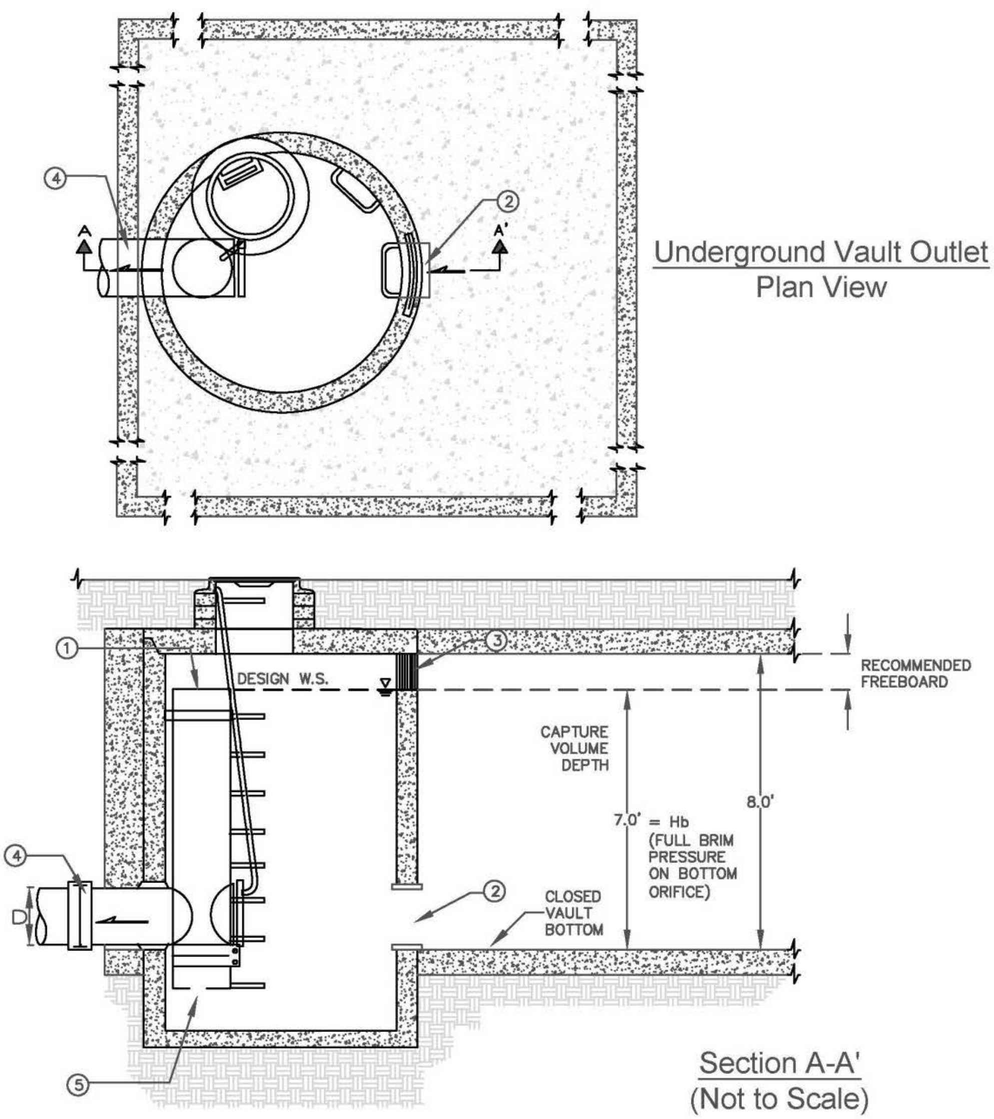
Photo Credits: 1 & 2 Contech Stormwater Solutions, Inc.

Application

- Roads and parking lots
- Parks and recreation areas
- Single and multi-family residential
- Commercial and mixed use
- Below permeable pavement or bioretention facilities

Preventative Maintenance

- Monitor pre-treatment facility if applicable
- Remove trash and debris
- Remove fine sediments and vegetation
- Periodically observe function under wet weather conditions
- Inspect for mosquito breeding



NOTES:

1. OVERFLOW DEVICE WITH WEIR LENGTH SIZED TO CONVEY THE DESIGN DISCHARGE AS REQUIRED BY THE VENTURA COUNTY LOCAL DRAINAGE MANUAL AND HYDROLOGY MANUAL OR THE LOCAL PERMITTING AUTHORITY
2. PRIMARY INLET
3. SECONDARY INLET
4. OUTLET PIPE SIZED TO CONVEY THE DESIGN DISCHARGE AS REQUIRED BY THE VENTURA COUNTY LOCAL DRAINAGE MANUAL AND HYDROLOGY MANUAL OR THE LOCAL PERMITTING AUTHORITY
5. RESTRICTOR PLATE WITH ORIFICE DIAMETER

Geosyntec consultants

Vault- Closed Bottom

Limitations

The following limitations should be considered before choosing to use underground detention.

1) All tanks must meet structural requirements for overburden support and traffic loading if appropriate.

2) Tanks must be placed on stable, well consolidated native material with suitable bedding.

3) Tanks should not be installed in fill slopes, unless inspected by a geotechnical engineer for stability and constructability.

4) Tanks located in areas with seasonal groundwater tables that may induce flotation, buoyancy tendencies may be balanced either by ballasting with backfill or concrete backfill, providing concrete anchors, increasing the total weight, or other methods to ensure stability. Calculations must be submitted that demonstrate stability.

Design Criteria

Underground detention facilities should be designed according to the requirements listed in Table 1 and outlined in the section below.

Table 1: Underground Detention Design Criteria

Design Parameter	Unit	Design Criteria
Detention Tank Bottom	Feet	Located 0.5 feet below the inlet and outlet for sediment storage.
Minimum pipe diameter (for detention tank)	Inches	36 inch diameter. Tanks larger than 36 inches may be connected to each adjoining structure with a short section (2-foot maximum length) of 36-inch minimum diameter pipe.
Maximum depth	Feet	From finished grade to tank or vault invert shall be 20 feet.
Access openings	Feet	Maximum 50 feet from any location in the tank.
Vault bottom	%	Vault bottom shall slope at least 5% from each side towards the center, forming a broad ‘v’ to facilitate sediment removal.
Outlet invert elevation for concrete vaults	Feet	Invert elevation shall be elevated to allow an average of 6 inches of sediment storage over the bottom. Elevate at least 2 feet above the orifice to retain oil within the vault.
Vault material	Psi	Minimum 3,000 psi structural reinforced concrete must be used for all concrete vaults. All

Design Parameter	Unit	Design Criteria
		construction joints much be provided with water stops.
Minimum Concrete vault dimensions	Feet	Minimum internal height shall be 7 feet and minimum width shall be 4 feet
Ventilation pipes		Shall be installed in all four corners of vaults to allow for ventilation prior to entry for maintenance.

Sizing Criteria

Underground detention facilities for hydromodification control can be sized using one of the sizing options described in Section 5.1.2:

- Nomographs or Sizing Factors for LID BMPs
- California Hydrology Model (CAHM) for Ventura County
- System-Specific Flow Duration Control Analysis
- System-Specific Erosion Potential Analysis

Sizing guidance for System-Specific Flow Duration Control Analysis and System-Specific Erosion Potential Analysis is provided in Chapter 6 of the Hydromodification Control Plan.

General

1. Tanks shall be designed as flow-through systems with manholes in line to promote sediment removal and facilitate maintenance.

   Exception: Tanks may be designed as back-up systems if preceded by water quality facilities since little sediment should reach the inlet/control structure and low head losses can be expected because of the proximity of the inlet/control structure to the tank.

2. Detention vaults shall be designed as flow-through systems with bottoms level (longitudinally) or sloped toward the inlet to facilitate sediment removal. Distance between the inlet and outlet shall be maximized (as feasible).

3. Control and access manholes shall have additional ladder rungs to allow ready access to all tank access pipes when the catch basin sump is filled with water.

4. Use of galvanized materials should be avoided. Where other metals, such as aluminum, stainless steel, or plastics are available, they shall be used. If these materials are not available, asphalt coated galvanized materials may then be used.

Access Requirements - Tanks

1. The maximum depth from finished grade to tank invert shall be 20 feet.

2. Access opening shall be position a maximum of 50 feet from any location within the tank.

3. All tank access openings shall have round, solid locking lids.

4. Thirty-six-inch minimum diameter CMP riser-type manholes of the same gage as the tank material may be used for access along the length of the tank and at the upstream terminus of the tank if a backup system. The top slab is separated (1-inch minimum gap) from the top of the riser to allow for deflections from vehicle loadings without damaging the riser tank.

5. All tank access openings must be readily accessible by maintenance vehicles.

6. Access roads are required to all detention tank control structures and risers.

Access Requirements – Vaults

1. Access consisting of a frame, grate, and locking cover shall be provided over the inlet pipe and outlet structure. Access openings shall be positioned a maximum of 50 feet from any location within the vault; additional access points my be required on large vaults. If more than one “v” is provided in the vault floor, access to each “v” must be provided.

2. For vaults with greater than 1250 square feet of floor area, a 5’ by 10’ removable, locking panel shall be provided. Alternatively, a separate access vault may be provided.

3. For vaults under roadways, the removable panel must be located outside of the travel lanes. Alternatively, multiple standard locking manhole covers may be provided. Spacing of manhole covers shall be 12 feet, measured on center, to facilitate removal of sediment. Ladders and hand-holds need only be provided at the outlet pipe and inlet pipe, and as needed to meet OSHA confined space requirements. Vaults providing manhole access at 12-foot spacing need not provide corner ventilation pipes.

4. All access openings, except those covered by removable panel, shall have round, solid locking covers or 3-foot square, locking diamond plate covers. For raised openings where the depth from the iron cover to the top of the vault exceeds 24 inches, an access structure equivalent to a Type 2 catch basin or Type 1 manhole shall be used. The opening in the vault lid need not exceed 24 inches in diameter.

5. Vaults with widths 10 feet or less must have removable lids.

6. The maximum depth from finished grad to the vault invert shall be 20 feet.

7. Internal structural walls of large vaults shall be provided with openings sufficient for maintenance access between cells. The openings shall be sized and situated to allow access to the maintenance "v" in the vault floor.

8. The minimum internal height shall be 7 feet from the highest point of the vault floor (not sump), and the minimum width shall be 4 feet.

   Exceptions:

   - Concrete vaults may be a minimum 3 feet in height and width if used as tanks with access manholes at each end, and if the width is no larger than the height.

   - The minimum internal height requirements may be waived for any areas covered by removable panels.

9. Ventilation pipes (minimum 12-inch diameter or equivalent) shall be provided in all four corners of vaults to allow for artificial ventilation prior to entry of maintenance personnel into the vault.

10. Access roads are required to the access panel (if applicable), the control structure, and at least one access point per cell.

Pretreatment

Pretreatment BMPs, such as biofiltration BMPs, catch basin inserts, and hydrodynamic separation devices, may be used to reduce the maintenance burden on tanks and vaults..

Operations and Maintenance

1. Accumulated sediment and stagnant conditions may cause noxious gases to form and accumulate in the detention facilities. Maintenance procedures must meet OSHA confined space entry requirements, which includes clearly marking entrances to confined space areas. This may be accomplished by hanging a removable sign in the access riser(s), just under the access lid.

2. Facilities should be inspected annually. Sediment should be removed when the sediment zone is full.

HCP-2 In-Stream Controls

For stream channels already impacted by erosive flows and altered land use, in-stream controls may present an alternative method of post-project hydromodification control. In-stream controls are designed to accommodate runoff flows from existing and future development and maintain or enhance the existing beneficial uses and physical and ecological functions of a creek or stream by modifying the channel's geometry (in profile, cross-section, or plan view) or its bed and bank material strength.

Slope Reduction Structures

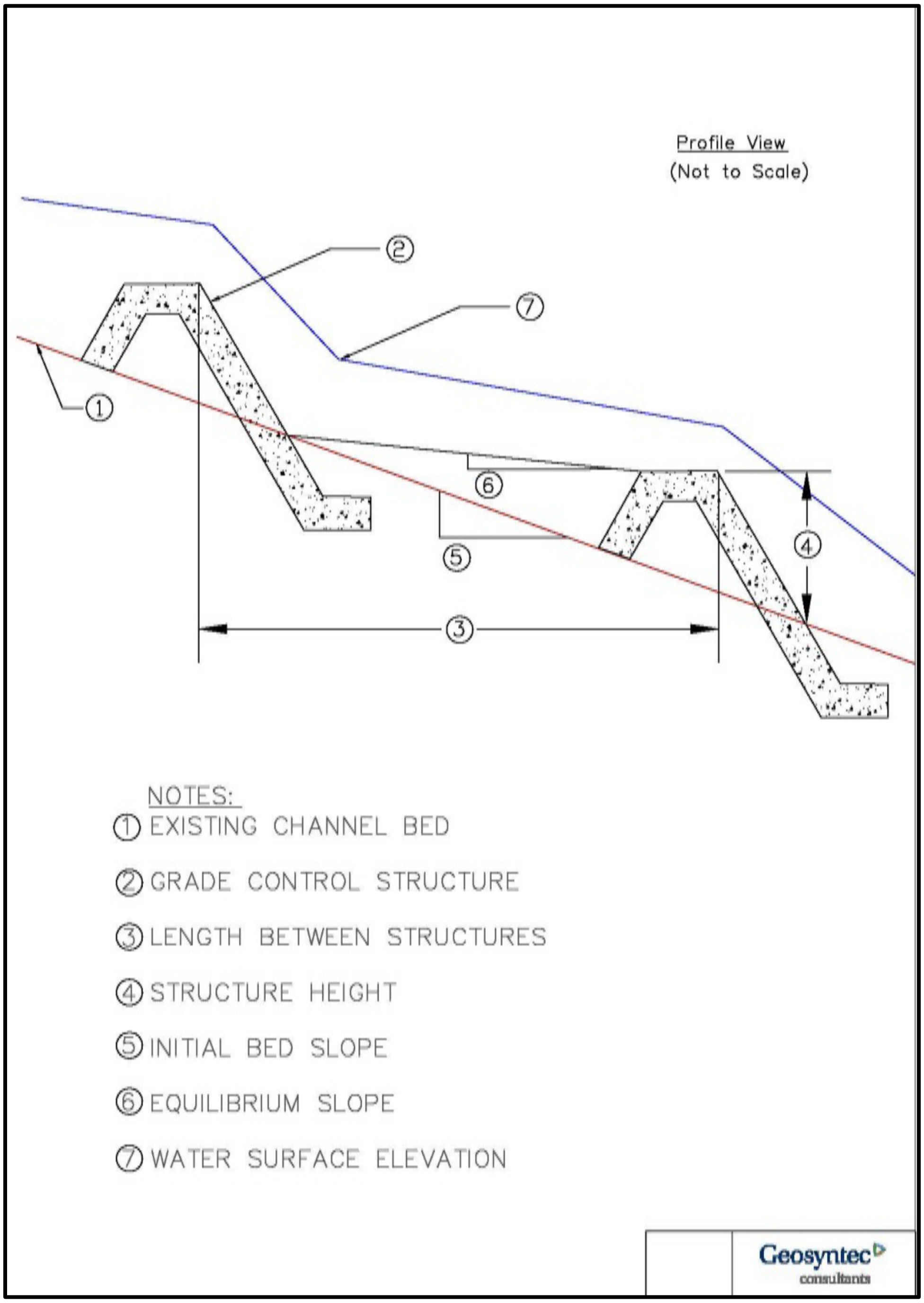
Photo Credits: Geosyntec Consultants and Salix Applied Earthcare

Application

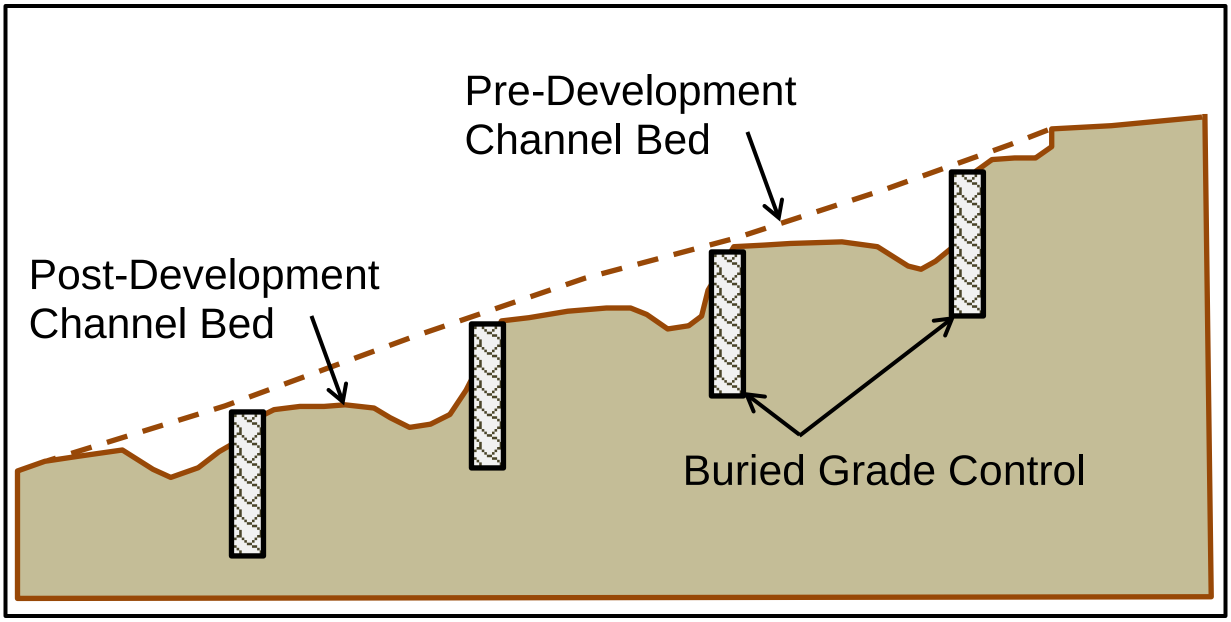
- Unstable streams
- Where an approved plan and funding mechanism is in place

Preventative Maintenance

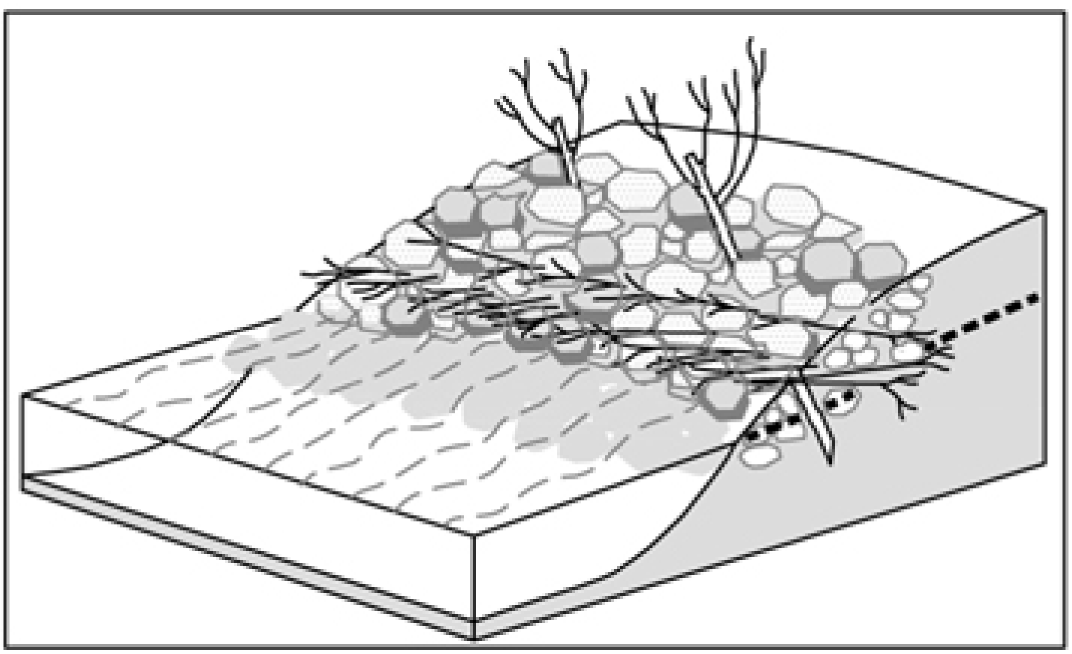
- Monitor channels and banks at key cross sections for erosion
- Monitor vegetation until plants become fully established.
- Replace dead vegetation as needed
- Repair grade control structure as needed to ensure step pools operate as designed.
- Periodically observe function under wet weather conditions



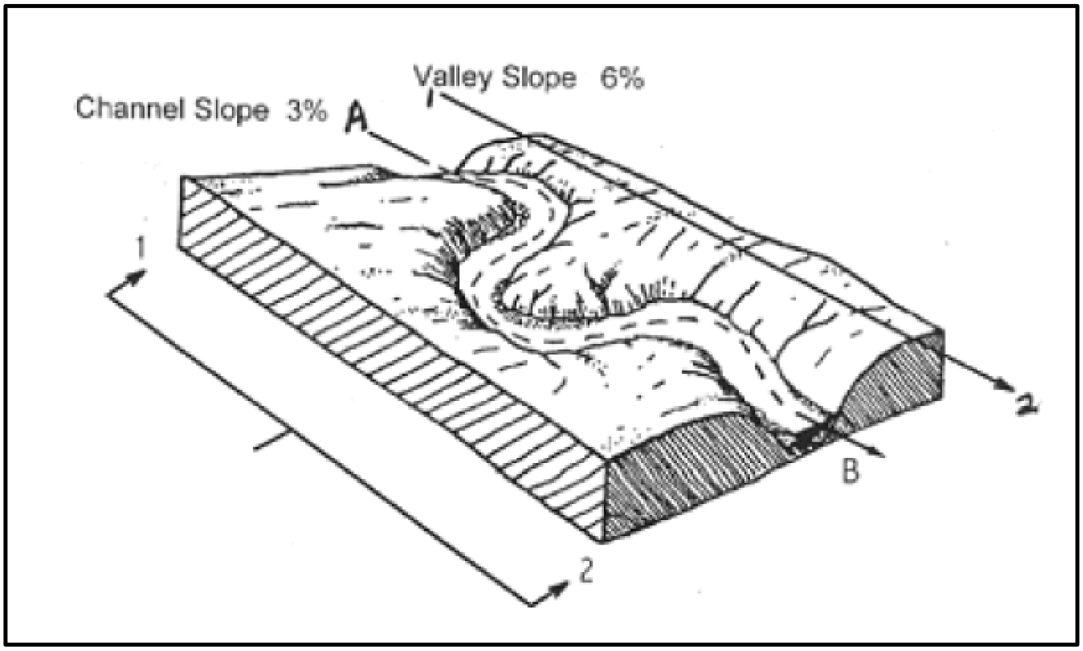
In-Stream Drop Structure Profile



In-Stream Buried Grade Control Profile



Channel Bank Reinforcement with Vegetated Riprap (Salix Applied Earthcare, 2004)



Gradient Reduction by Increasing Sinuosity (County of San Diego, 2009)

Limitations

1) Slope reduction and channel roughening methods may reduce the capacity of the channel to convey flows for flood control.

2) In-stream BMPs modify the receiving channel hydraulic properties and bed/bank material resistance without fully controlling increases in runoff magnitude and duration.

Design Criteria

The following describes general design criteria for different types of in-stream BMPs:

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 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. A number of vegetated approaches are increasingly utilized. Such approaches include large woody debris, live crib walls, vegetated mechanically stabilized earth, live siltation, live brushlayering, willow posts and poles, live staking, live fascine, rootwad revetment, live brush mattresses, and vegetated reinforcement mats. These technologies provide erosion control 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 (2) points to straight line distance) can serve to reduce the channel slope, thereby reducing the shear stresses generated by stream flows. However, forcing a channel to be too sinuous 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.

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).

Sizing Criteria

Sizing of in-stream controls is based on the following criteria:

1. Long-Term Erosion and Sedimentation Criteria: Maintain the long-term sediment transport capacity or cumulative work of the stream, per the Hydromodification Management Standard defined in Section 4.1 of the HCP. Sizing guidance using a System-Specific Erosion Potential (Ep) Analysis is provided in Section 6.3 of the HCP.

2. Peak Event Criteria: Ensure flood and scour protection associated with high-magnitude low-frequency storm events, per the Ventura County Hydrology Manual (2010) and the Ventura County Flood Control District Design Manual (1968).

3. Environmental Criteria: Support 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. 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 or to restore it to a previous, higher level function. Additionally, it should be determined whether in-stream BMPs should be designed with a level of conservatism to account for anticipated future buildout in the watershed.

Extent of In-Stream Controls

The upstream limit of in-stream BMPs is suggested to extend upstream of where project runoff discharges into the receiving channel to an existing or proposed grade control. The suggested downstream limit is where: (1) Ep is consistently near the target Ep (i.e.

within 5%) or less without in-stream BMPs; or (2) the stream connects to a non-susceptible receiving water. For the latter case at least one additional Ep calculation should be performed downstream of a non-susceptible receiving stream if it drains to a creek segment that is susceptible to hydromodification impacts.

Permitting

In-stream BMPs are subject to the permitting requirements of the resource agencies. In-stream BMPs may require the following permits:

- California Department of Fish and Wildlife – 1602 Streambed Alteration Agreement.
- US Fish and Wildlife Service – Authorization Under the Endangered Species Act.
- US Army Corps of Engineers – Clean Water Act Section 404 Permit.
- Regional Water Quality Control Board – Clean Water Act Section 401 Water Quality Certification.

Operations and Maintenance

1. Facilities should be visually inspected annually to check functionality and structural integrity of the in-stream controls. Some amount of physical adjustment is expected.
2. Repair or replace components of in-stream structures which have undergone severe damage such that functionality is compromised or the sizing criteria is no longer met.