SONOMA CREEK

Lower Sonoma Creek Flood Management and Ecosystem Enhancement

Prepared for
The California State Coastal Conservancy
and
The Sonoma County Water Agency

Prepared by
ESA PWA
with
Southern Sonoma County Resource Conservation District

October 22, 2012

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Executive Summary

Introduction/Background

Portions of Schellville and surrounding areas, in southern Sonoma County, California, are frequently flooded during relatively small winter storm events that cause flows to overtop the banks of Sonoma and Schell Creeks. Historic flooding has caused damage to private property and roadways. The Southern Sonoma County Resource Conservation District (District) undertook the management of the Lower Sonoma Creek Flood Management and Enhancement Alternatives Analysis, a study to identify and evaluate opportunities to address flooding issues and ecosystem enhancement in the Schellville area. The study focuses on the southern portion of the Sonoma Creek watershed, within the reaches of Sonoma Creek and Schell Creek from immediately upstream of Highway 121 to San Pablo Bay. The study was funded by the USACE, California Coastal Conservancy and the Sonoma County Water Agency. ESA PWA performed the basin hydrologic investigation, developed the hydrodynamic model, and performed the technical analyses and evaluation of project elements/alternatives, in addition to participating in public outreach with stakeholders. The Sonoma Ecology Center provided GIS watershed data and Watershed Sciences performed a geomorphology and assessment of existing drainage system as baseline information. Public involvement and outreach to stakeholders was an integral component of the technical studies.

Purpose/goals

The goals of the overall study are to identify a project or projects to alleviate flooding and reduce flood-related damage to public facilities, structures, roads, railroad tracks, pasture lands and crops while restoring and enhancing habitat and improving ecological and hydrological functions. The current study represents a key step in attempting to identify feasible alternatives to achieve the study goals. Initially, the study focused on determining feasibility to address flood management and habitat restoration. More recently, the study scope was expanded to include evaluation of sea level rise factors and vulnerability of lands. Moreover, during the study period, consideration and planning for climate adaptation became a required element, which the analysis addresses.

Study Scope

The principal technical studies included hydrology, hydraulics, sediment transport, geomorphology and hydrodynamic modeling. As part of this study the District worked with consultants to develop an opportunity and constraints analysis and conceptual design of potential projects for Sonoma Creek which built on previous studies that characterized the hydrology, hydraulics, and geomorphology. Limited survey work was completed to update the topography and available mapping for the study area. ESA PWA developed a hydrodynamic model and performed other hydrologic and geomorphic analyses to identify opportunities and constraints and identify and assess potential flood reduction and habitat restoration project elements. Each potential project element incorporated habitat features, including new and /or enhanced freshwater and tidal wetlands, floodplains, and riparian areas. The identified project elements ranged from small site-specific to large-scale measures, including:

- Full-length wide floodplain terrace or short narrow floodplain terrace downstream of Highway 121
- Highway protection levee spur
- Sonoma Creek right bank levee shift west downstream of Highway 121
- Weir connection between Sonoma Creek and Railroad Slough
- Tidal restoration near Wingo
- Creek channel expansion at Highway 121 bridge
- Floodplain lowering near Sonoma Creek/Fowler Creek
- Schell Creek overflow channel.

Alternatives were formulated by combining different project elements to assess flood hazard reduction and habitat enhancement outcomes. The purpose of analyzing alternatives was to determine whether they could achieve habitat enhancement and provide meaningful relief of flooding. The intent was to identify a preferred alternative for a flood management and ecosystem enhancement project in the study area. Because the study did not include a specific target for flood protection in terms of flood recurrence interval (e.g., a 25-year flood event), the conceptual level alternatives were evaluated for their relative benefits and consistency with the general project goals of reducing flood hazards and providing ecosystem benefits.

Conclusions and Recommendations

No distinct preferred flood reduction alternative emerged, largely due to the physical constraints inherent to the study area. These constraints include very low gradient (flat topography) in the lower watershed, considerable tidal influence extending above Highway 121 and low ground elevations aggravated by land subsidence.

Due to these constrained conditions coupled with anticipated sea level rise and lack of political support to fund an extensive new levee system, the study determined that none of the identified alternatives achieved sufficiently substantial flood reduction to warrant pursuit. Given the constrained setting, the study determined that the measures needed in the study area to provide relief from recurrent flooding are not physically feasible or are of such a magnitude that they are not economically feasible. Modeling indicated that although individual projects will not effectively achieve the flood reduction goals, a broader watershed approach may warrant future consideration. Therefore, the study report focuses on identifying and describing other opportunities and constraints for achieving the project goals to provide a framework for future decision making. Identified opportunities include tidal wetland and other habitat restoration, planning for anticipated increases in San Pablo bay tide levels, and alignment of land uses with existing and historic topography/hydrology.

Based on the modeling results and extensive evaluation of alternatives, the recommendation by stakeholders and local landowners is one that embraces a watershed-scale approach combining three elements: a) stormwater detention in the upper watershed, b) acquisition of easements on affected lands for seasonal floodwater conveyance, and c) acquisition of lands at risk for current or future flooding that may be restored to tidal wetlands. This recommended approach is now being considered for additional study. Stormwater management opportunities in the upper watershed are currently being pursued by the Sonoma County Water Agency. Acquisition of lands for the purposes of increasing tidal wetlands for ecosystem enhancement,   hydrologic function, and climate adaptation is a growing trend with priority from national and state initiatives and programs. The District will continue to investigate funding for acquisitions for seasonal floodwater and tidal wetland restoration and will work with willing property owners to implement these measures.

1. INTRODUCTION

Portions of Schellville and surrounding areas are frequently flooded during relatively small winter storm events that cause flows to overtop the banks of Sonoma and Schell Creeks. Schellville is located in the Sonoma Creek watershed in southern Sonoma County, California. In 1999 the Southern Sonoma County Resource Conservation District (DISTRICT) undertook the Lower Sonoma Creek Flood Management and Enhancement Project (project) to evaluate opportunities to address flooding issues and ecosystem enhancement in the Schellville area. With funding provided by the California State Coastal Conservancy (Conservancy), and the Sonoma County Water Agency (SCWA), the DISTRICT contracted with ESA PWA (originally Philip Williams & Associates, Ltd.) to conduct this study. This report summarizes the results of the study, presents information on opportunities and constraints for flood management and resource enhancement and makes recommendations, based on the findings of the study and stakeholder input.

Over the past ten years, the DISTRICT's ongoing pursuit of a solution to the flooding issues as well as the awareness of the community's concern for water quality and quantity management has resulted in coordinated efforts among many different organizations, agencies, NGOs and individual landowners. The following organizations have become partners in pursuing conservation and land management strategies and have expressed an interest in achieving a multiple benefit, watershed-wide project that will reach the goals of the original project while incorporating the flood management goals of the larger community:

- Sonoma County Water Agency
- USDA Natural Resources Conservation Service
- County of Sonoma
- California Department of Fish and Game
- Sonoma Ecology Center
- North Bay Agricultural Alliance
- Sonoma Valley Vintners & Growers Alliance
- City of Sonoma
- Valley of Moon Water District
- California State Coastal Conservancy
- Wildlife Conservation Board
- Sonoma Land Trust
- Sonoma County Agricultural Preservation & Open Space District
- U.S. Fish and Wildlife Service (USFWS)
- NOAA National Marine Fisheries Service (NMFS)

1.1 STUDY PURPOSE AND GOALS

The overall purpose of this study was to identify and evaluate alternatives that would have the potential to alleviate flooding and reduce flood-related damage to public facilities, structures, roads, railroad tracks, private property, homes and crops while incorporating habitat restoration and enhancement elements to improve ecological and hydrological functions. The intent of the analysis was to assess the feasibility of various alternatives and to identify a preferred alternative for a flood management and ecosystem enhancement project or set of projects in the study area.

Overall project goals include the following:

- Habitat enhancement;
- Minimize risks to life and property associated with flooding; and
- Improve water quality and supply.

More specifically, the study sought to identify and assess project elements that would alleviate flooding, improve road access during flood events, reduce flood-related damage to public and private facilities and incorporate habitat restoration and enhancement strategies and elements to improve ecological functions in the region. The goal was to develop a feasible alternative that would serve multiple purposes of restoring wetlands, preserving agriculture, and relieving flooding of major highways, homes and the railroad.

As the study progressed, evaluation of sea level rise (SLR) factors became a requirement due to State policy. Therefore, the study purpose was expanded to incorporate assessment of SLR in the study area. Furthermore, as the results of the modeling effort became evident, the study purpose was adjusted to more broadly identify opportunities and constraints and make useful watershed-scale recommendations for the future.

The study goals are consistent with adopted goals and objectives of the Sonoma County General Plan (2008), including the following relevant provisions:

GOAL AR-8:	Assist in formulating programs that could provide alternative sources of capital for agricultural production without selling or encumbering the farmland as collateral. These measures include, but are not limited to, voluntary programs for purchase and transfer of development rights.
Objective AR-8.1:	Continue participation in the Williamson Act and Farmland Security Zone programs.
Objective AR-8.3:	Encourage formulation of programs and evaluate alternative funding sources which offer financial incentives to the farm owner to reduce reliance on subdivision and sale of land to raise operating capital.
GOAL LU-7:	Prevent unnecessary exposure of people and property to environmental risks and hazards. Limit development on lands that are especially vulnerable or sensitive to environmental damage.
Objective LU-7.1:	Restrict development in areas that are constrained by the natural limitations of the land, including but not limited to, flood, fire, geologic hazards, groundwater availability and septic suitability.

GOAL LU-8:	Protect Sonoma County's water resources on a sustainable yield basis that avoids long term declines in available surface and groundwater resources or water quality.
Objective LU-8.1:	Protect, restore, and enhance the quality of surface and groundwater resources to meet the needs of all beneficial uses.
Objective LU-8.2:	Coordinate with operators of public water systems to provide an adequate supply to meet long term needs consistent with adopted general plans and urban water management plans.

1.2 BACKGROUND & HISTORY

The Schellville area has experienced recurrent flooding for more than 50 years. Historically these lands were tidal marsh. In the late 1800s farmers were encouraged by the federal government to "reclaim" these lands for agriculture. Since then the area has developed into productive lands that support cattle grazing, hay production, and vineyards.

At the request of local farmers, the U.S. Army Corps of Engineers (USACE) studied the feasibility of a flood control project in 1946 and in 1957. Another study was conducted by Office of Emergency Services (OES) in the 1980s. With each study, it was determined that there was not enough damage to warrant a flood control project. Federal monies would not be allocated to such a project because the "cost/benefit ratio" could not justify it.

A brief history of the modification of the baylands within the study area is provided in a prior geomorphic study (Collins and Leising, 2004). This background information provides a better understanding of current conditions. In summary, local landowners reclaimed about 3000 acres of marsh lying between Highway 37 and San Pablo Bay by constructing levees in 1882 to hold back tidewaters (USACE, 1963). Over time, the reclaimed lands began to settle, and by 1963, lands had subsided by as much as five feet below sea level (USACE, 1963). A system of ditches and pumping plants was constructed in the former tidal marshlands during 1917. Additions and modifications have been ongoing. Dredging of the stream channel took place on a regular basis to keep the channel navigable. However, dredging was discontinued sometime between the 1930s and 1950s and the channel filled in with sediment. The maintenance of the levee system was regarded by the USACE as the responsibility of the landowner that was receiving direct protection.

When the 1955 flood occurred, there was major backwater flooding upstream of Schellville and Highway 121 as well as breaches to the dike system in the tidelands. Appendix C contains various flood photographs that document some flood events post dating 1950. Following the 1955 flood, the Army Corps conducted emergency channel restoration and levee repairs at a cost of $20,000 (USACE, 1963).

1.3 STUDY SCOPE AND FUNDING PARTNERS

In 1999, the DISTRICT requested assistance from the USACE based on landowner and stakeholder input. DISTRICT, as the local sponsor, signed an agreement with the USACE to evaluate the feasibility of a flood reduction project for the Schellville area. USACE agreed to move forward with a joint study acknowledging that the cost-benefit ratio now factored in environmental restoration, and therefore may provide sufficient justification to pursue a flood management project. The Habitat Goals Project (California Coastal Conservancy, 1999) identified the Sonoma baylands as areas which could potentially be restored and returned to tidal marshlands.

The DISTRICT sought local funds from the Coastal Conservancy and, with USACE, began Phase I of the feasibility study, which included:

- Basin hydrologic investigation for entire watershed (PWA, 2004);
- Geomorphology (Collins and Leising, 2004);
- Cross sections and baseline topography survey work performed by the Corps' contractor, and GIS mapping support; and
- Public outreach and working with the Corps.

Building on the information developed during Phase I, the DISTRICT initiated Phase II of the study in 2006, but without USACE support due to funding issues. DISTRICT entered into a funding agreement with the Coastal Conservancy and SCWA to evaluate flood management and habitat enhancement project alternatives for the reach of Sonoma Creek from immediately north of Highway 121 to San Pablo Bay. Phase II included the following elements, which are summarized in this report or supporting technical memos:

- Hydraulics analysis to complement the hydrologic work;
- Sediment transport and additional geomorphic evaluation;
- Identification and evaluation of alternatives;
- Modeling of alternatives to include sea level rise/climate change (a new element added to the study)
- Public and stakeholder involvement and outreach (summarized in a separate report); and
- Final report preparation in 2011-2012.

1.4 STUDY APPROACH AND METHODOLOGY

The principal technical studies included hydrology, hydraulics, sediment transport, geomorphology and hydrodynamic modeling. ESA PWA developed a hydrodynamic model and performed other hydrologic and geomorphic analyses to identify and assess potential project elements that could achieve flood reduction and habitat enhancement within the Schellville study area.[1] As part of the baseline information development, opportunities and constraints for flood management and habitat enhancement were identified.

Each potential project element incorporated habitat features including new and /or enhanced freshwater and tidal wetlands, floodplains, and riparian areas. The identified project elements ranged from small site-specific to large-scale measures, including:

- Full-length wide floodplain terrace or short narrow floodplain terrace
- Highway protection levee spur
- Sonoma Creek right bank levee shift west
- Weir connection between Sonoma Creek and Railroad Slough
- Tidal restoration near Wingo
- Creek channel expansion at Highway 121 bridge
- Floodplain lowering near Sonoma Creek/Fowler Creek
- Schell Creek overflow channel.

Prior to developing the full-scale hydrodynamic model in MIKE FLOOD of these project elements, several simpler screening analyses were conducted to test their potential effectiveness. This was done with smaller-scale hydraulic models and basic hydraulic calculations. This process is described in Appendix C.

Alternatives were formulated by combining different project elements to optimize flood hazard reduction and habitat enhancement. The purpose of analyzing alternatives was to determine whether they could achieve habitat enhancement and provide meaningful relief of flooding. The intent was to identify a preferred alternative for a flood management and ecosystem enhancement project in the study area. See Appendix A1 for details on the alternatives analysis.

Because the project did not include specific targets for flood protection in terms of flooding recurrence frequency, the conceptual-level alternatives were evaluated for their relative benefits and consistency with the general goals of reducing flood hazards and providing ecosystem benefits. In addition to flood flow, topographic and tidal influence considerations, sea level rise factors were incorporated into the overall assessment.

Upon completion of the modeling and review of the alternatives analysis, local landowners requested a much larger plan that would include detention and storage of upstream water combined with a variety of projects that would open up a flood bypass area through Schellville. The study focus was then shifted to identify such a broader watershed-scale approach, rather than a project solely within the Schellville study area. This broader approach is described in Section 5.3.

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[1] The hydrodynamic modeling conducted for this study and presented in this report was developed for the purpose of the current project and may require refinement before being applied for other purposes, including those that warrant a greater level of accuracy for flood hazard conditions determination. Channel and floodplain geometry data, in particular, was limited in some areas.

Because the modeling resulted in no identification of a preferred alternative, rather than describing the studied alternatives in detail, this report focuses on identifying and describing opportunities and constraints for achieving the project goals to provide a framework for future decision making.

1.5 REPORT ORGANIZATION

The remainder of this report is organized as follows:

- **Chapter 2** – Describes the setting of the study area, including the landscape and waterscape of the Sonoma Creek watershed and the portions of Sonoma Creek, Schell Creek, and San Pablo Bay within the study area.
- **Chapter 3** – Describes the opportunities and constraints identified during the initial phase of the study.
- **Chapter 4 –** Presents the conceptual model of flood flow interactions based on simulations of watershed flood hydrology and hydrodynamics.
- **Chapter 5** – Identifies and describes our expanded understanding of opportunities and constraints for achieving project goals, based on results of the conceptual model presented in Chapter 4 and the alternatives formulation and analysis described in Appendix A-1.
- **Appendix A1** – Describes the process and analysis undertaken to identify and evaluate project alternatives and documents the initial project effort to develop viable flood management solutions for the study area. It discusses the formulation of the project alternatives including descriptions of the project elements, how they were refined through a screening analysis, and how they were further developed using hydrodynamic modeling. In addition, it describes the goals, elements, and benefits of two alternatives selected for further evaluation and provides a description of the No Action Alternative, including the expected project outcomes.
- **Appendices A2 –** Provides detailed background on the development of the hydrodynamic model and the results of the existing conditions modeling.
- **Appendices B through G** – Additional appendices provide more detailed technical information and documentation of work conducted as part of this project.

The vertical elevation datum referred to in this report is the North American Vertical Datum of 1988 (NAVD). Many of the analyses were performed in metric units, including the hydrodynamic modeling, but were converted to English units using the appropriate number of significant figures.

2. SETTING

This chapter summarizes existing landscape, hydrologic and tidal conditions in the study area and surrounding region. Recent flood events are also documented. This information provides the basis for understanding flooding issues and identifying opportunities to reduce the effects of flooding. The study focuses on the Sonoma Creek watershed area immediately around and to the south of State Highway 121, including the Schell Creek tributary to Sonoma Creek. The study area is shown in Figure 1.

2.1 LANDSCAPE

The following sub-sections describe the Sonoma Creek watershed and the study area. The watershed description was adapted from PWA, 2004.

2.1.1 Watershed Description

Sonoma Creek is among the five largest tributary watersheds to San Pablo Bay, in the San Francisco Bay-Delta Estuary (the Bay). The basin forms a 22-mile long valley within the Coast Range; it is bordered by the Napa River watershed to the east, San Pablo Bay to the south, Petaluma River basin to the west and the Russian River watershed to the north. Sonoma Creek has a total watershed area of about 166 square miles at San Pablo Bay. The drainage areas of Sonoma and Schell Creeks at Highway 121 are 93 and 20 square miles, respectively. Downstream of Highway 121, Schell and Sonoma creeks flow through a complex slough network within the Napa-Sonoma Marsh, before draining to San Pablo Bay.

Physiographically, the Sonoma Creek watershed is defined by the high parallel ridges on its eastern and western boundaries and its low lying, narrow valley floor, which widens towards the south, where the ridges end and the San Pablo baylands (Napa-Sonoma Marsh) begin. The western ridge is dominated by Sonoma Mountain, elevation 2463 ft. The Mayacamas Mountains to the east contain many high points, including Mount Hood (el. 2730 ft), North Bald Mountain (el. 2739 ft), South Bald Mountain (el. 2276 ft), and Mount Veeder (el. 2677 ft). At the southern end of the basin, the Sonoma and Mayacamas Mountains end at the flat baylands that form the Napa-Sonoma Marsh. In the tidal zone, watershed boundaries become less distinct as flows from Sonoma Creek and Napa River watersheds combine with saltwater from the bay.

The Sonoma Creek basin is primarily rural with one urban center, the City of Sonoma, which has a population of 9,100. Sonoma Creek flows through six developed areas in its course from its headwaters on north Bald Mountain to San Pablo Bay: Kenwood (el. 415 ft), Glen Ellen (el. 230 ft), Eldridge (el. 200 ft), Fetters Hot Springs/Agua Caliente/Boyes Hot Springs/El Verano (el. 98 ft), the City of Sonoma (el. 84 ft) and Schellville (el. 12 ft). Sonoma Creek has historically experienced flooding, especially in the Schellville area. Flooding in Schellville may occur numerous times annually (see discussion below).

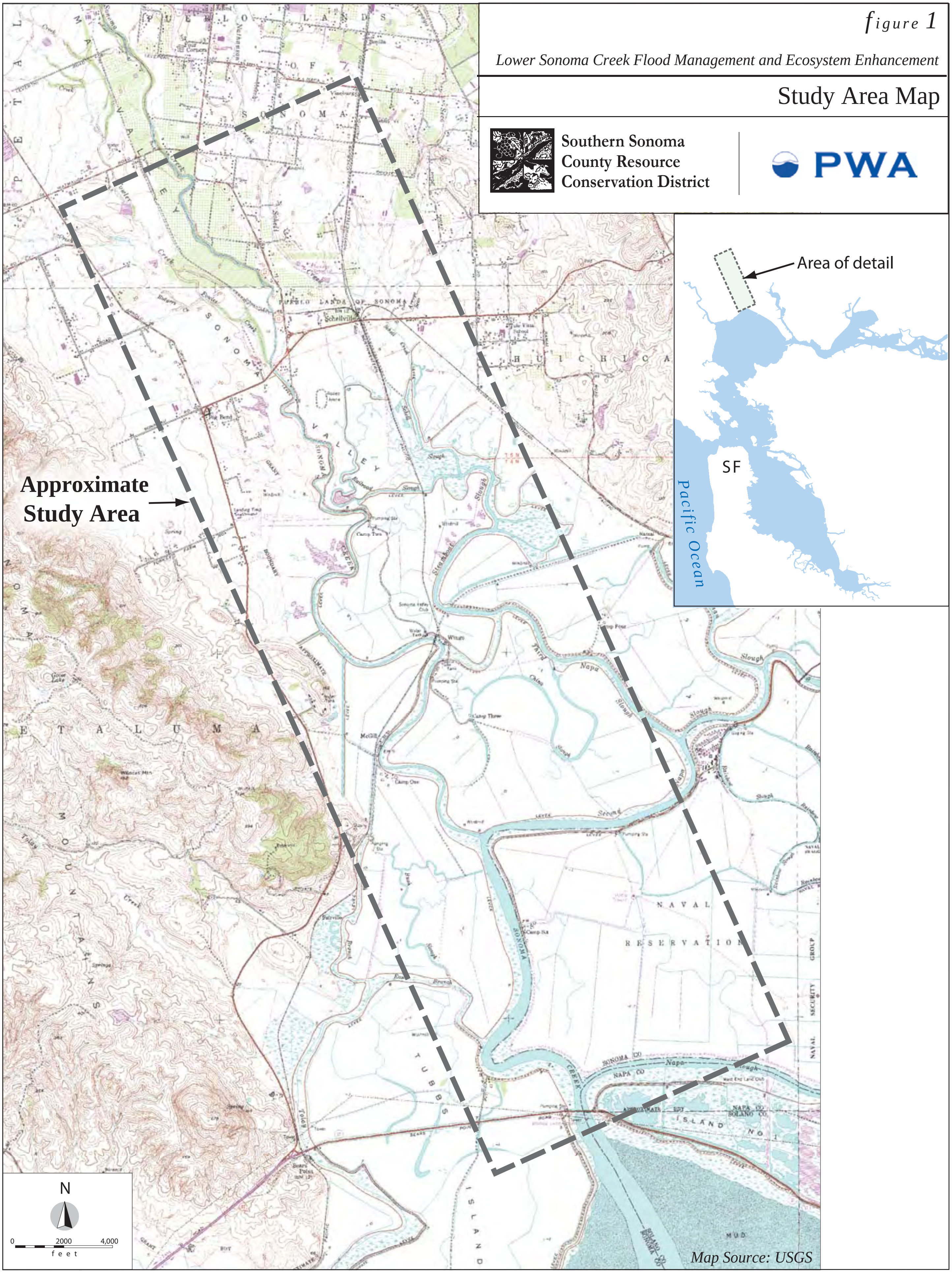
figure 1

Lower Sonoma Creek Flood Management and Ecosystem Enhancement

Study Area Map

Southern Sonoma County Resource Conservation District

PWA



2.1.2 Study Area Description

This study focuses on the reaches of Sonoma Creek and Schell Creek from immediately upstream of Highway 121 to San Pablo Bay. The drainage network for Sonoma and Schell Creeks includes sections of Fowler Creek and Railroad, Steamboat, 3rd Napa, 2nd Napa, and Napa Sloughs. Lands draining to Sonoma Creek included the current and former diked baylands used to grow oat hay and other crops, known as Camp 1, Camp 2, Camp 3, and Camp 4 (see Figure 2). Also included in this area is the small community of Wingo, as well as the Sonoma Valley Airport and portions of the Northwestern Pacific Railroad and Southern Pacific Railroad corridors.

2.1.2.1 Land Uses

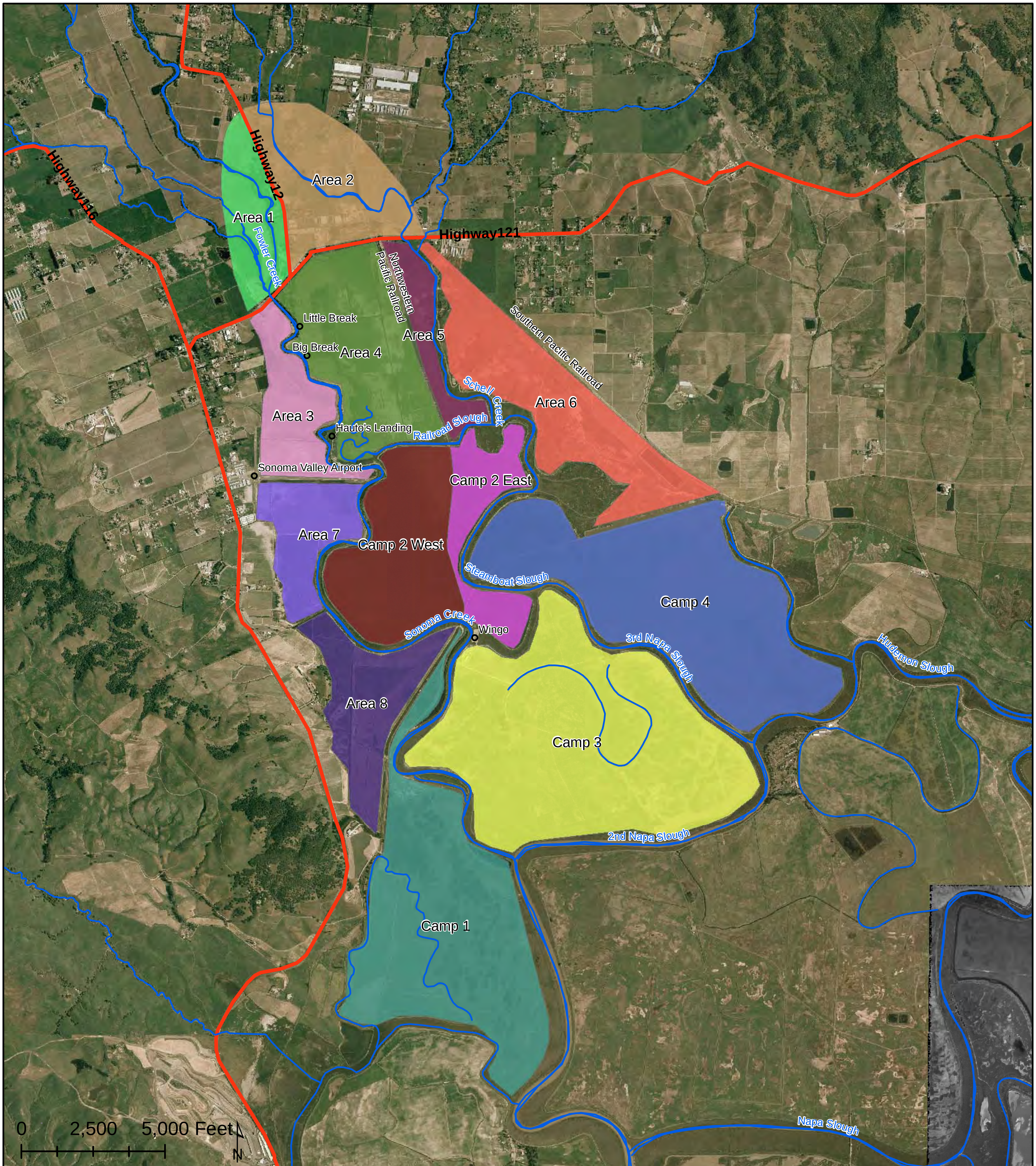
Aside from the relatively small developed area of Schellville adjacent to Highways 121 and 12, land use in the majority of the study area is a mix of agriculture, rural residential, and open space. Agricultural space is dominated by hay production with smaller plots of land devoted to wine grape and dairy cow production. Residential properties are concentrated along Millerick Road, south of its junction with Highway 121. Open space is typically tidal wetland and fresh or saltwater marsh.

2.1.2.2 Physical Characteristics

Upstream of Schellville, Sonoma Creek is a fluvial system that has experienced significant morphological changes typical of streams in the San Francisco Bay Area following land use changes and population increases of the 19th and 20th centuries. Paved roads, development and other land uses in the upper watershed reduce the capacity for soils to infiltrate moisture and result in increased runoff to stream channels. Levees and infrastructure adjacent to the stream channel reduce connectivity with the adjacent floodplain and concentrate flows within the channel, increasing the amount of runoff and sediment delivered to the lower watershed from the upper watershed over time.

In the vicinity of the Highway 121 crossing, Sonoma Creek transitions from being fluvial-dominated to tidal-dominated and the longitudinal slope of the channel decreases dramatically from this location to the Bay. Historically, much of the area downstream of Highway 121 was marshland, bounded roughly by the rail corridor commonly known as the Northwestern Pacific Railroad to the east and the Sonoma Valley Airport to the West (see Figure 3). Between Highway 121 and Railroad Slough, the marshlands were bisected by the Sonoma Creek alluvial fan, and the creek channel is somewhat perched above the surrounding lands in this reach. The historic marshlands were regularly inundated by tidal waters from the Bay as well as floodwaters from the upper watershed during higher runoff events. As the region was developed for agriculture in the late 1800's, the marshes were drained, distributary channels were combined and ditched, and levees were built to contain flood waters and prevent tidal inundation (USACE, 1963).

Over time, the changes to the drainage network of lower Sonoma Creek have reduced tidal flushing and increased channel confinement resulting in channels that are significantly smaller than the historic channels and less able to distribute sediment delivered from the upper watershed. Additionally, these changes have caused the former marshlands to subside, due to oxidation of the underlying organic marsh soils and possibly the lack of natural sediment deposition, resulting in ground elevations that are lower than historic levels (Collins and Leising, 2004) and in many cases below sea level, as illustrated in Figure 4. Levees along the creek and distributary channels protect these areas from regular inundation by high tides. However, when the levees are breached or overtopped due to extreme tides or fluvial flows, the Camp areas quickly fill with water and are not able to drain readily due to the low elevations. Maintenance of the system of levees, dikes, and ditches that control flows along the creek and slough channels of lower Sonoma Creek and Schell Creek is primarily the responsibility of individual landowners.



Legend

Camp 1	Area 1	Area 5
Camp 2 East	Area 2	Area 6
Camp 2 West	Area 3	Area 7
Camp 3	Area 4	Area 8
Camp 4		

figure **2**

Lower Sonoma Creek Flood Management and Ecosystem Enhancement

Area, Stream, and Place Names

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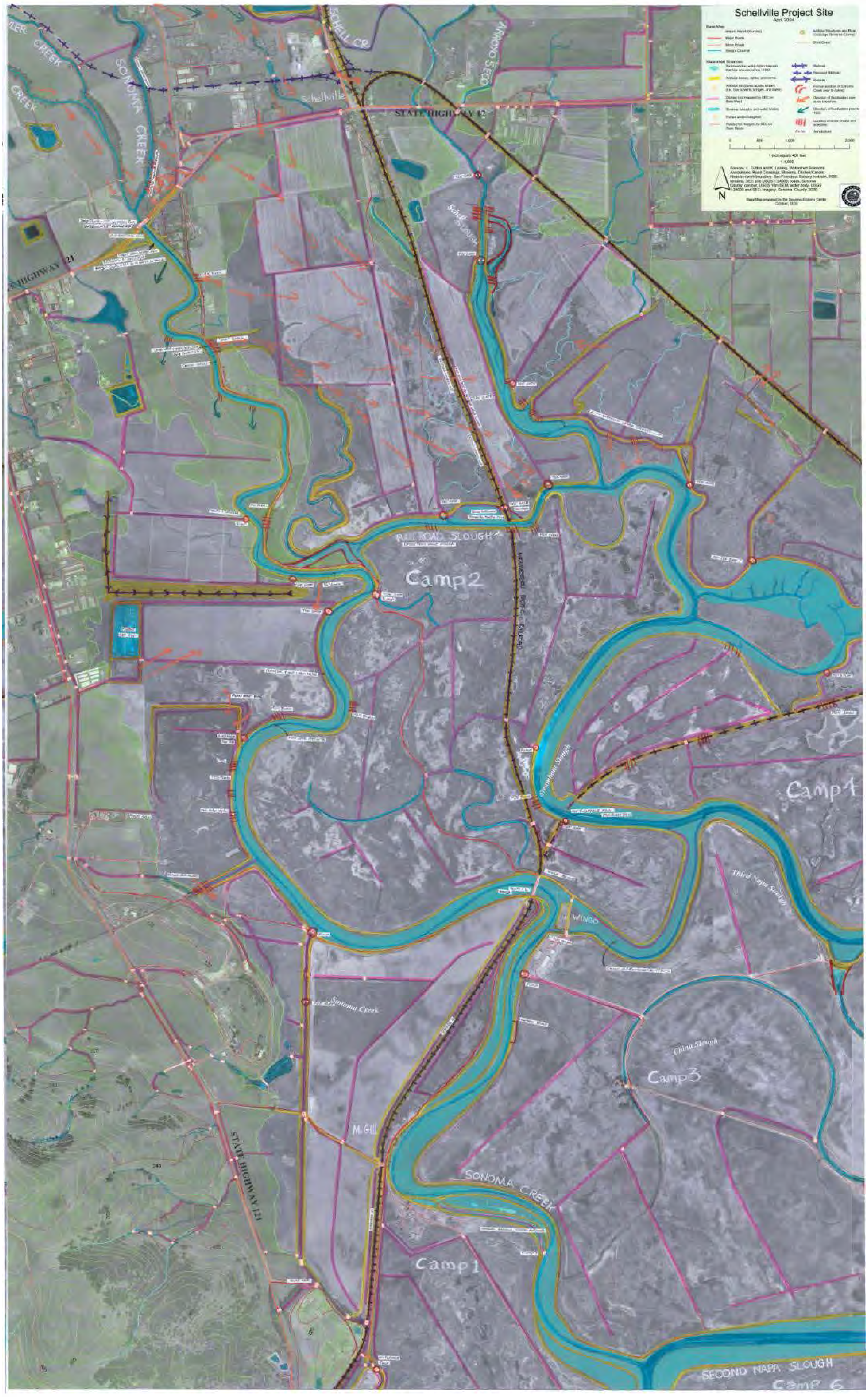

Source: Collins and Leising, 2004

figure **3**

Lower Sonoma Creek Flood Management and Ecosystem Enhancement

Historic Marsh Extent and Overflow Flood Paths

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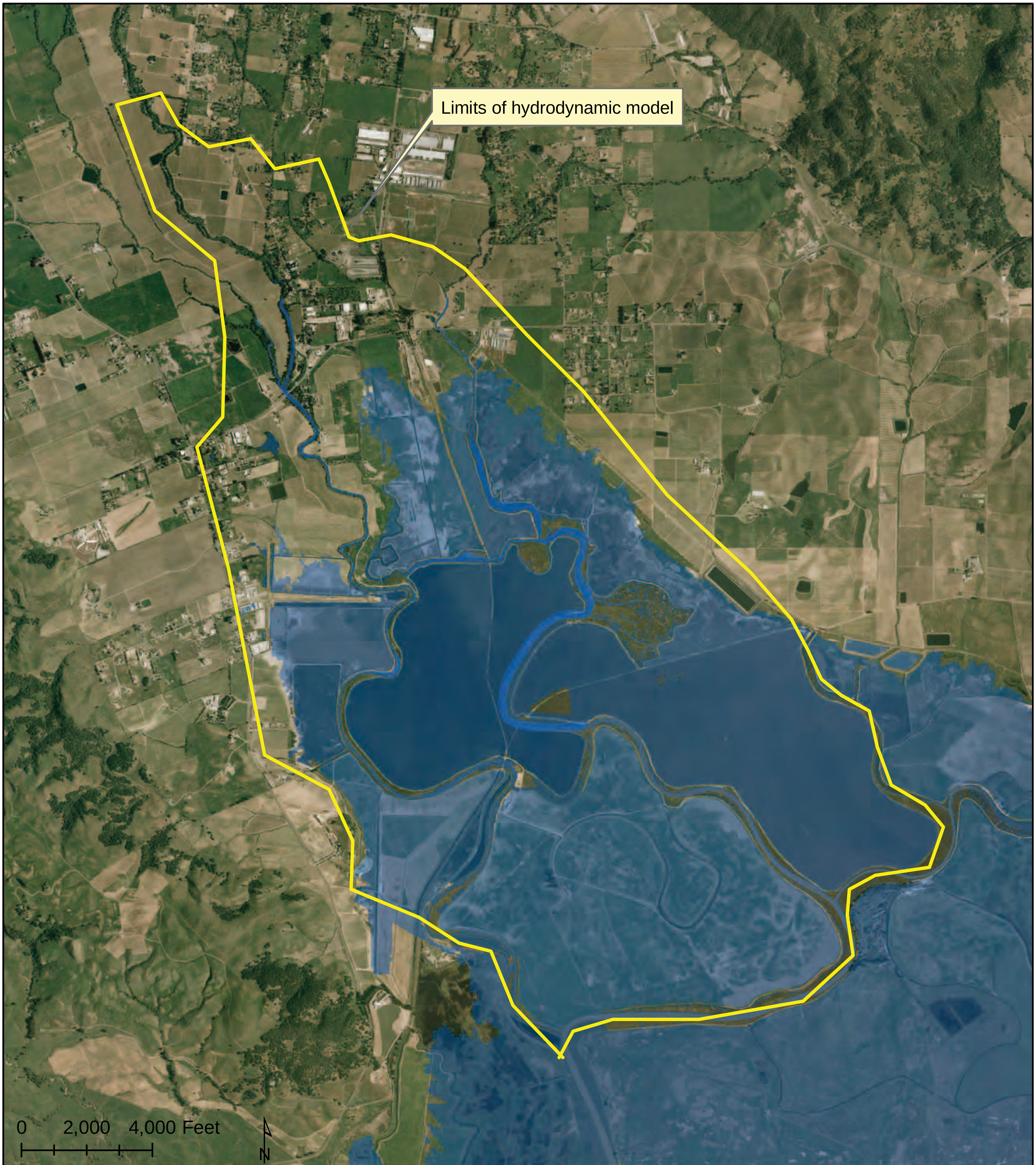

Note: The area mapped in Figure 4 is based on the hydrodynamic model topography which is generalized into 15 meter square grid cells.

Legend

Areas Less Than MHHW (approximately 6.3ft NAVD)

figure **4**

Lower Sonoma Creek Flood Management and Ecosystem Enhancement

Areas with Elevation Less than MHHW

PWA Ref.# 1844.00

PWA

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2.2 WATERSCAPE

The following sections describe the hydrologic conditions of Sonoma and Schell Creeks, the existing and expected future tidal conditions in San Pablo Bay, and recent flood events affecting Schellville and Lower Sonoma Valley.

2.2.1 Lower Sonoma Creek and Schell Creek

2.2.1.1 Watershed Hydrology

Design hydrographs used in this study were derived from earlier hydrologic analyses performed for the US Army Corps of Engineers (ESA PWA, 2004). For the 2004 study, ESA PWA developed an existing conditions watershed model and calibrated it based on measured flows at the USGS's Agua Caliente gauge on Sonoma Creek (11458500). Future peak flows were estimated based on General Plan build-out conditions for Sonoma Valley.[2] For the current analysis, ESA PWA revisited the 2004 hydrologic model and incorporated data from the New Year's Eve 2005 flood event (Appendix A-2.) In addition, the 2004 model was updated to include a node at Watmaugh Road, which is the upstream boundary of the hydrodynamic model used in this study.

Table 1 shows the design flood peak discharge values for Sonoma Creek at the Agua Caliente gauge and other key locations in the watershed for the 2-, 10-, 25-, and 100-year events. The 2-year event is the flood event that occurs, on average, once every two years and has a 50% chance of occurring in any given year as averaged over a long period of time; similarly, the 100-year event is the event that has a 1% chance of occurring in any given year. Design flows were derived from hydrologic modeling previously conducted by PWA (2004).

TABLE 1

DESIGN FLOOD PEAK DISCHARGES FOR SONOMA CREEK AND ITS TRIBUTARIES[1]

Return Period (years)	Peak Flow in Sonoma Creek at Agua Caliente (cfs)	Peak Flow in Sonoma Creek at Watmaugh Road (cfs)	Peak Flow in Fowler Creek at Sonoma Creek (cfs)	Peak Flow in Schell Creek d/s of Arroyo Seco Creek (cfs)[2]
2	2,910	3,390	563	867
10	10,640	12,510	2,631	3,110
25	14,610	17,200	3,693	4,200
100	20,660	24,360	5,320	5,910

[1] Source: see Appendix A2
[2] Sum of multiple flow input locations in the hydrodynamic model (i.e. Schell, Nathanson, and Arroyo Seco Creeks)

2.2.1.2 Runoff and Flooding Patterns

Relatively frequent runoff events from the Sonoma Creek watershed can cause out of bank flooding from Sonoma and Schell Creeks in the Schellville area. Figure 3 shows typical flow paths during flood events

[2] Future conditions were based on an assumed buildout of the 1989 Sonoma County and 1995 City of Sonoma General Plans.

(Collins and Leising 2004), which are further described below. This description is based on hydrodynamic modeling results, anecdotal accounts, and personal observations.

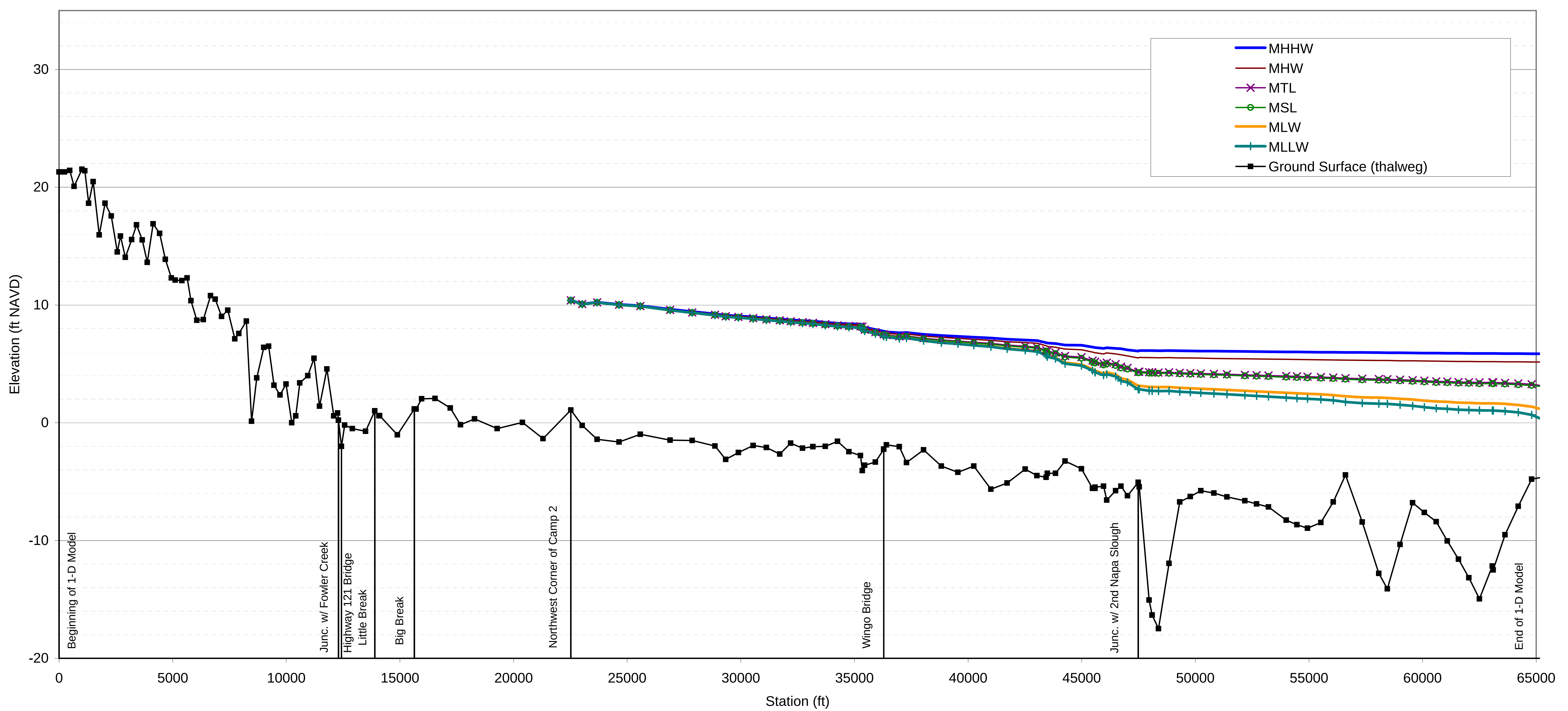
At approximately the 2-year flood level, Sonoma Creek begins to overtop the levees at Big Break, Little Break, and Hauto's Landing (see Figure 2). Big Break and Little Break are low spots on creek's eastern or left (facing downstream) levee and subject to frequent overtopping and scour (the scour associated with Big Break can easily be seen in aerial photos). Annually County Road crews grade Millerick Road in this area.

At similar or slightly greater flows, overtopping of the creek's left bank also begins to occur near the junction of Highways 121 and 12. Levees adjacent to Sonoma Creek on its left bank contain breaches; currently, informal berms have been constructed for a brief distance just upstream of Highway 121 east of the breached levees to contain flood flows, but these berms often fail during storm events. Escaping water flows southwest and crosses Highway 121 near the Schell-Vista Fire Department station. At flows equal to about a 10-year flood event, Schell Creek also overtops its banks upstream of Highway 121. Flows overtopping the right bank bypass the creek's large meander and flow overland south to the highway. Downstream of Highway 121, Schell Creek overtops its right and left banks upstream of the tide gates. Also at these flows, Camp 2 may begin to flood from levee overtopping at its northeast corner. In events of this magnitude, the area south of the airport and north of Camp 1 floods from the overtopping of Sonoma Creek levees.

At flows approximately equal to a 25-year event, out-of-bank flows from Sonoma, Schell, and Fowler Creeks are comingled upstream of Highway 121. Additionally, flood waters in Camp 2 are deeper due to additional overbank flow locations along Sonoma Creek and Steamboat Slough. During the 100-year flood event, additional locations that are flooded include the area north of the airport and Camp 4.

2.2.2 San Pablo Bay

San Pablo Bay tide levels provide the downstream boundary condition for water levels in Sonoma Creek, Schell Creek and the related slough channel network, including the Napa, 2nd Napa, 3rd Napa, and Steamboat Sloughs. Tidal datums for Sonoma Creek and Schell Creek are shown in Figures 5 and 6, respectively. Bay tide levels are the primary control on water levels downstream of Camp 2, and tidal effects can be measured as far upstream as Highway 121. The sections below describe San Pablo Bay tide levels including the potential effect of sea level rise.



Notes: MIKE Flood model

figure **5**

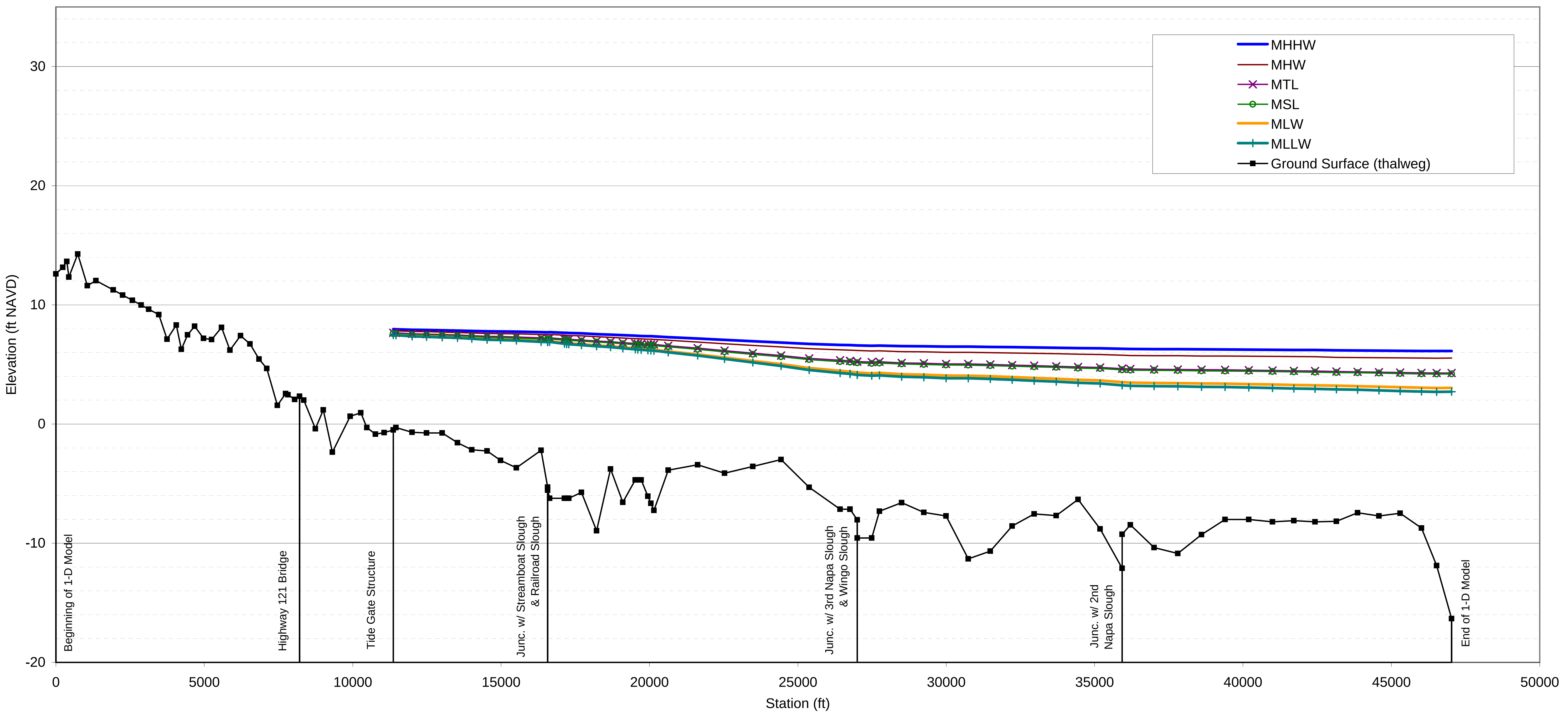
Lower Sonoma Creek Flood Management and Ecosystem Enhancement

Tidal Datums for Sonoma Creek - Q2 Inflow and No Sea Level Rise

PWA Ref# 1844.00

PWA

1844_TidalDatums_fromM11.xls / SC - Run2all - LPfig



Notes: MIKE Flood model

figure ***6***

Lower Sonoma Creek Flood Management and Ecosystem Enhancement

Tidal Datums for Schell Creek - Q2 Inflow and No Sea Level Rise

PWA Ref# 1844.00

PWA

1844_TidalDatums_fromM11.xls / Sch - Run2all - LPfig

2.2.2.1 Tidal Datums

Tide levels for San Pablo Bay as recorded at Mare Island Strait are shown below in Table 2.

TABLE 2
TIDAL DATUMS FOR SAN PABLO BAY

Tidal Datum	Description	Elevation[1] (feet, NAVD88)
MHHW	Mean higher high water	6.29
MHW	Mean high water	5.72
MTL	Mean tide level	3.56
MLW	Mean low water	1.39
MLLW	Mean lower low water	0.43

[1] Mare Island Strait gauge (NOAA 9415218)

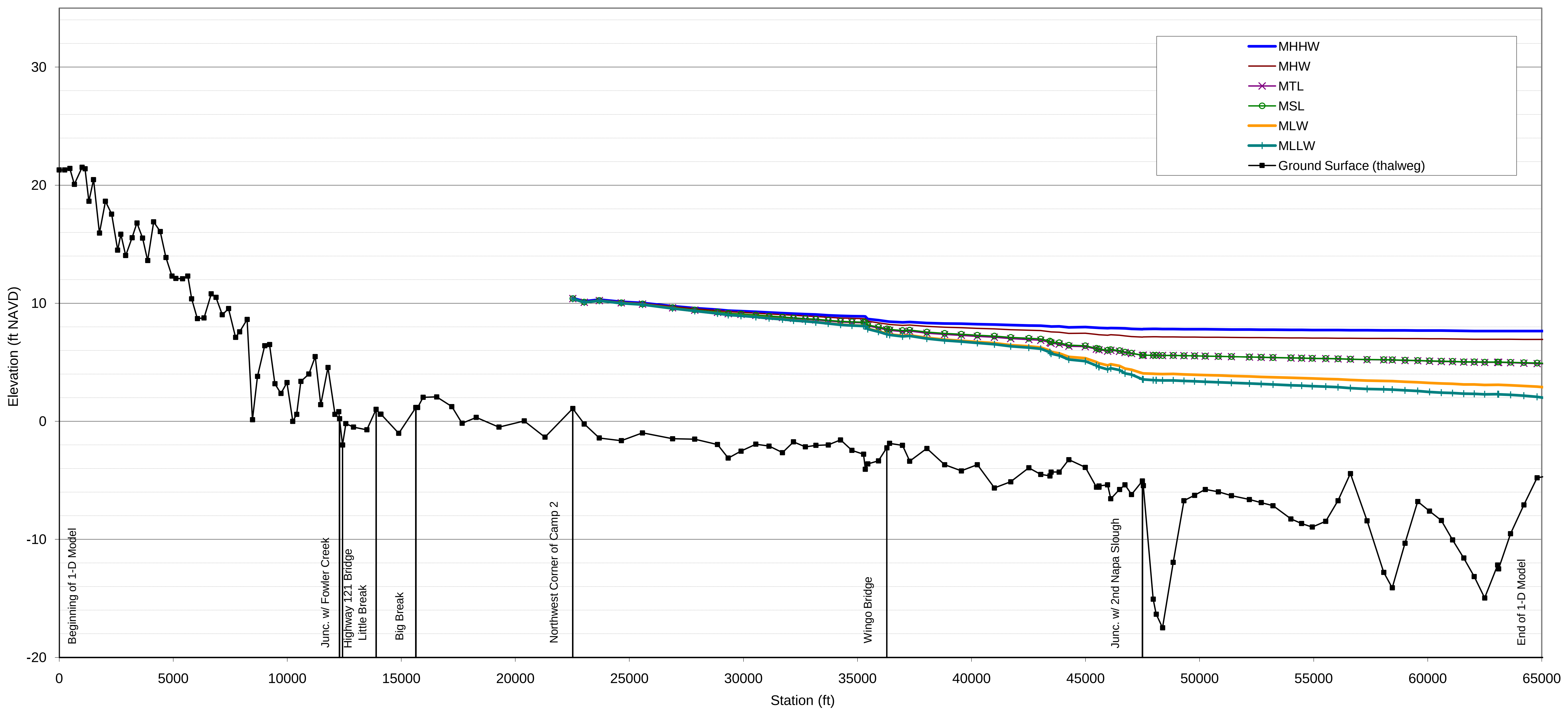
2.2.2.2 Sea Level Rise

Sea level rise (SLR) has the potential to increase the severity of flooding in the project area. To assess the potential effects of SLR, ESA PWA estimated future tide levels by adjusting tidal datums for SLR using US Army Corps of Engineers (USACE) guidance on incorporating SLR into civil works projects (USACE, 2009). Following the USACE guidance, a project planning horizon of 100 years was used to calculate the increase in sea levels under “low,” “medium,” and “high” scenarios (based on the NRC-I, NRC-II, and NRC-III curves, respectively). The “low” scenario is simply an extension of historic rates, while the “medium” and “high” scenarios include increasing SLR rates over time. Table 3 shows the low, medium and high estimates for SLR and future MHHW in San Pablo Bay.

TABLE 3
ESTIMATED 100-YEAR SEA LEVEL RISE FOR SAN PABLO BAY

	Low	Medium	High
Sea Level Rise (ft)	0.66	1.81	5.54
Future MHHW (ft NAVD88)	6.96	8.10	11.84

The effect of this increased base level in San Pablo Bay as a result of sea level rise on Sonoma and Schell Creeks is illustrated by the shift in tidal datums predicted with various levels of sea level rise as shown in Figures 7-10. Figure 11 shows the effect of sea level rise on the predicted extent of lands inundated at MHHW.



Notes: MIKE Flood model

figure 7

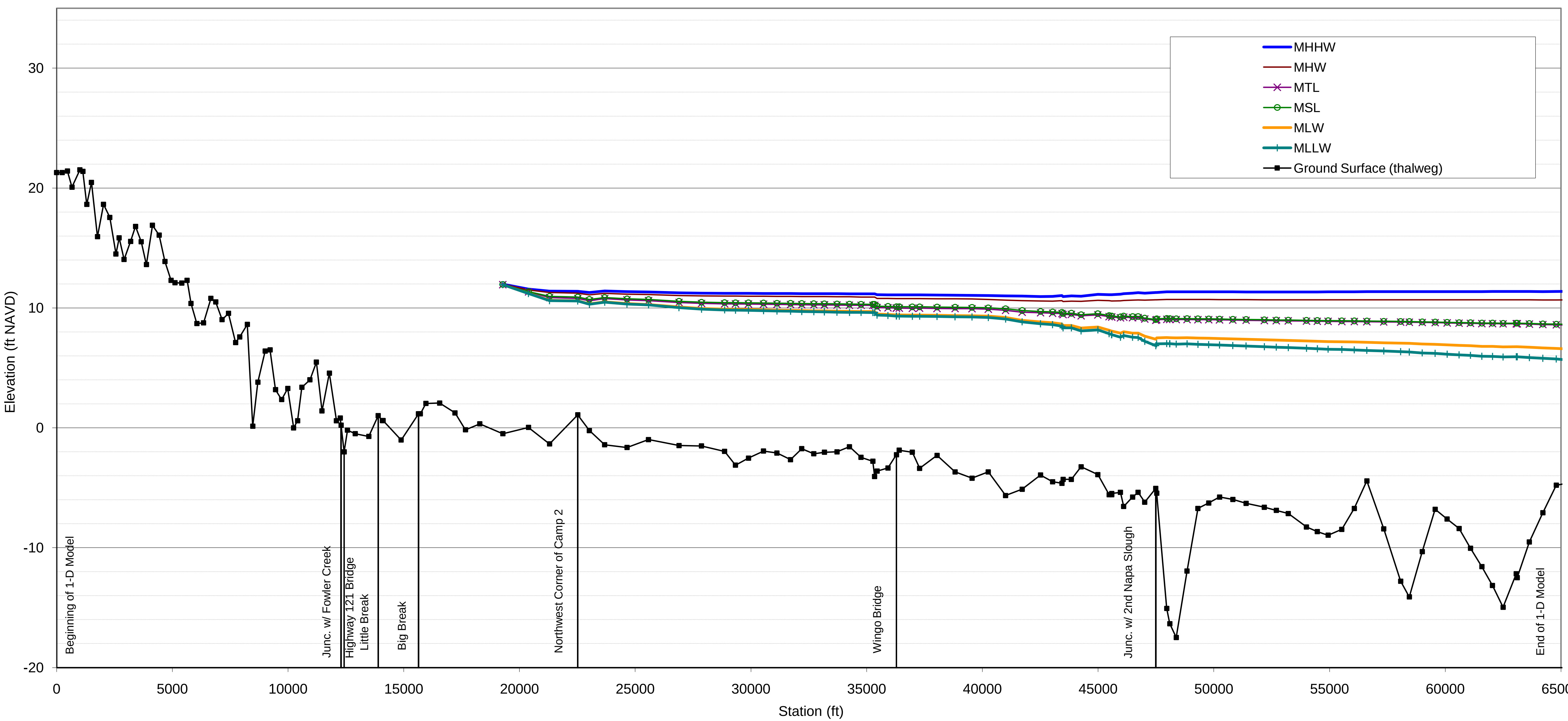
Lower Sonoma Creek Flood Management and Ecosystem Enhancement

Tidal Datums for Sonoma Creek - Q2 Inflow and 'Medium' Sea Level Rise

PWA Ref# 1844.00

PWA

1844_TidalDatums_fromM11_v5.xlsx / SC - 0.55 - LPfig



Notes: MIKE Flood model

figure **8**

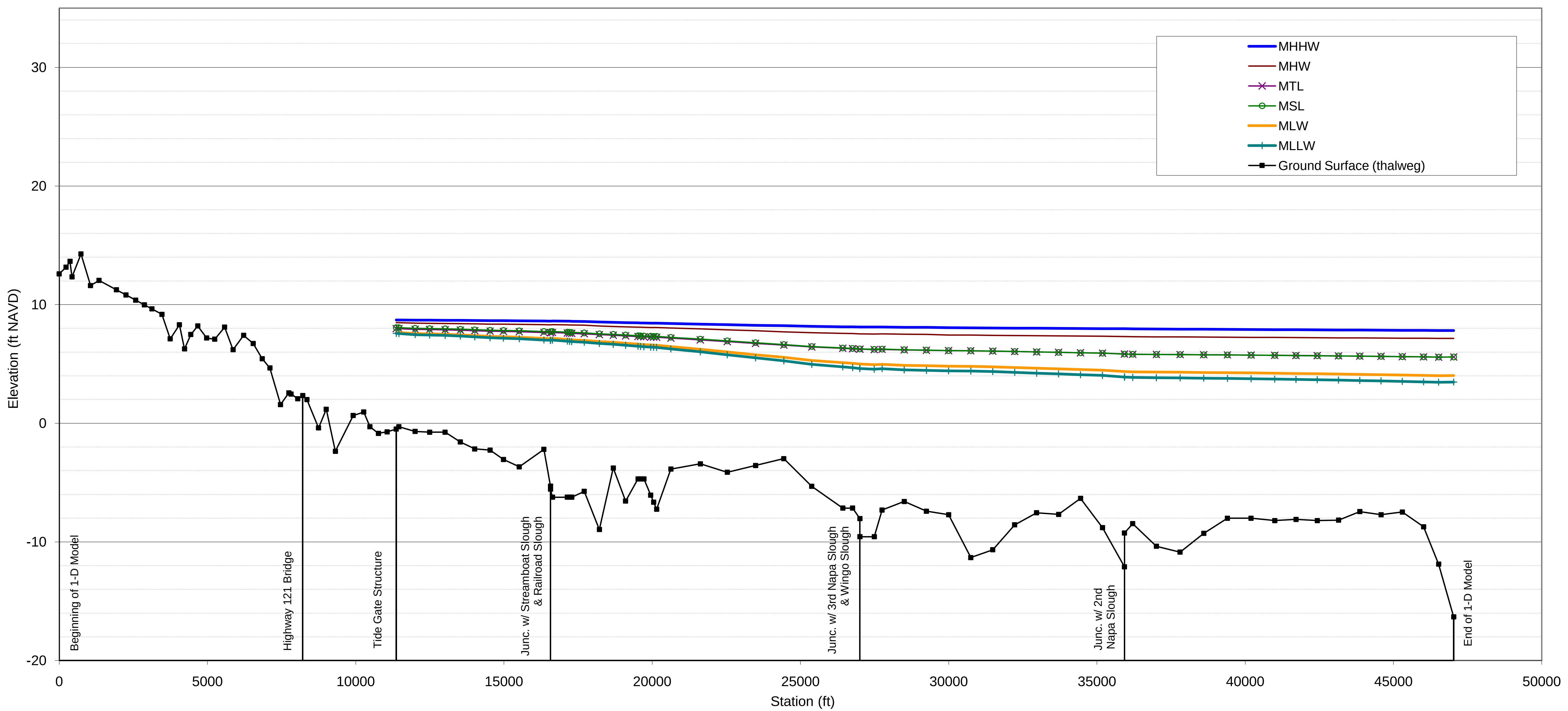
Lower Sonoma Creek Flood Management and Ecosystem Enhancement

Tidal Datums for Sonoma Creek - Q2 Inflow and 'High' Sea Level Rise

PWA Ref# 1844.00

PWA

1844_TidalDatums_fromM11_v5.xlsx / SC - 1.69 - LPfig



Notes: MIKE Flood model

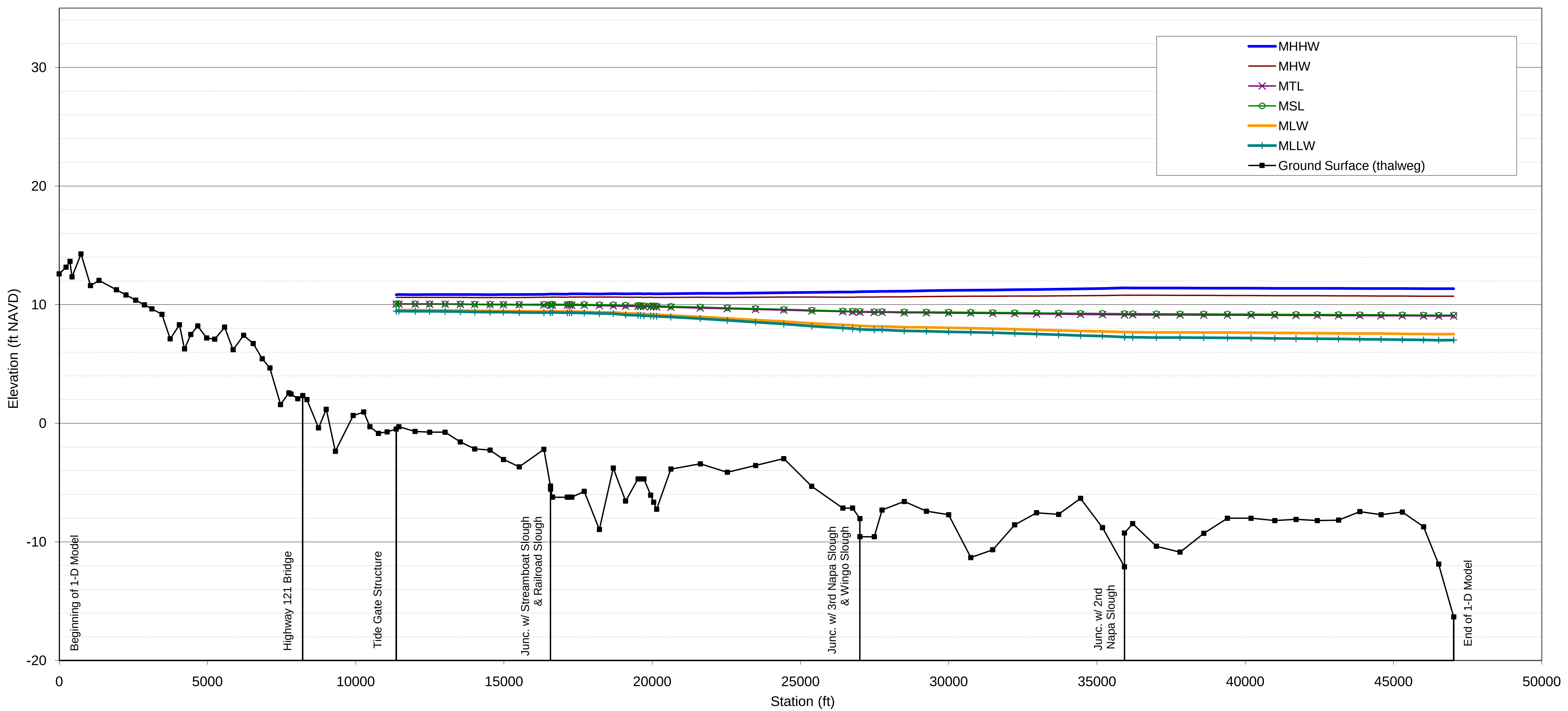
figure **9**

Lower Sonoma Creek Flood Management and Ecosystem Enhancement

Tidal Datums for Schell Creek - Q2 Inflow and 'Medium' Sea Level Rise

PWA Ref# 1844.00

PWA



Notes: MIKE Flood model

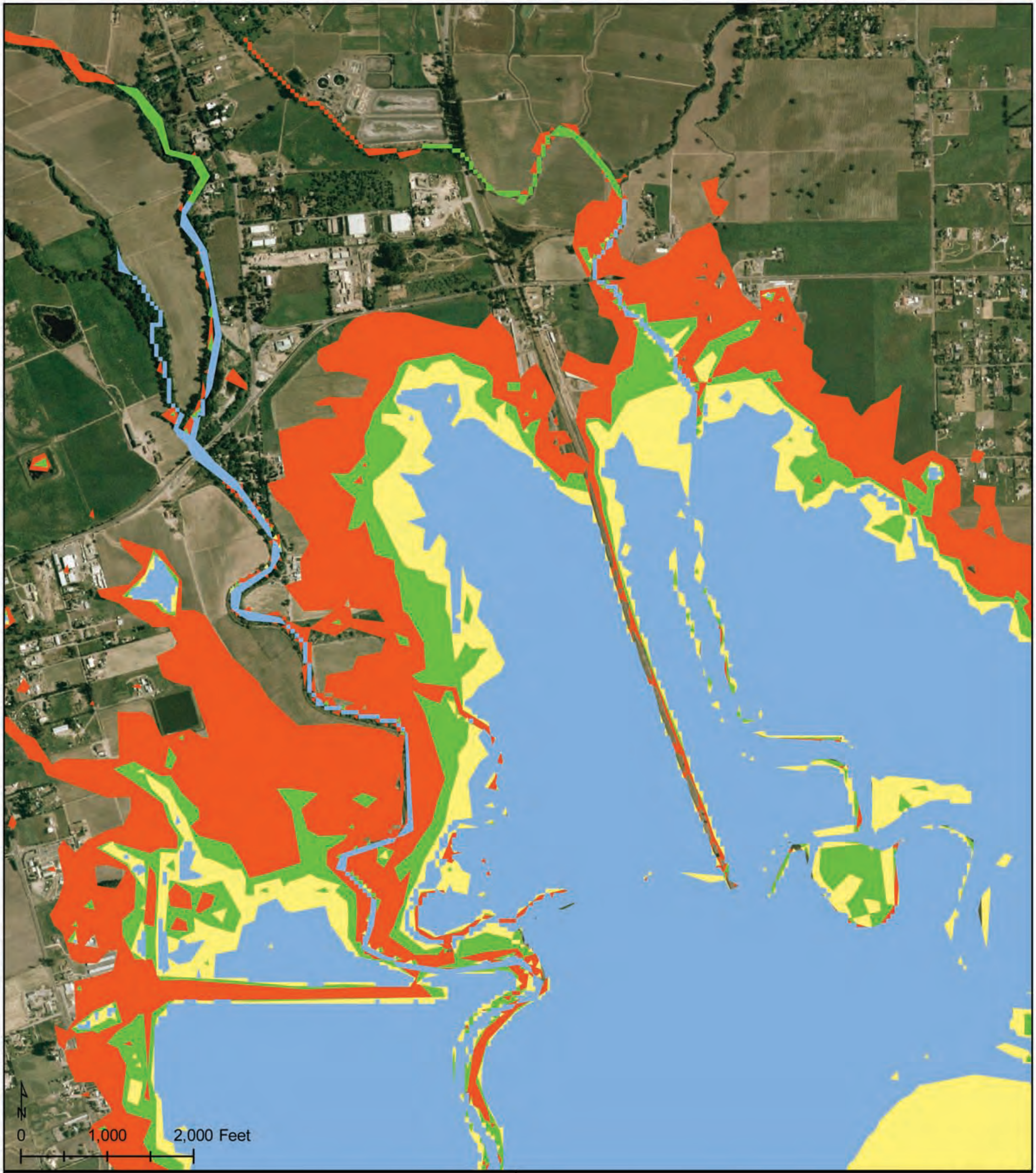
figure ***10***

Lower Sonoma Creek Flood Management and Ecosystem Enhancement

Tidal Datums for Schell Creek - Q2 Inflow and 'High' Sea Level Rise

PWA Ref# 1844.00

PWA



Note: All areas are approximate

- Existing locations with elevations less than MHHW
- With projected sea level rise: 0.7 ft (0.2 m)
- With projected sea level rise: 1.8 ft (0.6 m)
- With projected sea level rise: 5.5 ft (1.7 m)

figure ***11***

Lower Sonoma Creek Flood Management and Ecosystem Enhancement

Areas with Elevations Less than MHHW - with Sea Level Rise

PWA Ref.# 1844.00

PWA

\\Sfo1\GIS\1844_SonomaCreek\Figures

2.2.3 Recent Flooding Events

2.2.3.1 New Years Eve, 2005

An extreme flood event occurred in the lower Sonoma Creek watershed on December 31st and January 1st, 2006. The USGS reported a peak flow of 20,300 cfs at Agua Caliente, which is the highest peak flow on record at Agua Caliente and is approximately equal to the 100-year design flood peak used in this study. This event resulted in extensive flooding in the vicinity of Schellville and throughout the project area. Several levee failures occurred and Camp 1, Camp 2, and Camp 4 all were flooded (Camp 3 did not flood). The areas south of the airport and west of Camp 3 also flooded. Photos of the flood damage following this storm can be seen in Appendix B. This storm event was used to validate the results of the hydrodynamic model developed for this study, and a description of this process can be found in Appendix A2.

2.2.3.2 January 4th, 2008

During the course of this study, an intense rainfall event occurred concurrently with approximately two feet of storm surge in San Pablo Bay on January 4th, 2008. That level of storm surge would have affected water levels at least as far as the upstream side of Camp 2 and potentially some distance further upstream. Sonoma Creek overtopped its banks upstream of Highway 121, flowing east across Highway 12, south across Highway 121 and down Millerick Road. Highway 121 was closed at approximately 9:15 am due to the overtopping. Based on data from the USGS gauge at Agua Caliente and an estimated travel time to Highway 121, flows were approximately 3,500 to 4,000 cfs at this time. The peak flow measured at Agua Caliente was 7,820 cfs, which is slightly less than a 5-year event as estimated by the Bulletin 17B analysis of the gauge (see Appendix A2). Photos from the flood event can be seen in Appendix B.

3. OPPORTUNITIES AND CONSTRAINTS FOR FLOOD MANAGEMENT AND RESTORATION

This section describes flood management and environmental restoration opportunities and constraints in the project area, including fiscal considerations.

3.1 OPPORTUNITIES

Reducing the frequency and extent of flooding in the study area would require increasing the amount of flow that can be contained within the Sonoma and Schell Creek channels through Schellville, and increasing the conveyance and/or storage capacity of the drainage network downstream of Highway 121. This section describes potential opportunities for increasing the conveyance and/or storage capacity of the system, as well as environmental restoration/enhancement opportunities in the area.

3.1.1 Flood Management

Upstream of Highway 121, the ability of the Sonoma Creek channel to contain flood flows is limited primarily by the channel cross-sectional area, low points in the levees that allow water to escape at a relatively low flood stage, and by backwater effects from the bridge at Highway 121. Opportunities exist to increase the channel capacity by addressing each of these issues as described below.

3.1.1.1 Channel Capacity

The current bottom width of the Sonoma Creek channel at the Highway 121 Bridge is approximately 75 feet. Sediment has accumulated within the channel at this vicinity, likely due to the reduction in channel slope that occurs downstream of the bridge, possibly in combination with backwater effects from the bridge itself. There may be an opportunity to expand the channel cross section dimensions in this vicinity by setting back the levees and/or excavating accumulated sediment with the existing channel cross section.

3.1.1.2 Levee Maintenance

Low points or gaps in the right bank levee upstream of Highway 121 prevent the levee from performing as it was designed. Regular levee repair and maintenance may improve the ability of the existing levee to contain flood waters up to the design elevation of the levee.

3.1.1.3 Highway 121 Bridge

The opening under the Highway 121 bridge confines the creek channel to a width of 75 feet. However, design drawings for the Highway 121 bridge show that the bridge was designed for a channel with a maximum bottom width of 130 feet (CalTrans, 1971). There may be an opportunity to expand the bridge opening to increase the conveyance capacity of the channel at this location.

3.1.2 Ecosystem Enhancement

There is potential for a significant ecosystem enhancement component associated with any project, especially in the area south of Highway 121 that was historically tidal marsh and is now used for hay production. These areas occasionally flood from fluvial or tidal events and will become more and more susceptible to flooding with rising sea levels. To protect these areas from future flooding, larger and higher levees will need to be built. Restoring large portions of land adjacent to lower Sonoma Creek back to tidal marsh may support long-term resiliency against sea level rise as the marsh habitat can evolve with increased sea levels, and levees do not need to be continually raised or rebuilt.

An obvious location for tidal marsh restoration is Camp 2, former tidelands that were historically diked and farmed as hayfields. Camp 2 flooded via multiple levee breaches in the New Year's Eve 2005 event and was not effectively drained for several years. (Ground levels in Camp 2 have significantly subsided in the last century to well below mean tide level and, following breaching, the area was subject to continual tidal inflows prior to repairing.) The CA Department of Fish and Game (DFG) took over management of this land in the early 2000's; they have expressed disinterest in restoring the land to tidal marsh habitat (Larry Wyckoff, pers. comm.). While DFG has indicated that occasional overtopping from Sonoma Creek is acceptable, their plan for land management is to keep the area in seasonal freshwater wetland habitat.

Other areas potentially suitable for tidal restoration include portions of Camp 1 (770 acres), Camp 3 (1450 acres), Camp 4 (1100 acres), Area 7, and Area 8. These locations are identified in Figure 2 and it should be noted that these areas may not be available for purchase and have not been thoroughly vetted for their suitability for restoration. They are all directly adjacent to Sonoma Creek or Steamboat Slough and in a restoration scenario would probably be directly connected to Sonoma Creek, Steamboat Slough, or 2nd Napa Slough. If so, they would be exposed to a full tidal action from San Pablo Bay and would have the added effect of increasing tidal scour and, subsequently, cross sectional area in the waterways to which they are connected.

3.1.3 Reduction in Frequency of Flooding of Highway 121

Out-of-bank flooding occurring from Sonoma Creek upstream of Highway 121 overtops the highway during most events greater than approximately a 2- to 5-year peak flow. This flooding near the highway's junction with Highway 12 typically results in road closure, affecting both travel and public safety. Highway 121 is a heavily traveled east-west route connecting the lower Sonoma and Napa Valleys and the Schell-Vista Fire Department station is located near the Highway 121 and Highway 12 junction where overtopping is most severe. An alternative that includes some channel enlarging and a small levee has the potential to reduce out of bank flooding during small floods. While such a project wouldn't completely eliminate closing of the road due to overtopping during moderate and larger flood events, it has the potential to greatly reduce the frequency.

3.1.4 Willing and Engaged Landowners

Landowners in the Schellville area south of Highway 121 have been perennially affected by flooding from Sonoma and Schell Creeks and, in general, are informed and engaged in the process of developing flood management solutions. Some landowners have been on the DISTRICT board of directors and many are involved in on-going stakeholder meetings regarding water quality, groundwater recharge and solutions for the watershed.

3.2 CONSTRAINTS

There are significant constraints on developing a successful project in just the Schellville area, including challenges with the topography of the creek and surrounding lands, tidal influences, a high ratio of construction and maintenance costs relative to flood management benefits, and the likely effect of SLR on long-term solutions.

3.2.1 Topographic Challenges and Tidal Influence

As previously discussed, lower Sonoma Creek historically formed an alluvial fan, which was surrounded by tidal marsh downstream of Highway 121 (see Figure 3). The alluvial fan allowed the historic Sonoma Creek channel to be slightly ‘perched’ above the surrounding topography. Over time, the marshlands were drained and cultivated for agricultural use and, as a result, further subsided below the level of the creek channel. Levees were built to keep tidewaters out and to protect reclaimed farmland. They were intended to confine the creek and slough channels or to prevent flooding of subsided overbank areas.

Because the surrounding land slopes away from the Sonoma Creek channel, widening the channel to increase conveyance capacity requires building higher levees to confine flood waters to the channel. Additionally, these levees would require an outlet to allow drainage of water that falls on the areas behind the levee as rain reaches these areas from upstream overtopping. While this condition could potentially be solved with one-way culverts, it would be challenging since the land surface elevations are often lower than water levels in the Bay, causing outflow to be very limited and drainage to occur very slowly.

Tide levels in San Pablo Bay control water levels a considerable distance upstream on Sonoma and Schell Creeks. During conditions of storm surge, commonly experienced during the types of winter and spring storm events that bring rain floods to the fluvial system, water levels in Sonoma Creek are driven by tide levels as far upstream as Railroad Slough, at the upstream end of Camp 2, and beyond. This is probably the greatest constraint on addressing flood conditions in lower Sonoma and Schell Creeks.

In addition to topographic challenges related to fluvial flows, most of the project area downstream of Highway 121 is also subject to tidal inundation due to pre-existing low ground elevations and more recent land subsidence. A complex network of levees and dikes, mostly constructed and maintained by local landowners, currently confines high tides to the slough channels and prevents frequent tidal inundation of the Camps and other low-lying areas. However, the levees confine the channels and restrict the amount of flood water they can convey, as well as impeding drainage of low-lying areas when they do flood.

3.2.2 Fiscal Constraints

The task and potential costs of coping with continued flooding and sea level rise are daunting. The tasks and costs for improving water quality and protecting water availability to all beings are similarly quite challenging. This subsection provides a brief description of the fiscal context for the project, aimed at addressing these challenges.

3.2.2.1 Flood Zone Tax Support Limitations

One important fiscal constraint is the fact that the study area is not located within the existing designated flood zone. Flood zones were established in the late 1950s by the Sonoma County Water Agency, formerly the Sonoma County Flood Control and Water Conservation District. The agency's enabling act established zones to undertake projects or works of improvement and six of the eight zones were established in 1959. A ninth zone, (Bay Zone 9A) was proposed in September 1967 to cover the lower portions of Sonoma Creek and Petaluma River, however due to local opposition, proceedings for its' establishment were terminated in December of that year. Historically, the upper and lower portions of the Sonoma Creek watershed have been separated both physically and politically for a number of reasons, including low population and no local tax support.

The lands, while currently farmed, were once tidal marshes and mudflats ringing San Pablo Bay. Under the Swamp Land Act of 1849 (and modified in 1850 and 1860), private individuals were offered land at no cost, provided that they drain and develop these wetlands, which were defined as "wet and unfit for cultivation." Landowners installed a system of levees and pumps to keep tidewaters out and to pump stormwater and farm productively. (It should be noted that the federal "swamp lands" reclamation policy experienced a reversal in 1988 with adoption of the "no net loss" of wetlands policy.) The cost of maintaining the levee and pump infrastructure necessary to grow agricultural crops is borne by landowners, which is predominately private, but also includes federal, state and local government agencies.

3.2.2.2 Cost – Benefit Ratio

The cost to benefit ratio for a project in the Schellville area has been considered and determined several times in the past. In 1997, the RCD and USACE agreed to study the feasibility for flood management in the Schellville area even though there had been numerous studies of the area in the past starting in 1946. More current practice was to consider the benefits of an integrated project that contained elements of habitat conservation and restoration with flood protection and management, thus serving to improve the ratio of project benefits over costs. Thus, the USACE feasibility study included the consideration of habitat conservation and restoration (enhancement opportunities). In the past, in determining federal flood control study and project support, the USACE's cost/benefit analysis excluded habitat restoration benefits. Therefore, in the past, a flood management project alone was deemed infeasible economically.

Floodprone lands in the study area are primarily agricultural, sparsely populated, and the value of the developments on the land is comparatively low for Sonoma County. Given this situation, the number of individuals and the value of the property potentially benefiting from a flood reduction project would be relatively low compared to the expected costs of a project of this scale.

3.2.2.3 Competing Costs

In 2011, the US Fish and Wildlife Service (USFWS) added about 3,100 acres of Skaggs Island to the San Pablo Bay National Wildlife Refuge for the purpose of restoring and managing habitat for fish and wildlife, including restoration of tidal wetlands. The property is subject to an agreement, executed by the U.S. Navy in 1943 that requires that the property owner (the USFWS) maintain the system of levees and drainage ditches and maintain and operate pumps necessary to prevent flooding and retain farmable conditions on the remainder of Skaggs Island, a 1000 acre privately owned property. This agreement obligates the USFWS in perpetuity and tidal marsh restoration on the USFWS property will include the significant cost of constructing an adequate levee system to protect the adjacent property. To the extent this expense prevents restoration of Skaggs Island to tidal wetlands, it will impede creation of a continuous tidal wetland habitat corridor from San Pablo Bay further upstream along Sonoma or Schell Creeks.

Given the intended conversion of the adjacent Skaggs Island to tidal wetland, identified habitat restoration needs (see, e.g., Baylands Ecosystem Habitat Goals, 1999[3]; USFWS Draft Tidal Wetland Recovery Plan, 2010), together with the expected levels of SLR, the benefits of initiating such restoration in the near term, and the number of landowners in the Schellville area with potentially suitable lands, the opportunities associated with this type of project are large and multi-faceted.

3.2.2.4 Limitations on Public Land Purchase Prices

There may be lands available in this area for tidal restoration. Some state, federal and regional public agencies include among their objectives acquisition and restoration of wetlands along San Pablo Bay. They may acquire fee and/or easement interests in property either directly or through a grant to another conservation organization. However, these buyers may only pay fair market value as determined by a qualified appraiser. Fair market value is based on the highest and best use of the property that is legal, physically possible, financially feasible and results in the highest values. For much of the land in the study area downstream of Highway 121, which is largely subsided land in the floodplain, the highest and best use is for oat hay agriculture. Although society recognizes the important functions and values that tidal wetlands provide, this potential future benefit is not part of the appraisal calculation. In many cases, landowner expectations of value exceed appraised value.

It is the goal of the RCD to work with landowners, policy makers, granting agencies and private organizations to determine a mechanism for more appropriate appraisal of the tidelands throughout the San Francisco Bay Area that are deemed essential for restoration and to alleviate the effects of sea level rise on those communities above the tidelands. There are landowners willing to sell their agricultural lands either in fee or for conservation easements that allow for seasonal farming.

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[3] A report of habitat recommendations prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. U.S. Environmental Protection Agency, San Francisco, Calif./S.F. Bay Regional Water Quality Control Board, Oakland, Calif.

3.2.2.5 Funding Mechanisms

The opportunities discussed in this document significantly interweave the possibilities and wishes of the landowners in the Schellville area with those of the upper watershed communities. There is an opportunity to leverage investments in this region to benefit both climate change resilience and flood hazard reduction goals in the Schellville area. Despite funding constraints, there are several mechanisms available to provide funding for projects, such as Prop 84 or 1E. For restoration projects, there are multiple federal, state and local private and public funding sources, such as CDFG, State Water Resources Control Board, Department of Water Resources, California Coastal Conservancy and USFWS.

The US Department of Agriculture's Natural Resource Conservation Service (NRCS) may be able to provide eligible and willing landowners in the Lower Sonoma Creek watershed with cost share funding for flood detention basins and wetland habitat enhancement through their Environmental Quality Incentives Program (EQIP). Contingent on US Farm Bill annual appropriations in watershed, the NRCS may also have funds for eligible landowners available through the Wetlands Reserve Program (WRP), a voluntary program offering landowners the opportunity to protect, restore, and enhance wetlands on their property. Currently, the program is unfunded as the Farm Bill has not been re-authorized. NRCS provides technical and financial support to help landowners (public or private) with wetland restoration efforts with the goal of achieving the greatest wetland functions and values, along with optimum wildlife habitat, on every acre enrolled in WRP. Lands eligible for the WRP include: wetlands farmed under natural conditions; farmed wetlands; prior converted cropland; farmed wetland pasture; certain lands that have the potential to become a wetland as a result of flooding; rangeland, pasture, or forest production lands where the hydrology has been significantly degraded and can be restored; riparian areas which link protected wetlands; lands adjacent to protected wetlands that contribute significantly to wetland functions and values; and wetlands previously restored under a local, State, or Federal Program that need long-term protection. Due to limited funding, priority funding may be given to projects that have engineering designs and permits in-hand. Several properties in the Sonoma Creek and Petaluma watersheds have utilized the WRP as cost-share funding to assist in their restoration goals.

3.2.3 Lack of Political Support for Extensive New Levees or Routine Dredging

A project attempting to prevent inundation of floodprone lands within the study area during flood events greater than approximately a 5-year flood would most likely require the construction of new and higher levees, due to the local topography and influence of San Pablo Bay. A significant constraint affecting the flood management component of potential designs is the lack of political support and funding for new levee construction and maintenance. An extensive levee system was therefore assumed to be incompatible with the goals and management objectives of the project.

Additionally, there is a lack of support from the responsible agencies for a project that would require a significant level of ongoing maintenance. Increasing the existing channel capacity through dredging or excavating could increase conveyance and most likely reduce out-of-bank flooding, however it would also create an effective sediment trap. Downstream of Highway 121, the channel's existing depth, top width, and shape are based on a balance between sediment input from the upper watershed, sediment input from the Bay, fluvial flows, tidal flows, and the channel slope. Simply increasing the cross sectional area would affect the balance of these elements in a way that would most likely cause the channel to fill in with sediment until it returns to its existing equilibrium state. (Because dredging has not occurred since the mid 1900's, per Collins and Leising, 2004, it is assumed that the channel is currently in equilibrium.) If a project was designed with deepened cross sections and counted on this increase in conveyance area for a reduction in flooding, continuous maintenance would be required to ensure sediment would not fill the channel and compromise the effectiveness of the project.

3.2.4 Sea Level Rise and its Effect on Long Term Solutions

Projects designed to reduce flooding in the Schellville area would need to accommodate sea level rise (SLR) and its impacts on coastal and fluvial flooding potential. Under projected "high" sea level rise conditions, water levels in San Pablo Bay would increase by approximately 5.5 feet in 100 years as estimated from procedures outlined by the USACE (2009). An increase in Bay water levels of this magnitude would result in greatly increased pressure on the current system of levees and dikes. SLR would have to be addressed as part of the initial project or with an adaptive management approach. In either case, the project would potentially be constrained due to an increased project footprint and increased costs associated with higher and wider levees (if used) and additional grading. With or without a project, as SLR increases, the effects of higher water levels from the bay would increase flood levels in lower Sonoma Creek. SLR may additionally cause sedimentation in the creek channel, reducing the effective flow area below the existing natural and managed levee elevation and would, most likely, result in increased flooding. Increased water levels and the corresponding geomorphic response would have to be considered in any design.

4. CONCEPTUAL MODEL OF FLOOD FLOW INTERACTIONS ALONG LOWER SONOMA CREEK

This chapter summarizes the understanding developed as an outcome of the hydrodynamic modeling effort, which simulated flood conditions in the study area. The model provided a better understanding of flooding sequences, interactions and the dominant physical factors contributing to flooding in this lower area of the Sonoma Creek watershed.

Due to an abrupt change in topographic slope as Sonoma Creek reaches the low-lying baylands, sediment is deposited, forming an alluvial fan at the mouth of the valley in the transition zone from fluvial to tidal dominance (Watershed Sciences, 2004). The alluvial fan setting results in the creek channel being somewhat perched above the surrounding topography in the vicinity of Highway 121. Flood waters that escape Sonoma Creek in this vicinity therefore tend to flow away from the channel and toward Schell Creek and the low-lying baylands to the east.

The current Sonoma Creek channel profile reflects a distinct transition at the Highway 121 Bridge. Upstream of Highway 121, the channel slope is typical of a fluvial system in this environment, at approximately 0.18%. Downstream of Highway 121, the slope flattens dramatically to approximately 0.02%, which is more typical of slough channels in the tidal environment. The reduction in channel slope near the Highway 121 Bridge causes flow velocity in the channel to drop, reducing the channel's ability to convey flood flows. Flood flows tend to break out of both Sonoma Creek and Schell Creek upstream of Highway 121. During high creek flood flows, overbank flows from Sonoma Creek also break out upstream of Highway 121, passing through low spots and breaks in the levees along the creek and overtopping and eroding the informal berms along Broadway at Highway 121 as they move south and east toward the baylands. Some overbank flows from Sonoma Creek reach Schell Creek before continuing east and south, either flowing down Schell Creek or flowing with Schell Creek overbank flows across Highway 121 to the south.

Further downstream on Sonoma Creek, additional flood flows escape to the east near the southern end of Millerick Road, where breaches and low spots in the informal eastern levee allow water to flow out of the channel and into farmed lands.

To a significant extent, flood conditions on Sonoma and Schell Creeks are affected by downstream tidal boundary conditions. High tide levels, often including higher than predicted tides due to storm surge during rainfall events, backs water up in the lower channel and can directly control water levels up to approximately the upstream side of Camp 2. This dynamic can trigger flooding at the low spots in the levees downstream of Highway 121 during even minor creek flood flows. During larger flood events, these downstream "breaks" in the levees often become active prior to the initiation of overbank flows upstream.

While most flood flow arrives at the upstream end of the study area by way of Sonoma Creek, our analysis of the NYE 2005 flood event showed that in large floods, most flood flow actually reaches San Pablo Bay by first traveling east of Sonoma Creek to Schell Creek, Schell Slough, Steamboat Slough, and/or 2nd and 3rd Napa Sloughs to the east. As described above, some flood flow moves from Sonoma Creek to Schell Creek upstream of Highway 121. Additional flood waters move east to the south of Highway 121, crossing the railroad corridor at Camp 2 and upstream: flowing through culverts, Railroad Slough, over the top of the embankment, and through the unnamed slough at Wingo to reach these waterways east of the railroad embankment. At the downstream end of 2nd Napa Slough, most flood flows rejoin and continue down lower Sonoma Creek to reach the Bay.[4]

Downstream of Highway 121, flood flow movement from west to the lower lying lands to the east across the railroad corridor is constrained by the railroad embankment, as well as levees around Camp 2 and along Sonoma Creek. Both the limited capacity of the Sonoma Creek channel downstream of Railroad Slough and the hydraulics of the connections across the railroad embankment have a significant role to play in determining how much water leaves the Sonoma Creek system upstream of 2nd Napa Slough and how much stays in Sonoma Creek.

[4] Some flow mixing between Sonoma Creek and Napa River flood systems can occur in large events, but are not important to flood conditions in the system, as they occur at the downstream limits, where water levels are primarily controlled by San Pablo Bay.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY OF CONCLUSIONS

The initial screening analyses conducted as part of this study indicated that the flooding issues in and around the Schellville study area would not be readily addressed by the alternatives identified for this localized area. Nonetheless, we proceeded to explore the potential of several alternatives to determine more precisely what was possible so that the question of potential project benefits could be more fully answered and documented. These investigations provided information and demonstrated that none of the alternatives were a viable project concept in terms of providing needed flood reduction. No preferred alternative emerged due largely to the physical constraints inherent to the project site. These constraints include very low gradient (flat topography) in the lower watershed, considerable tidal influence extending above Highway 121 and pre-existing low ground elevations and more recent land subsidence. Due to these constrained conditions coupled with anticipated sea level rise and lack of political support to fund an extensive new levee system, the study determined that none of the identified alternatives achieved substantial flood reduction. The analysis leading to this conclusion is fully as documented in Appendix A1.

Given the constrained setting, the study determined that alternatives such as floodplain terraces, levee adjustments or other physical flood reduction measures needed in the specific study area (Schellville) to provide relief from recurrent flooding are of such a magnitude that they are not economically justified or physically feasible. Smaller-scale project alternatives do not provide adequate relief of flooding. Modeling indicated that individual projects will not effectively achieve the flood reduction goals. However, a broader watershed approach with a variety of measures established throughout the watershed warrants future consideration.

With the new understanding of watershed flood hydrology and hydraulics developed during the course of this study and documented as a conceptual model in Section 4, the project team concludes the current study with a recommendation for a revised watershed scale approach to addressing flooding issues in and around Schellville combining three elements: a) stormwater management (decrease flows, increase conveyance) and groundwater recharge in the upper watershed, b) acquisition of easements on affected lands for seasonal floodwater conveyance, and c) acquisition of lands at risk for current or future flooding that may be restored to tidal wetlands.

This section describes the need for watershed-scale approaches to managing flood hazards in lower Sonoma Creek. It also identifies opportunities and constraints associated with a larger-scale effort to address flood hazards, groundwater and surface water management together with restoration of tidal flows to diked agricultural areas within the lower Sonoma Creek corridor to achieve valuable habitat enhancement, as well as resiliency with respect to anticipated climate change.

Stakeholders and planning partners have suggested a multiple benefit project that potentially includes the following types of elements:

- Detention ponds in the upper watershed
- Acquisition of land for habitat protection or restoration
- Acquisition of flood easements
- Watershed protection
- Restoration or enhancement of natural habitats
- Education projects or facilities
- Stormwater management for groundwater recharge and peak flow attenuation

Opportunities include tidal wetland and other habitat restoration, addressing anticipated increases in San Pablo Bay tide levels, and alignment of land uses with existing (and historic) topography/hydrology. Constraints include the topography of the project area (much of which is below current high tide levels), existing land uses and infrastructure, and lack of funding/support for new levees or extensive levee maintenance.

Projects to reduce flood hazards may include such elements as reconfigured levees, new designated flow areas, modified channels, retention/detention areas and other stormwater management strategies, as well as including habitat features such as new and/or enhanced freshwater and tidal wetlands and a restored floodplain and riparian corridor.

5.2 NEED FOR WATERSHED-SCALE APPROACH

The downstream tidal influence poses a significant constraint to ameliorating flood conditions in lower Sonoma Creek. In essence, flood hazards arrive from two directions in the vicinity of Schellville: both upstream, from the watershed, and downstream, from San Pablo Bay. Bay water levels cannot be controlled except by the exclusion of water through an extensive new levee system. The option of using extensive new levee systems has been excluded in the current investigation, for the reasons described in Section3.2.3. Due to the hydraulic control exerted by San Pablo Bay tide levels and the hydrologic linkages between Sonoma and Schell Creeks, water levels can only be reduced by actions upstream in the watershed, with the exception of a very short reach of Sonoma Creek between Camp 2 and Highway 121.

The area of the current study was limited to lower Sonoma Creek and did not address any opportunities in the upper watershed,[5] but recent studies and emphasis on integrated water management indicate that the upper watershed is where the greatest opportunity lies to address fluvial flood hazards while providing multiple benefits before Sonoma Creek reaches Schellville. Similarly, addressing bay-driven flood hazards will require the broad perspective afforded by a long-term, regional view. A watershed-scale approach is needed to address flood hazards within lower Sonoma Creek.

[5] Such a study was initiated by the Sonoma County Water Agency in November 2010.

5.3 CONSTRAINTS AND OPPORTUNITIES: A NEW LOOK

In this section, the constraints and opportunities discussed in Section 3 3 are augmented with additional considerations associated with 1) potential land use change approaches to flood hazard reduction in lower Sonoma Creek—specifically, accommodating flooding and tidal wetland restoration; and 2) potential actions in the Sonoma Creek watershed upstream of Schellville that improve groundwater recharge, allow for detention and storage of storm waters, and improve water quality while reducing flood hazards in lower Sonoma Creek.

5.3.1 Constraints

5.3.1.1 Balance of Flows between Sonoma and Schell Creeks

As discussed in Section 4, the distribution of flows between lower Sonoma and Schell Creeks creates a delicate balance with regard to flood hazards. Improvement of the conveyance of flood waters down Sonoma Creek will reduce flooding along Schell Creek, but only at the expense of aggravating flood hazards along Sonoma Creek—the tidal boundary control means that there is nowhere else for that additional water to go. The reverse would be true if conveyance along Schell Creek enhanced and Sonoma Creek flows were routed there as a result. Such improvements in conveyance could occur as a side effect of tidal wetland restoration, which will tend to increase channel scour. Thus, careful consideration of the connection of any restored tidal wetland areas should be made, as unintended flood consequences could result from resulting channel changes over time. Similarly, the seemingly obvious step of fixing the low spots in the levees along Sonoma Creek could create aggravated flood hazards along Schell Creek, as higher water levels upstream in Sonoma Creek would cause additional overbank flows to Schell Creek during flood events. Essentially, any change in the hydraulics of the Sonoma Creek – Schell Creek channel system has the potential to trigger changes in the distribution and severity of flood hazards.

5.3.1.2 Existing Infrastructure

The existing infrastructure along lower Sonoma and Schell Creeks poses some constraints on changes that might be considered in this area. For example, the existing at-grade private road across Camp 2 (southern extension of Millerick Road) provides landowner access that must be maintained, replaced or otherwise compensated for if Camp 2 is proposed for restoration as tidal wetland. The railroad corridor is now in use by the North Coast Railroad Authority; flooding of lands to the east or west of the railway embankment will need to provide flood protection of the embankment to protect this feature from flooding for that future use or otherwise compensate for the resulting impacts.

Additionally, movement of water from Sonoma Creek to the Schell Creek side of the railroad embankment is constrained by levees, channel capacity, and the railroad embankment itself, as discussed in Section 4. Implementation of changes to either system that modifies flow conveyance, including tidal wetland restoration, will need to consider the potential for modifications not only to creek channels but also to east-west linkages and creek crossings, which may include:

- The 8th Street crossing, railroad bridge, and Highway 121 Bridge across Schell Creek,

- The Highway 121, Wingo[6], and Highway 37 Bridges across Sonoma Creek,
- Railroad Slough channel and the railroad bridge crossing of it,
- Culverts under the railroad embankment and
- The unnamed connecting channel at Wingo.

Modifications to bridges and road crossings are expensive to undertake.

Additional existing infrastructure includes the levees and berms along the eastern and western margins of Sonoma Creek downstream of Highway 121. Enlargement of the channel may require reconstruction of these features, or comparable provision of flood protection, or compensation.

5.3.1.3 Salinity Intrusion

The introduction of conditions that enhance the transport of saline bay waters into the Schellville area may have the potential to aggravate or create groundwater quality issues. Salinity intrusion is already a problem in the groundwater of the Schellville area (Farrar et al., 2006).

5.3.1.4 Camp 2 Unit, Napa-Sonoma Marshes Wildlife Area (DFG)

Camp 2 is specified for management as a freshwater seasonal wetland in perpetuity under the terms of grant funding provided for its establishment by North American Wetlands Conservation Act (NAWCA) grant funds (Larry Wyckoff, pers. comm.); its levees must be maintained for that purpose. Alternatively, it is conceivably possible that comparable lands for establishment of seasonal wetlands may be provided elsewhere, together with funding for their establishment.

5.3.1.5 Adjacent Land Uses

Most of the lands along lower Sonoma Creek in the Schellville area are working landscapes that presume existing levels of exposure to flood hazards and saline water. Any action that will change adjacent land uses so as to increase the exposure of these lands to flood and water quality risks will need to incorporate mitigations to compensate the affected landowners accordingly.

5.3.1.6 San Pablo Bay National Wildlife Refuge: Skaggs Island (USFWS)

The US Fish and Wildlife Service (USFWS) is in the process of adding Skaggs Island to the San Pablo Bay National Wildlife Refuge for the purpose of restoring tidal wetlands. However, they also signed a contract with Jim Haire, owner of property in the northeast corner of the island, to protect his lands from flooding. Thus, the USFWS' ability to proceed with restoration of Skaggs Island is currently limited by the significant cost of constructing an adequate levee system to protect Haire's property. To the extent this limitation prevents restoration of Skaggs Island to tidal wetlands, it will preclude creation of a continuous tidal wetland habitat corridor from San Pablo Bay further upstream along Sonoma or Schell Creeks.

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[6] Local landowners report that the Sonoma Creek channel at Wingo Bridge has experienced significant sedimentation, and that the channel has narrowed considerably since the bridge was constructed. Thus, it may be able to accommodate significant channel scour.

5.3.2 Opportunities For A Watershed-Scale Approach

5.3.2.1 Create Upstream Detention or Retention in the Watershed

Sonoma Creek is the source of the great majority of the flood flows reaching Schellville. The hydrologic model for the Sonoma Creek watershed originally developed in an earlier study (PWA, 2004), would be a powerful tool for the purpose of assessing detention/retention potential in the subwatersheds of Sonoma Creek. Given the shape of the overall watershed, we believe that any new detention or retention of peak flood flows upstream of the City of Sonoma will contribute to reducing peak flows at Schellville. A study to scope such opportunities was initiated by the Sonoma County Water Agency in November 2010 and is scheduled for completion in 2012[7].

Actions in the Sonoma Creek watershed that reduce the peak flows reaching Schellville could take a few different forms. For example, detention of floodwaters might occur in large, centralized off-stream surface water storage facilities that hold (and potentially infiltrate) water diverted from Sonoma Creek. Alternatively, surface water flows might be routed into an major infiltration facility that causes all received flows to be retained in groundwater storage. At another scale, facilitation and support for development of decentralized stormwater storage or infiltration facilities (e.g., household-scale rainwater storage, bioswales, rain gardens) may be an avenue to reduce or slow the delivery of surface flows to Sonoma Creek and thereby reduce peak flows.

5.3.2.2 Shift to Flood-compatible Land Uses

While it is not practical to protect existing land uses downstream of Highway 121 by using an extensive new levee system, it is possible to reduce flood hazards by changing land uses to those compatible with flooding. Changing land uses to support flood-compatible uses would also eliminate flood hazards, though it may or may not be capable of reducing flood extents.[8] An approach focused on land use change was not specifically explored during this study of flood management alternatives, but stakeholders and the DISTRICT have considered it extensively outside of this study.

There are a variety of approaches available to accomplish a change to flood-compatible land uses. The actual change in land use may occur gradually over time. For example, it may be possible to purchase the lands in fee title or to buy easements that allow flooding (though the easements may be broader in purpose: e.g., conservation easements). It may be more economically viable to continue existing agricultural production in the near-term, for example, with income from such an easement. Alternatively, lands purchased to facilitate creation of a flood corridor may allow farming to continue in the near-term through leasing to farmers, even if the arrangement does not include a commitment to repair or maintain levees. Another approach may be purchase of the lands for conversion to wildlife habitat. Passive

[7] The study is titled *Sonoma Valley Stormwater Management and Groundwater Recharge Scoping Study*.

[8] There is some possibility that elimination or modification of certain existing hydraulic controls and designation of a large portion of the Schellville-area lands as a flood corridor could reduce flooding in certain areas. If the corridor were identified on the west side of the railroad embankment, topographic conditions suggest all or almost all lands between the embankment and Sonoma Creek would need to be included, since they lie below MHHW and Sonoma Creek is actually perched above them.

conversion may be feasible, though active enhancement actions would likely speed the conversion and produce more sustainable habitat and more habitat value within a planning time frame of 50 years.

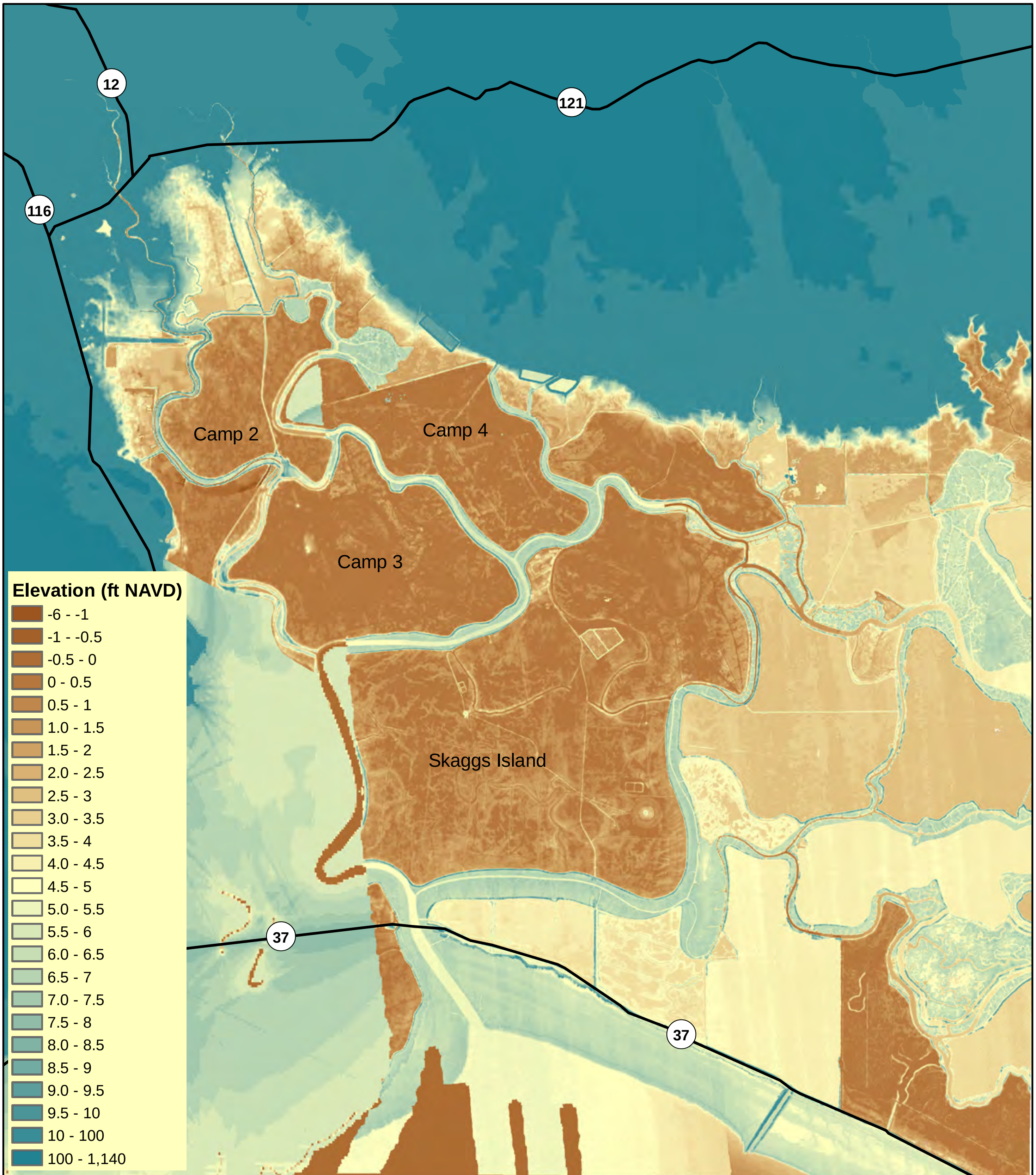
5.3.2.3 Restore Tidal Wetlands

One particular type of flood-compatible land use that could be considered is the restoration of tidal wetlands. Much of the land in and around Schellville would be potentially suitable for this purpose. While our original project alternatives considered restoration of a moderate level of tidal wetland restoration (400 acres), there is no particular rationale for limiting such a restoration initiative in this area. Appendix G provides a brief introduction to tidal wetland restoration design in the San Francisco Bay Area.

A specific opportunity exists to simultaneously address concerns related to sea level rise while creating critical habitat for species of special concern by restoring tidal wetlands, including the California clapper rail; the salt marsh harvest mouse and four rare plants, as well as supporting 11 other imperiled species that do not have formal protection under the federal Endangered Species Act. The baylands of lower Sonoma Creek are former tidal marshlands that could be returned to that habitat through a range of potential restoration actions. Tidal marshes along San Pablo Bay also have tremendous value as buffers between inland land uses and the erosion and flood hazards posed by the bay. With the future anticipated levels of SLR, existing tidal marshes are likely to be inundated. Based on our analysis of SLR scenarios at a moderately high rate of sediment concentrations, we expect baylands in the Lower Sonoma Creek area that are restored to tidal action in the very near term to be able to accrete at a rate that *may* be able to keep pace with SLR. The uncertainties regarding sediment concentrations and rates of SLR create significant uncertainties with respect to marsh accretion rates as well. Potentially-restorable lands that have subsided below MHHW[9] may or may not be capable of naturally evolving to tidal marsh without the addition of outside sources of sediment. Creation of low marsh will be more readily achievable than mid-marsh or high marsh and will be capable of persisting over a longer time frame (e.g., 100 years). See Appendix F for a discussion of our analysis of potential marsh evolution scenarios for Lower Sonoma Creek, which was developed using methods similar to those being applied by PRBO Conservation Science in their current analysis of San Francisco tidal marsh habitats under various climate change scenarios (http://data.prbo.org/apps/sfbslr). Figure 12, Sonoma Creek Bayshore Lands Regional Topography, shows the approximate elevation of lands in and around lower Sonoma Creek based on available data sources;[10] lands shown in brown and light blue are estimated to be below MHHW and therefore conceivably physically appropriate for restoration to tidal marsh lands without excavation. The darker brown areas are more deeply subsided.

[9] Our limited analysis of current tidal datums suggests that MHHW at Wingo is approximately 7.8 ft NAVD88 (see Appendix A1, Table A1-3). Based on the topographic data used in this study, the average land elevation at representative lands in the area (Camp 2 -- 1.0 ft; Camp 3 -- 0.7 ft; Camp 4 -- 0.8 ft, NAVD88 datum), suggests that about 7 feet of sedimentation and/or fill placement will be needed to bring the subsided lands in this area up to the level at which they can function as tidal marshes, as marshplains typically form at about MHHW in and around San Francisco Bay.

[10] There are evident discontinuities in the topographic data, but it is sufficient to approximately identify the general extent of the areas with potential for restoration to tidal marsh.



Topographic data source (resolution): NCALM (1m), IFSAR (5m), Towill (5m), USGS (25m)

figure **12**

Lower Sonoma Creek Flood Management and Ecosystem Enhancement

Sonoma Creek Bayshore Lands
Regional Topography

PWA Ref# - 1844.00

PWA

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Eventually, as a result of SLR, San Pablo Bay and its fringe of tidal marshes will almost certainly continue to move inland and flood out (eliminate) the broad expanses of tidal marsh lands that presently exist or could be restored at its margins. In the meantime, however, such marshes could provide extremely valuable buffering of bay-driven erosion and flooding hazards for inland land uses. In essence, they could buy the community more time in which to address these significant challenges of sea level rise.

A further benefit of restoration of baylands to tidal action is that it will create a significant increase in what is called “tidal prism”: the volume of water that moves in and out with the tides each day. The actual increase in tidal prism will depend in significant part on the acreage of lands reopened to tidal action, the elevation of those lands relative to tidal datums, and the amount of fill that may be added to the restored tidal areas at the outset to speed the restoration trajectory. Still, any increase in tidal prism will increase tidal scour (see Appendix F), leading to an increase in the size of the channels connecting bay tides to the restored tidal wetlands. While the increase in size may have limited effects on fluvial (creek-driven) flooding extents due to the hydraulic control exerted by the downstream tidal boundary, it could significantly change the speed with which inundated lands drain after a fluvial flood event. In addition, the increase in downstream channel size can be expected to trigger some degree of channel enlargement in creek channels upstream; we anticipate these effects to extend upstream to a location near the vicinity of the limit of the tidal hydraulic control. On both Sonoma and Schell Creeks, this location would fall between Railroad Slough at the upstream side of Camp 2 and the Highway 121 Bridge.

Additionally, conversion of lands to tidal marsh will have an effect on levee maintenance. Once restored marshes have developed, it may be possible to reduce or eliminate levee maintenance activities for the levees that have previously protected those lands. In essence, the conversion to tidal marshes could facilitate a “managed retreat” in the face of SLR, allowing society to focus on protecting lands elsewhere—ideally, upstream, lands that we can plan to cost-effectively protect over the very long-term (e.g., much longer than 100 years).

Lastly, tidal marshes can effectively sequester carbon. A market for this service is anticipated to develop in the next decade, which may add a source of revenue or value to any proposed tidal marsh creation initiative.

Given the intended conversion of the adjacent Skaggs Island to tidal wetland, identified habitat restoration needs (see, e.g., California Coastal Conservancy Baylands Ecosystem Habitat Goals, 1999; USFWS Draft Tidal Wetland Recovery Plan, 2010), together with the expected levels of SLR, the benefits of initiating such restoration in the near term, and the number of landowners in the Schellville area with potentially suitable lands, the opportunities associated with this type of project are large and multi-faceted.

5.3.3 Strategy for the Future

Flooding in Schellville is driven by both fluvial and bay conditions. With SLR, the exposure to hazards from San Pablo Bay will increase over time. With extensive new levee systems deemed infeasible, the best solution for reducing flood hazards in the Schellville area is to reduce the amount of investment within the flood zone that is susceptible to flood damages. Actions to reduce fluvial-driven flooding will primarily need to occur in the Sonoma Creek watershed upstream of Schellville. If the Sonoma Creek flood peak can be reduced upstream through attenuation or diversion into storage, peak flows reaching Schellville will also be reduced.

The reduction in peak flow will reduce overbank flows into Schell Creek and across Highway 121. Flood hazard reduction benefits may be accrued as far downstream as Camp 2. In combination with a conversion of most flood-prone lands downstream of Highway 121 to flood-compatible uses, it may be feasible to implement selected improvements, such as elevating or floodproofing buildings or constructing small lengths of levee, to protect any remaining developments within the floodplain from most flood hazards.

As described in Section 5.3.2.3, there are tremendous opportunities to restore valuable tidal wetlands in the Schellville area. Such wetlands are expected to provide the following benefits:

- Habitat for endangered species;
- Buffer zones to protect inland land uses from some of the flooding hazards due to sea level rise (“managed retreat”);
- A means to convert lands to a flood-compatible use, thereby reducing flood hazards;
- Carbon sequestration;
- Promotion of tidal scour, thereby improving channel capacity for drainage; and
- Potential reduction in levee maintenance costs.

If Skaggs Island is eventually restored as tidal marsh, as planned by the USFWS, there is potential to create a significant corridor of restored and enhanced habitat along lower Sonoma Creek that extends from tidal wetlands at Skaggs Island at San Pablo Bay upstream to upland ecotones. Provision of this range of habitats in a continuum will become of increasing importance as San Pablo Bay expands inland in response to SLR.

There are great benefits in restoring tidal marshes along lower Sonoma Creek in the near term instead of waiting for land use changes to be driven by SLR:

- It will be more feasible and less expensive. The sooner tidal connection is restored and the process of marsh accretion initiated, the more likely marshplain will develop and be sustained for an extended period, given SLR.
- There is an opportunity to create a significant amount of mid-marsh. There is expected to be much less mid-marsh than low marsh in the future, and it is valuable for habitat. Additionally, it will likely persist longer than low marsh given SLR. The sooner tidal connection is restored and the process of marsh accretion initiated, the more likely mid-marshplain will develop and be sustained for an extended period, given SLR.

If marshplain does not develop in inundated baylands, these areas will be open water, providing less valuable habitat and no protection against wave-induced erosion or bay-generated flood hazards for inland land uses.

The DISTRICT has been working with individual landowners and the North Bay Agricultural Alliance to determine any interest to sell flood easements or fee lands for restored wetlands. Numerous willing sellers have been identified, but the next steps of conducting appraisals, soliciting funds and negotiating purchase agreements have not been initiated.

To our knowledge there have not yet been any studies of the current major transportation infrastructure investments in the Schellville area downstream of Highway 121, the Northwestern Pacific railroad embankment and Highway 37, which examine potential management of these facilities given SLR. Yet we expect both these facilities to be significantly affected by sea level rise within the next 50 to 100 years. As part of the investigation of potential conversion of land uses and other changes in the Schellville area recommended above, we recommend that a larger initiative be undertaken to accomplish climate change adaptation planning that also includes major infrastructure, such as these two transportation corridors, as well as other infrastructure, such as sanitation district outfalls, etc. There is an opportunity to leverage investments in this region to benefit climate change resilience and achieve flood hazard reduction goals in the Schellville area.

The DISTRICT and other partners are engaged in watershed-wide collaborative effort to establish parameters of a multiple benefit integrated project. Over the past fifteen years the community has come together to work on issues such as the 303(d) listing of Sonoma Creek as an impaired waterbody (sediment, nutrients, pathogens), ground water depletion in the watershed, water storage possibilities, use of recycled water, tidelands restoration, seasonal easements to allow continued agriculture, flooding in both the upper watershed and lower watershed and most recently issues around stormwater.

The on-going collaboration and cohesiveness of the Sonoma Creek community as well as our local Sonoma County Water Agency, Board of Supervisors, Zone 3A Flood Control Zone and other agencies sets the stage for a phased approach that will eventually incorporate all issues and solutions into a project that the entire community could support.

Purchase of wetlands along with a variety of projects in the upper watershed to “slow it, spread it, sink it” can move the Sonoma Creek watershed to a place of self management and resource protection that may enhance safety during flood events, as well as improve water quality and quantity for future generations. These recommendations are consistent with the plans for restoration and habitat conservation of the California Department of Fish and Game, Napa-Sonoma Restoration Committee Project, CalTrans, and the Sonoma County Water Agency.

The question of the appropriate extent of tidal wetland restoration acreage that should be considered in the Schellville area should be fully explored in a broader context than has been done within the current study.

6. ACKNOWLEDGEMENTS

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APPENDICES

LIST OF APPENDICES

APPENDIX A1

INITIAL INVESTIGATION OF PROJECT ALTERNATIVES FOR FLOOD MANAGEMENT AND HABITAT ENHANCEMENT IN SCHELLVILLE, SONOMA COUNTY, CALIFORNIA

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INTRODUCTION

This document describes the analysis of alternatives conducted as part of the Lower Sonoma Creek Flood Management and Ecosystem Enhancement project, conducted in collaboration with the Southern Sonoma County Resource Conservation District for the California Coastal Conservancy and the Sonoma County Water Agency and described in the main body of this report.

1. FORMULATION OF ALTERNATIVES

Two conceptual-level alternatives were developed to address the flood management and habitat enhancement goals of the SSCRCD, Conservancy, and SCWA, which include reducing flood damage in Schellville while increasing ecosystem functions. The main tool used to compare the alternatives was the MIKE FLOOD (MIKE FLOOD) hydrodynamic model of Sonoma and Schell Creeks (as well as the Napa River and Napa-Sonoma Marsh). The model consists of two portions: the one-dimensional, cross-section based MIKE11 model and the two-dimensional, grid-based MIKE21 model. Other tools, including smaller-scale one-dimension hydraulic models and geographic information system analyses, were also used to test the effectiveness of the alternative elements.

1.1 APPROACH

The alternatives were formulated by combining different project elements, including levee construction and shifting, channel widening, floodplain lowering, overflow into Camp 2, connection to Railroad Slough, channels for floodplain overflow, and enhanced tidal scour. The elements were analyzed in different combinations as 'sub-alternatives' and, from these, two final alternatives were selected and presented to the SSCRCD Board of Directors. The analysis focused on hydraulic conditions immediately upstream of Highway 121 to around Wingo. Additionally, this analysis assumed that all upper watershed flows reach Watmaugh Road and that no upstream flow is lost to out-of-bank flooding or flow reduction activities, such as detention in the upper watershed.

1.1.1 Project Elements

The following is a description of each of the project elements that were considered in developing the overall alternatives.

Full Length Wide Floodplain Terrace – This element consisted of excavating a conveyance corridor from Highway 121 downstream to the northwest corner of Camp 2 with the goal of containing large floods below the adjacent ground surface, without levees. The terrace would provide approximately 10 acres of tidal marsh habitat; riparian habitat could be provided on the banks, but the acreage would be minor (less than an acre). For initial evaluation purposes, the corridor dimensions were sized to accommodate the 100-year peak flow based on a simple Manning's equation analysis. From this, it was estimated that at least 5,000 ft^2 of the cross sectional area would be required to convey the 100-year peak flow. The existing channel cross sectional area is approximately 1,000 ft^2, so to add an additional 4,000 ft^2, the floodplain was lowered by approximately four feet for a width of 1,000 feet from the channel. At locations where lowering the floodplain by four feet would result in a elevation less than MHHW (6.29 feet NAVD), the depth of lowering was reduced as it was assumed that a floodplain at an elevation less than MHHW would eventually fill in with sediment from the Bay. The terrace has uniform elevations in the transverse (perpendicular) direction of the proposed flow in the corridor. The slope of the conveyance corridor along the direction of the flow was designed utilizing linear interpolation of the existing channel elevations at the Highway 121 and the near Hauto's Landing. The portion of the active channel lower than the floodplain terrace (the low flow channel) was not adjusted.

Short Narrow Floodplain Terrace – This element is similar to the full length wide floodplain terrace but minimizes the terrace footprint by matching channel dimensions between the widened reach upstream of and through Highway 121 (see element description below) and the channel downstream of the highway with the floodplain terrace. Beginning with the previous element's floodplain terrace dimensions, the terrace widths were reduced until the channel area approximately corresponded with the area of the upstream reach. These widths ranged from approximately 200 to 400 feet. The entire floodplain terrace was set at an elevation of MHHW. The total area of tidal marsh habitat would be approximately 10 acres (7.5 acres on the west side of the creek and 2.5 acres on the east side of the creek).

Highway Protection Levee Spur – For both the Full Length Wide and Short Narrow floodplain terraces, a small levee is included in each element's design. This levee is on the north side of Highway 121 and extends from the bridge at Sonoma Creek northeast along the highway and north along Highway 12 approximately 1250 feet.

Right Bank Levee Shift – This element shifted Sonoma Creek's right levee downstream of Highway 121 from its location adjacent to the creek to the western side of the Short Narrow Floodplain Terrace. This prevented the terrace from intersecting the existing ground surface at an elevation much lower than the existing right levee and thus causing a significant increase in flooding on the western side of Sonoma Creek. (The areas to the west and east of the existing Sonoma Creek channel are lower than the outboard toe of the levees due to Sonoma Creek's historic alluvial fan and to more recent subsidence. (See Figure A1-1 and Figure A1-2.)

Weir Connection Between Sonoma Creek and Railroad Slough – The element includes a hydraulic connection between Sonoma Creek and Railroad Slough through a weir on the left bank of Sonoma Creek downstream of Big Break. The thalweg elevation of the weir was assumed to be equal to MHHW. This link intended to provide conveyance from Sonoma Creek through Railroad Slough to Steamboat Slough during moderately low flow conditions.

Tidal Restoration at Wingo – This element assumed that 400 acres of land would be restored to tidal marsh in the vicinity of Wingo. While the specific location of this restoration was not explicitly identified, there are several possible sites, including portions of Camp 1, Camp 3, Area 7, and Area 8. It was assumed that the increase in tidal prism (the volume of water exchanged in an average tide cycle) from the tidal marsh restoration would scour the channel downstream of the restoration and increase channel cross sectional area. Equilibrium channel dimensions for the reach downstream of the Wingo Bridge and upstream of 2nd Napa Slough were estimated using San Francisco Bay hydraulic geometry relationships

(Williams et al., 2002; PWA and Faber, 2004). These channel dimensions were generally two to four times larger than the existing channel cross sections. It was assumed that the increased channel dimensions resulted in head-cutting upstream of the restoration and that the channel transitioned from the expanded dimensions at Wingo to the existing dimensions at the northwest corner of Camp 2.

Tidal Restoration at Camp 2 – This element assumed that portions of Camp 2 were restored to tidal action and reverted to tidal marsh habitat with the hydraulic connection to Sonoma Creek at the northwest corner of Camp 2. Two scenarios were evaluated: the part of Camp 2 west of the Northwestern Pacific Railroad tracks and 500-foot wide strip in Camp 2 adjacent to Sonoma Creek. This element was later determined to be incompatible with the DFG's management objectives of Camp 2.

Channel Expansion at Highway 121 – This element consisted of expanding the cross section dimensions for locations at, immediately downstream, and for approximately 2,800' upstream of the Highway 121 Bridge. The bottom width of the channel cross sections (from toe to toe) was increased to 130 feet, but the bank side slopes were left at the same angle as current conditions. This width was based on the design drawings for the bridge, which showed that the bridge was designed for a channel with a bottom width of 130 feet, at a maximum (CalTrans, 1971). (It was unclear why the channel was not excavated to this bottom width during the construction of the bridge and the current bottom width of the channel at the bridge is approximately 75 feet wide).

Floodplain Lowering near Sonoma Creek / Fowler Creek – This element lowered the floodplain bench between Sonoma Creek and Fowler Creek by approximately 9.8 feet beginning at the junction of the two creeks and extending upstream for approximately 2,500 feet with the goal increasing floodplain storage.

Camp 2 Flow Bypass – This element included two approximately 1,000 foot long weirs connecting Sonoma Creek to Camp 2 near its northwest corner and near Wingo. The intent of this element was to use the western portion of Camp 2 as both a flood storage basin and a bypass reach to significantly reduce the amount of in-channel flow in Sonoma Creek and thus lower water levels. The weirs were set at an elevation equal to MHHW and, although re-connecting Camp 2 would possibly cause sedimentation in the future, ground elevations for Camp 2 were not adjusted. Currently Camp 2 is well-below MHHW due to subsidence and therefore this element had potential flood reduction benefits from both offline routing of and storage of Sonoma Creek flows. This element was also later determined to be incompatible with the DFG's management objectives of Camp 2.

Schell Creek Overflow Channel – Flows breaking out from Schell Creek upstream of Highway 121 typically flow south between two large white-roofed buildings on the north side of the Sonoma Pacific Co. property and cross Highway 121 on the west side of the large field next to the Mulas dairy. To contain these flows and to estimate what size structure (culvert or bridge) would be required to contain them during a 10-year event, a small channel was dug. The channel extended from upstream of Highway 121 to the downstream end of the field.

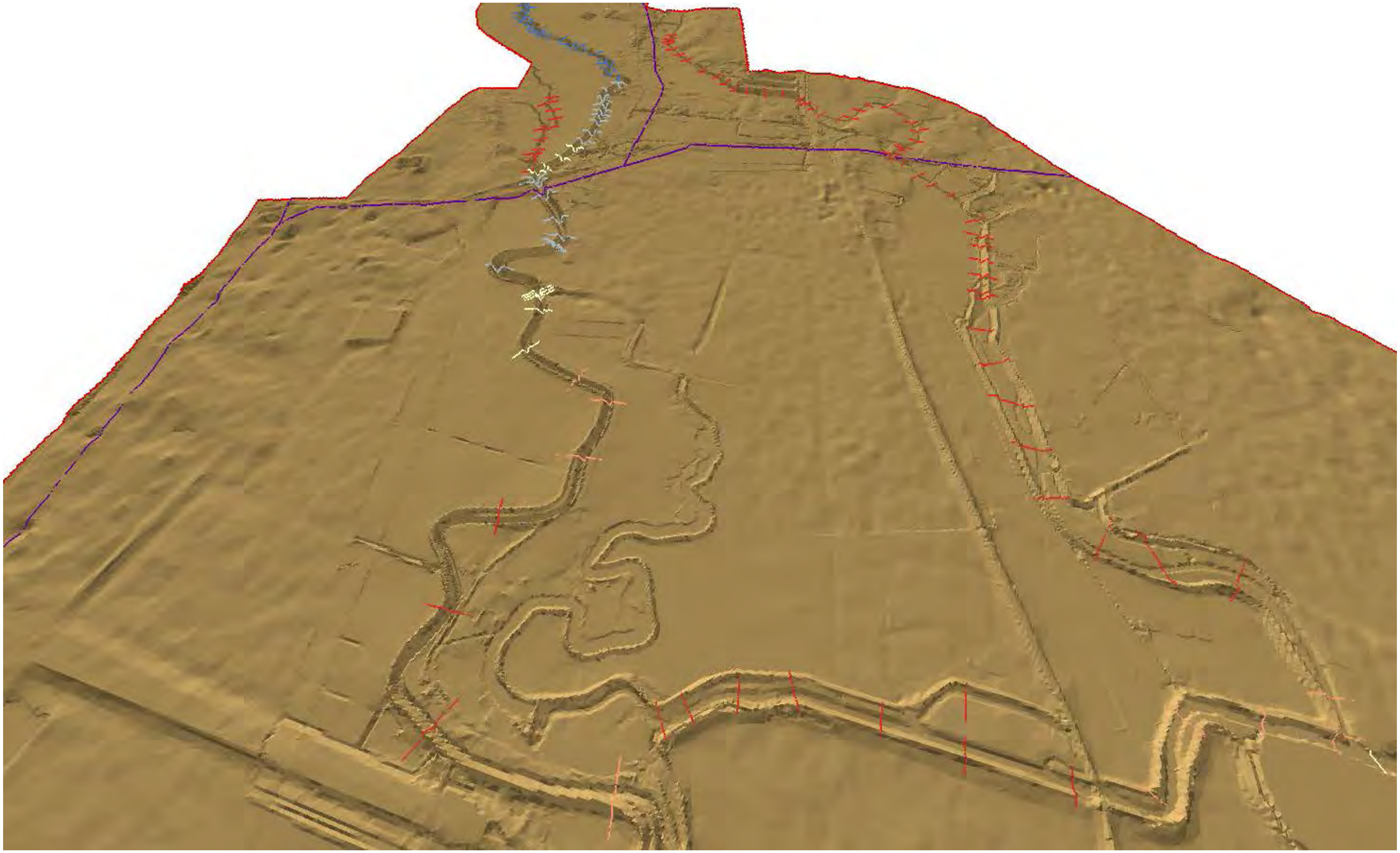

figure ***A1-1***
Lower Sonoma Creek Flood Management and Ecosystem Enhancement

Existing Topography Oblique Map

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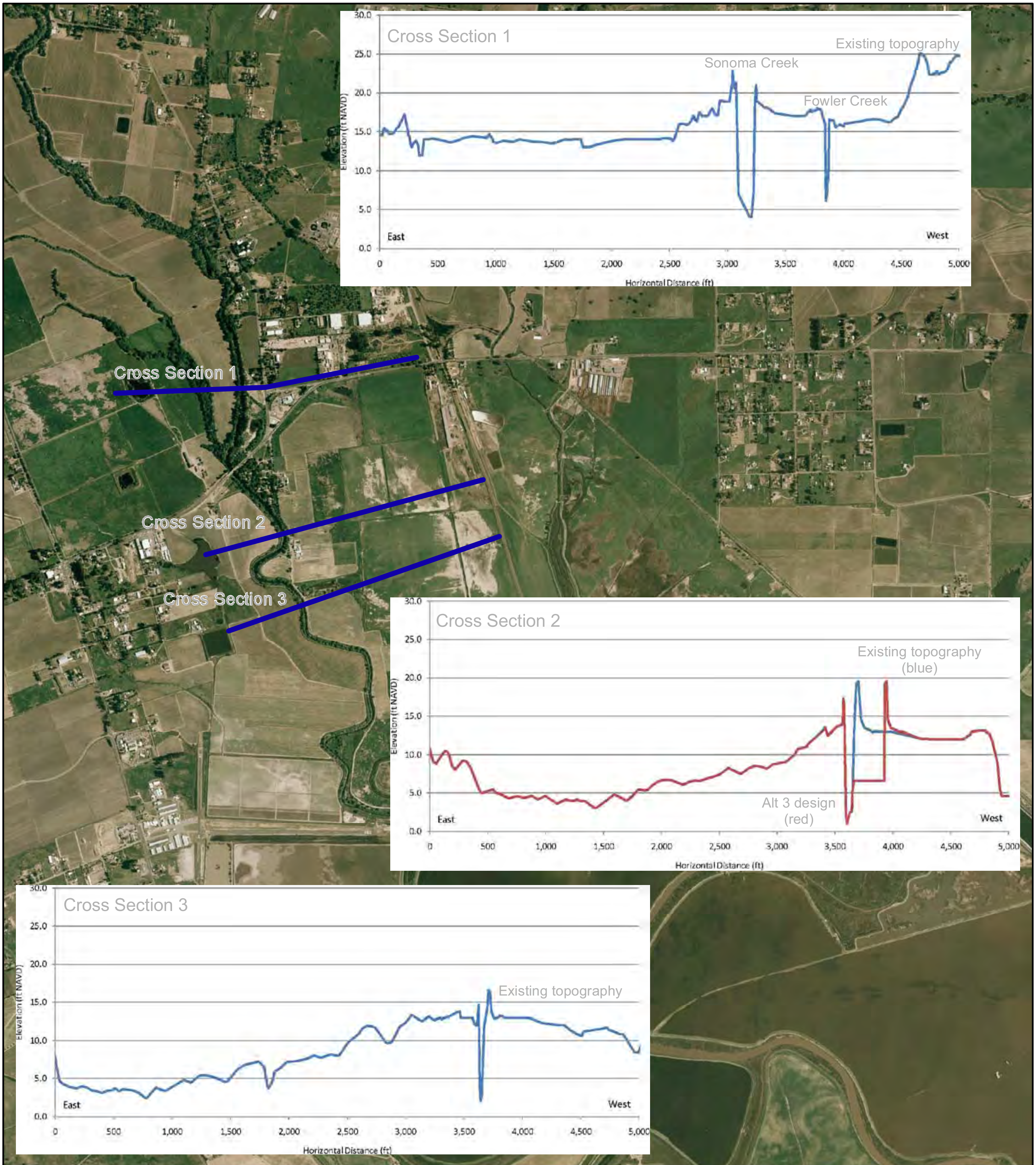

Cross Section Location (Plots facing left to right looking downstream)

figure ***A1-2***

Lower Sonoma Creek Flood Management and Ecosystem Enhancement

Existing Conditions Cross Section Map

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1.1.2 Screening Analysis

Prior to developing the full-scale hydrodynamic model in MIKE FLOOD of these project elements, several simpler screening analyses were conducted to test their potential effectiveness. This was done with smaller-scale hydraulic models and basic hydraulic calculations. This process is described in Appendix C and the results are briefly summarized below.

Floodplain Terraces – While this element would reduce peak water levels and channel overtopping, it most likely could not be enough to contain large flood events without very high levees or becoming a sediment trap. To accommodate large floods with no out-of-bank flooding, the channel dimensions would need to increase by approximately three times for the 10-year event and approximately five times for the 100-year event.

Weir Connection between Sonoma Creek and Railroad Slough – This element only resulted in local stage reductions for minor floods (e.g. 2-year) and caused an increase in water levels in Schell Creek due to an increase in the volume of water transferred from Sonoma Creek through Railroad Slough to Steamboat Slough.

Tidal Restoration at Wingo – Depending on the area of Camp 2 utilized, an increase in channel dimensions due to tidal scour would be approximately 2 to 13 times the existing channel area. This would most likely have a significant effect on water levels.

Channel Expansion at Highway 121 – This element was determined to be essential to providing conveyance through the Highway 121 Bridge and reducing the backwater effects of the bridge and consequential channel overtopping upstream of the highway. The channel near the Highway 121 is more of a constraint than the bridge structure and the channel could be expanded without compromising the bridge.

Camp 2 Flow Bypass – Using Camp 2 as a storage element (not considering flow bypassing) would require most of the area of Camp 2 to achieve a significant reduction in water levels in Sonoma Creek.

1.1.3 Refinement

Based on the results of the screening analyses and initial hydrodynamic model simulations, several elements were eliminated and the remaining elements were combined in multiple iterations as initial alternatives. These initial alternatives were simulated for various design storm conditions using the MIKE FLOOD model and were refined to optimize the effectiveness of each element individually and its ability to act in concert with the other elements. From this, three main groups of alternatives were identified, summarized in Table A1-1 and further described below.

TABLE A1-1
ALTERNATIVE SCENARIOS EVALUATED

Scenario	1A	1B	2A	3A	3B	3C
Description	**Initial Large Project**	**Initial Small Project**	**Refined Large w/Camp 2**	**Highway 121 Focused – Short**	**Highway 121 Focused – Narrow**	**Highway 121 Narrow & Camp 2**
Full-Length Wide Floodplain Terrace	✓		✓			
Short Wide Floodplain Terrace				✓		
Short Narrow Floodplain Terrace					✓	✓
Sonoma Creek / Railroad Slough Weir Connection	✓	✓				
Tidal Restoration at Wingo	✓	✓	✓	✓	✓	✓
Channel Expansion at 121	✓		✓	✓	✓	✓
Floodplain lowering near Sonoma Creek / Fowler Creek	✓		✓			
Camp 2 Flow Bypass			✓			✓
Schell Creek Overflow Channel				✓	✓	✓
Sonoma Creek Right Bank Levee Shift West					✓	✓

As the alternative refinement continued, it became clear that a major flood management accomplishment would be challenging due to the previously-identified constraints (e.g., tidal elevations and lack of support for new levees). On the other hand, habitat enhancement benefits associated with floodplain corridor enlargement and returning former tidal lands back to tidal action were possible in all of the alternatives. Two final alternatives were selected that represent the ‘bookends’ of the initial alternatives: a large, conveyance-focused alternative and a smaller, Highway 121-focused alternative. These alternatives were initially referred to as Scenarios 1A and 3B but are from here forward referred to as Alternative 1 and Alternative 3, respectively.

1.2 ALTERNATIVES IDENTIFIED FOR ANALYSIS

The alternatives identified in the previous section as the bookend scenarios are summarized in Table A1-2 below.

TABLE A1-2
SUMMARY OF ALTERNATIVES

Element	Alternative 1	Alternative 3
Full-Length Wide Floodplain Terrace	✓	
Short Narrow Floodplain Terrace		✓
Highway Protection Levee Spur	✓	✓
Sonoma Creek Right Bank Levee Shift West		✓
Weir Connection Between Sonoma Creek and Railroad Slough	✓	
Tidal Restoration near Wingo	✓	✓
Channel Expansion at Highway 121	✓	✓
Floodplain Lowering near Sonoma Creek / Fowler Creek	✓	
Schell Creek Overflow Channel		✓

2. EVALUATION OF ALTERNATIVES

The following sections describe the goals, elements, and benefits of each of the two selected alternatives, referred to as Alternatives 1 and 3. See the accompanying Appendix D for a brief description of the approaches used to represent the alternatives in the hydrodynamic model.

2.1 ALTERNATIVE 1

2.1.1 Goals

Alternative 1 is a large-scale, conveyance-focused alternative that channels fluvial floodwaters underneath Highway 121, past Millerick Road, and into Sonoma Creek downstream of Camp 2 through channel expansion and a large floodplain terrace. The flood-management objective of this alternative is to eliminate overtopping of Highway 121 during the 10-year event and to significantly reduce highway overtopping for the 100-year event. The second major goal of this alternative is to provide large-scale ecosystem enhancement opportunities via the large floodplain terrace and the tidal restoration near or downstream of Wingo.

2.1.2 Elements

Alternative 1 includes the full length floodplain terrace, the highway protection levee spur, a weir connection from Sonoma Creek to Railroad Slough, tidal restoration at Wingo, channel expansion at Highway 121, and floodplain lowering near Sonoma and Fowler Creeks. The layout of Alternative 1 is shown in Figure A1-3.

2.1.3 Benefits

In general, Alternative 1 achieves the flood management and ecosystem-enhancement goals described above. It does, however, require a large footprint and a significant amount of grading and material removal.

2.2 ALTERNATIVE 3

2.2.1 Goals

Alternative 3 focuses on reducing flood flows from impacting Highway 121 during events less than the 10-year flow with the minimum amount of project footprint. Similar to Alternative 1, the second major goal of this alternative is to provide significant ecosystem enhancement opportunities by restoring approximately 400 acres of land to tidal marsh habitat.

figure **A1-3**

Lower Sonoma Creek Flood Management and Ecosystem Enhancement

Alternative 1 Schematic Layout

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2.2.2 Elements

Alternative 3 includes the short narrow floodplain terrace, tidal restoration at Wingo, highway protection levee spur, right bank levee shift, channel expansion at Highway 121, and the Schell Creek overflow channel. The layout of Alternative 3 is shown in Figure A1-4.

2.2.3 Benefits

Results from the Alternative 3 MIKE FLOOD model indicate that for the 10-year fluvial flood event, water from Sonoma Creek no longer crosses the Highway east of the creek (a small amount of water spills out of the creek but is contained by the levee described above). The area east of Sonoma Creek and south of Highway 121 still floods under the alternative due to overtopping at Big Break. Some of this water is routed north due to the very low ground surface elevations in this vicinity. Flooding is greatly reduced on the west side of Sonoma Creek adjacent to Camp 2 and south of the airport, and on the east side of Schell and Steamboat Sloughs. Peak water surface elevations are reduced in Sonoma and Schell Creeks during the 10-year fluvial flood event.

figure ***A1-4***

Lower Sonoma Creek Flood Management and Ecosystem Enhancement

Alternative 3 Schematic Layout

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3. NO ACTION ALTERNATIVE

3.1 DESCRIPTION

Under the No Action alternative, no changes to lower Sonoma or Schell Creeks, or the levee systems that constrain them, will be made. No new undercrossing of Highway 121 will be constructed for floodwaters, and no tidal wetland restoration along the lower reaches of these creeks will be undertaken. Current land management practices will continue.

3.2 PROJECT OUTCOMES

Under the No Action Alternative, flooding from fluvial events will continue and worsen over time as Sea Level Rise causes tidal boundary conditions to rise and associated geomorphic change unfolds. Existing diked or leveed areas will be exposed to greater risk of erosion and overtopping over time. (See Appendix E for a description of the expected response to SLR.) The reaction to these conditions may be reinforcement and raising of levees in place, or the gradual conversion of these lands to open water or tidal marsh.

3.2.1 Floodplain Inundation Extents

The MIKE FLOOD model was used to map the floodplain inundation extents for the 2-, 10-, 25-, and 100-year design storm events. These are shown in Figure A1-5. A description of the hydrodynamic model used to produce these results is in Appendix A2.[1]

3.2.2 Effects of Sea Level Rise

The MIKE FLOOD model was also used to map the floodplain inundation extents for the 2-, 10-, 25-, and 100-year design storm events with both “medium” (1.81 ft) and “high” (5.54 ft) sea level rise assumptions. These are shown in Figure A1-6 and Figure A1-7.

To assess the relative influence of the tides on peak water levels during small runoff events, the hydrodynamic model was used to calculate tidal datums along the entire tidally-driven reaches of Sonoma and Schell Creeks and 2nd Napa, 3rd Napa, and Steamboat Sloughs. This was done under a flood scenario of a constant flow rate equal to the 2-year flow using water level data for the entire month of July 2001 with no SLR and with “medium” and “high” SLR. The results of this analysis are shown in Figure 5 through Figure 10 of the main report in this volume and are also presented for three locations on Sonoma Creek in Table A1-3 below. The values for MHHW may not accurately predict future conditions due to possible morphological changes in the bathymetry of the bay and channels that will occur as a result of SLR.

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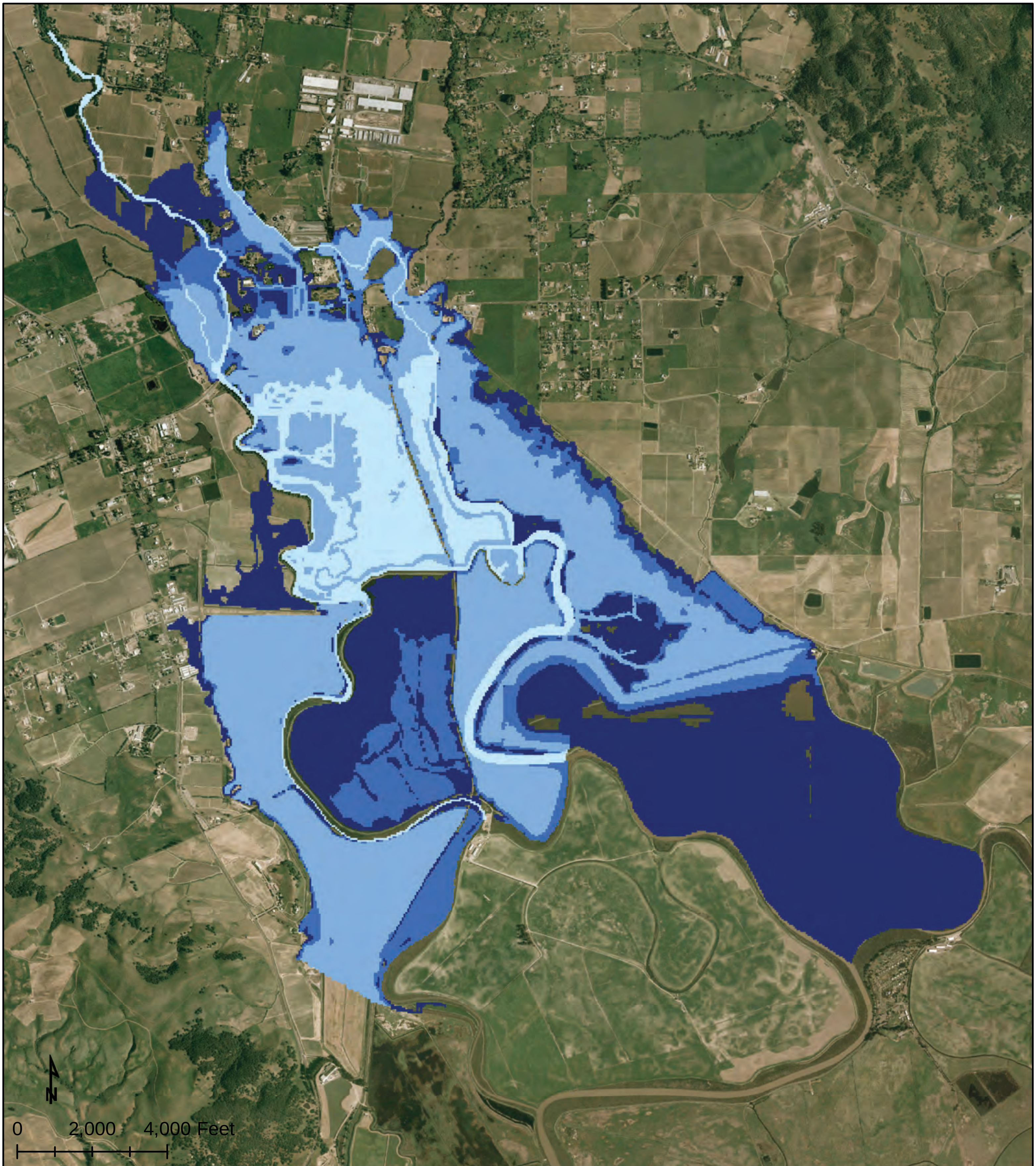
[1] It should be noted that further model refinements have been made since the flood inundation extents shown in Appendix A2; what is presented there is superseded by results presented in this appendix.



Existing Conditions 2-yr Flood Inundation Extent
Existing Conditions 10-yr Flood Inundation Extent
Existing Conditions 25-yr Flood Inundation Extent
Existing Conditions 100-yr Flood Inundation Extent

figure ***A1-5***

Lower Sonoma Creek Flood Management and Ecosystem Enhancement

Existing Condition Inundation Extents for the 2-, 10-, 25-, and 100-Year Design Storm Events

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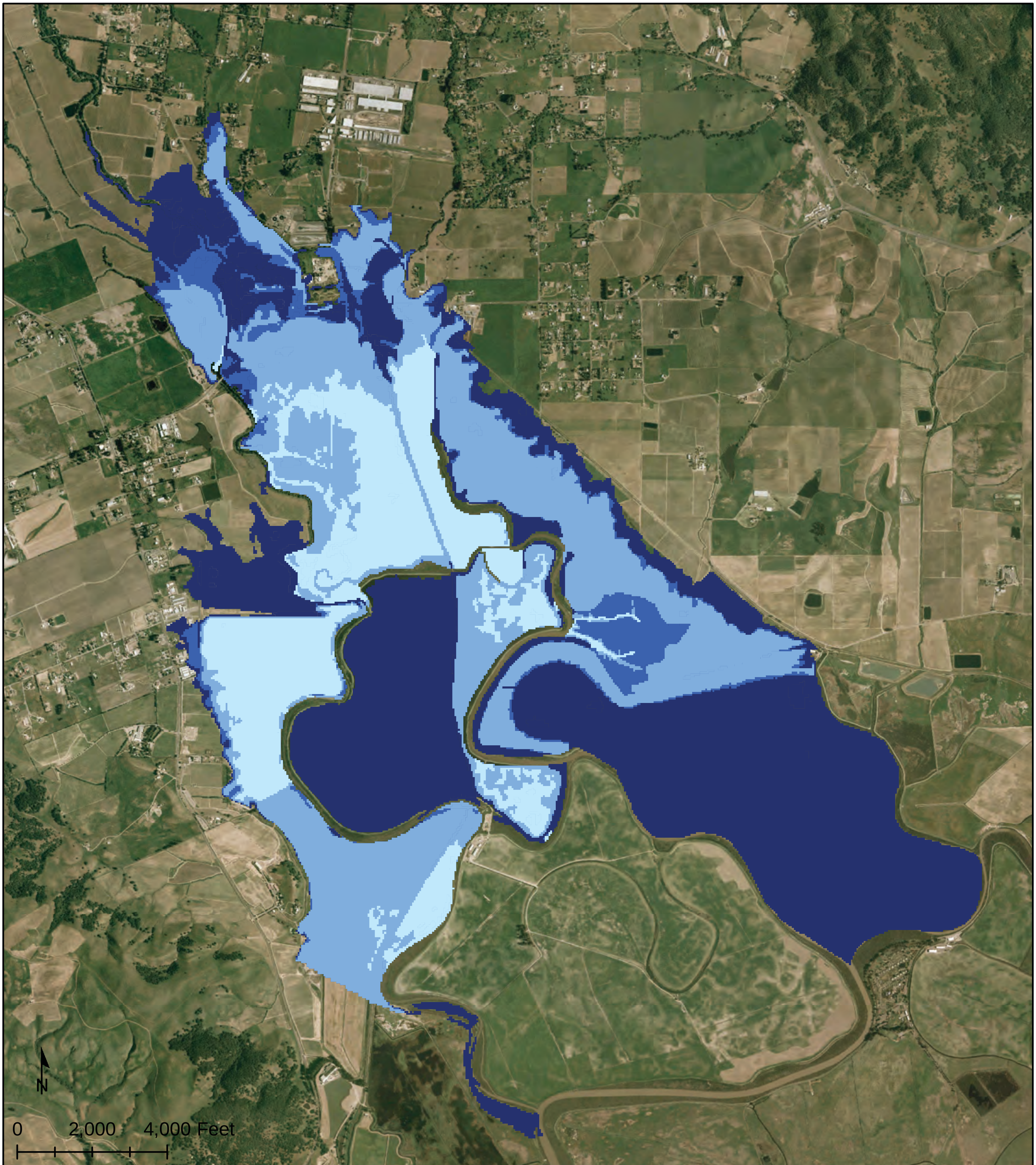

Existing Conditions 2-yr Flood Inundation Extent with Medium SLR

Existing Conditions 10-yr Flood Inundation Extent with Medium SLR

Existing Conditions 25-yr Flood Inundation Extent with Medium SLR

Existing Conditions 100-yr Flood Inundation Extent with Medium SLR

figure **A1-6**

Lower Sonoma Creek Flood Management and Ecosystem Enhancement

Existing Condition Inundation Extents for the 2-, 10-, 25-, and 100-Year Design Storm Events Under Medium SLR

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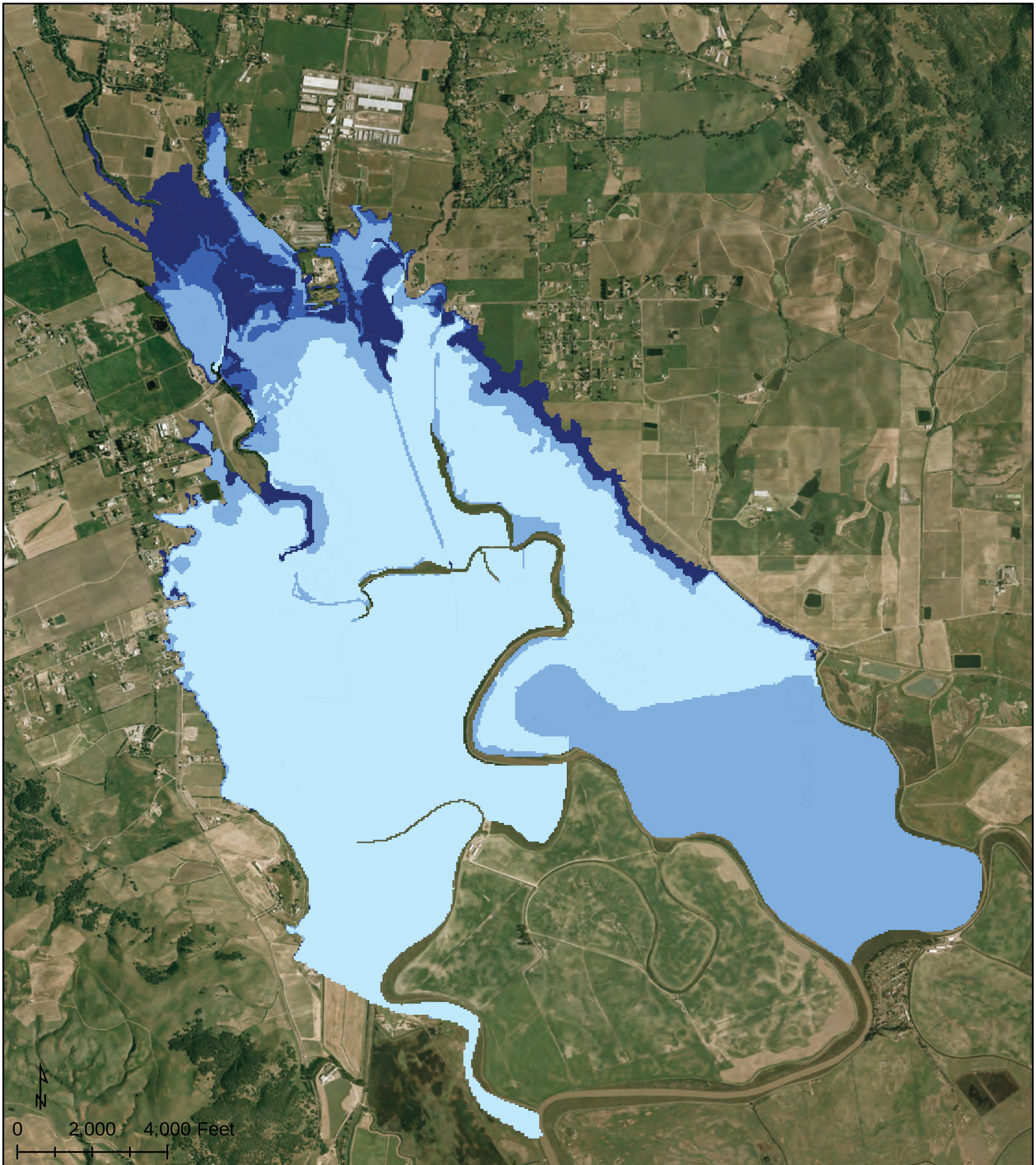

Existing Conditions 2-yr Flood Inundation Extent with High SLR
Existing Conditions 10-yr Flood Inundation Extent with High SLR
Existing Conditions 25-yr Flood Inundation Extent with High SLR
Existing Conditions 100-yr Flood Inundation Extent with High SLR

figure ***A1-7***

Lower Sonoma Creek Flood Management and Ecosystem Enhancement

Existing Condition Inundation Extents for the 2-, 10-, 25-, and 100-Year Design Storm Events Under High SLR

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TABLE A1- 3
CALCULATED TIDAL DATUMS UNDER A CONSTANT 2-YEAR FLOW SCENARIO FOR EXISTING, MEDIUM AND HIGH SLR CONDITIONS (ELEVATIONS IN FT NAVD88)

Location	SLR Scenario[1]	MHHW	MTL	MLLW
Sonoma Creek at NW corner of Camp 2				
	None (existing)	10.40	10.39	10.38
	Medium SLR	10.44	10.40	10.38
	High SLR	11.39	10.80	10.57
Sonoma Creek at Wingo Bridge				
	None (existing)	7.78	7.51	7.35
	Medium SLR	8.42	7.80	7.38
	High SLR	11.09	9.98	9.32
Sonoma Creek at San Pablo Bay				
	None (existing)[2]	5.86	3.07	0.08
	Medium SLR	7.50	4.71	1.72
	High SLR	11.38	8.55	5.62

[1] "Low" SLR scenario not modeled for tidal datums.

[2] Note that values in this row are different than those shown in Table 2 in the main document for several reasons, with the most significant being the relatively short time period modeled compared to the time period used to establish tidal datums at the gauge.

Table A1-3 shows that under existing and "medium" SLR conditions, there is negligible tidal action at the northwest corner of Camp 2 (just downstream of Hauto's Landing) under minor flood conditions. Under "high" SLR conditions, however, there is a significant variation between MHHW and MLLW, indicating that water level conditions in San Pablo Bay will have a greater effect on flooding potential farther upstream in Sonoma and Schell Creeks. At this location, a SLR value of 5.54 feet in San Pablo Bay translates only to a 1-foot increase in MHHW during a 2-year flood event, most likely because of the fluvial flood effectively "pushing" the tides toward the Bay.

For each SLR scenario, land elevations that were less than MHHW given SLR were mapped and compared to the existing extent of land area with elevations less than MHHW. Figure 11 in the accompanying main report compares these extents. With the "low" and "medium" SLR scenarios, the areas mapped were slightly greater but relatively similar to existing conditions. The "high" SLR scenario has a much greater footprint of area lying below MHHW, which crosses to the north side of Highway 121 at and immediately to the east of the Schell Creek crossing and approaches Highway 121 directly across from the Sonoma Pacific Company property.

3.2.3 Future Hydrologic Conditions and Climate Change

In addition to increasing sea levels, climate change will affect precipitation patterns and temperatures, and, subsequently, stream runoff peaks and volumes. The California Resources Agency (2009) expects that by 2050, temperatures will increase by between 2 and 5 degrees and precipitation will decrease in depth by 12 to 35%. Additionally, the intensity and frequency of extreme weather events is also changing

(CNRA, 2009). It is unclear how climate change will affect the Sonoma Creek watershed specifically, but if it follows the estimated trends for California, the watershed will most likely experience higher temperatures and evaporation, as well as reduced rainfall and runoff.

3.2.4 Future Geomorphic Conditions

As a result of SLR, the low-lying land areas of lower Sonoma Creek, those lands currently below MHHW, or baylands, are expected to change dramatically in the future. Over time, existing diked or leveed areas will become exposed to greater risk of erosion and overtopping as sea levels rise and resulting wave energy reaching the levees grows. SLR will likely occur as gradual change punctuated by episodic, dramatic increases in tide elevations. These dramatic increases are likely to trigger levee overtopping and breaching along the lower Sonoma Creek system. Since most areas protected by levees are subsided, lands exposed to flooding by levee breaches will suddenly be converted to relatively deep open water areas, increasing the hazards of wave-induced erosion at their margins. Because the former tidelands are significantly subsided, our analysis suggests that they are unlikely to convert to tidal marsh over time if no additional fill material is provided (see Appendix F for further discussion of our analysis of the potential for tidal marsh creation through natural sedimentation processes under various SLR scenarios).

The reaction to these conditions may be reinforcement and raising of levees in place, or the conversion of these lands to open water.

See Appendix E for a discussion of our conceptual model of shoreline response to SLR.

4. PREFERRED ALTERNATIVE

After reviewing the screening analyses and initial modeling results, the SSCRCD and local landowners and agency partners initially considered, and then rejected, Alternative 3 as the preferred project alternative. This section first describes Alternative 3 and then provides the rationale for its rejection.

4.1 DESCRIPTION

As previously described, the alternative initially selected as preferred, Alternative 3, focuses on reducing flood flows from impacting Highway 121 during events less than the 10-year flow with the minimum amount of project footprint. The second major goal of this alternative is to provide significant ecosystem-enhancement opportunities by restoring approximately 400 acres of land to tidal marsh habitat.

The design elements included in Alternative 3 are shown in Table A1-2 and illustrated in Figure A1-4. The area of the conveyance and habitat enhancement corridor is approximately 10 acres and is at an elevation of MHHW. Downstream of Wingo, the channel was expanded using empirical relationships between marsh area and channel dimensions based on the assumed 400 acres of tidal wetland restoration. Upstream of Highway 121, the channel was enlarged based on the original Highway 121 bridge design plans that suggest the bridge was originally designed to accommodate a 130-foot channel bottom width. The overflow channel collects flows spilling out of Schell Creek that, under existing conditions, cross the highway in several locations, and routes them underneath the highway through a culvert or small bridge. To avoid flood flows from spilling over the west (right) bank of Sonoma Creek downstream of the highway, this scenario also includes shifting the western levee from its current location to the western edge of the conveyance corridor. Additionally, this alternative includes a short levee extending east from Sonoma Creek just north of Highway 121 and curving north to follow Highway 12.

4.2 PROJECT OUTCOMES

4.2.1 Floodplain Inundation Extents

The design storm floodplain inundation extents for Alternative 3 in a 2- and 10-year flood event under current sea level conditions are shown in Figure A1-8. No significant changes in floodplain extents are expected in larger storm events.

4.2.2 Effects of Sea Level Rise

The 2- and 10-year design storm floodplain inundation extents for Alternative 3 for “medium” ” (1.81 ft) and “high” (5.54 ft) sea level rise scenarios are shown in Figure A1-9 and Figure A1-10.

4.2.3 Future Hydrologic Conditions and Climate Change

Similar to the No Action alternative, climate change will affect runoff volumes, peaks, and patterns in the Sonoma Creek watershed under Alternative 3 in ways that are not well understood or quantifiable. We have not made any attempt to evaluate this alternative under future hydrologic conditions resulting from climate change-induced impacts besides sea level rise.

Alt3B 2-yr Flood Inundation Extent

Alt3B 10-yr Flood Inundation Extent

figure ***A1-8***

Lower Sonoma Creek Flood Management and Ecosystem Enhancement

Alternative 3 Inundation Extents for the 2-, 10-, 25-, and 100-Year Design Storm Events

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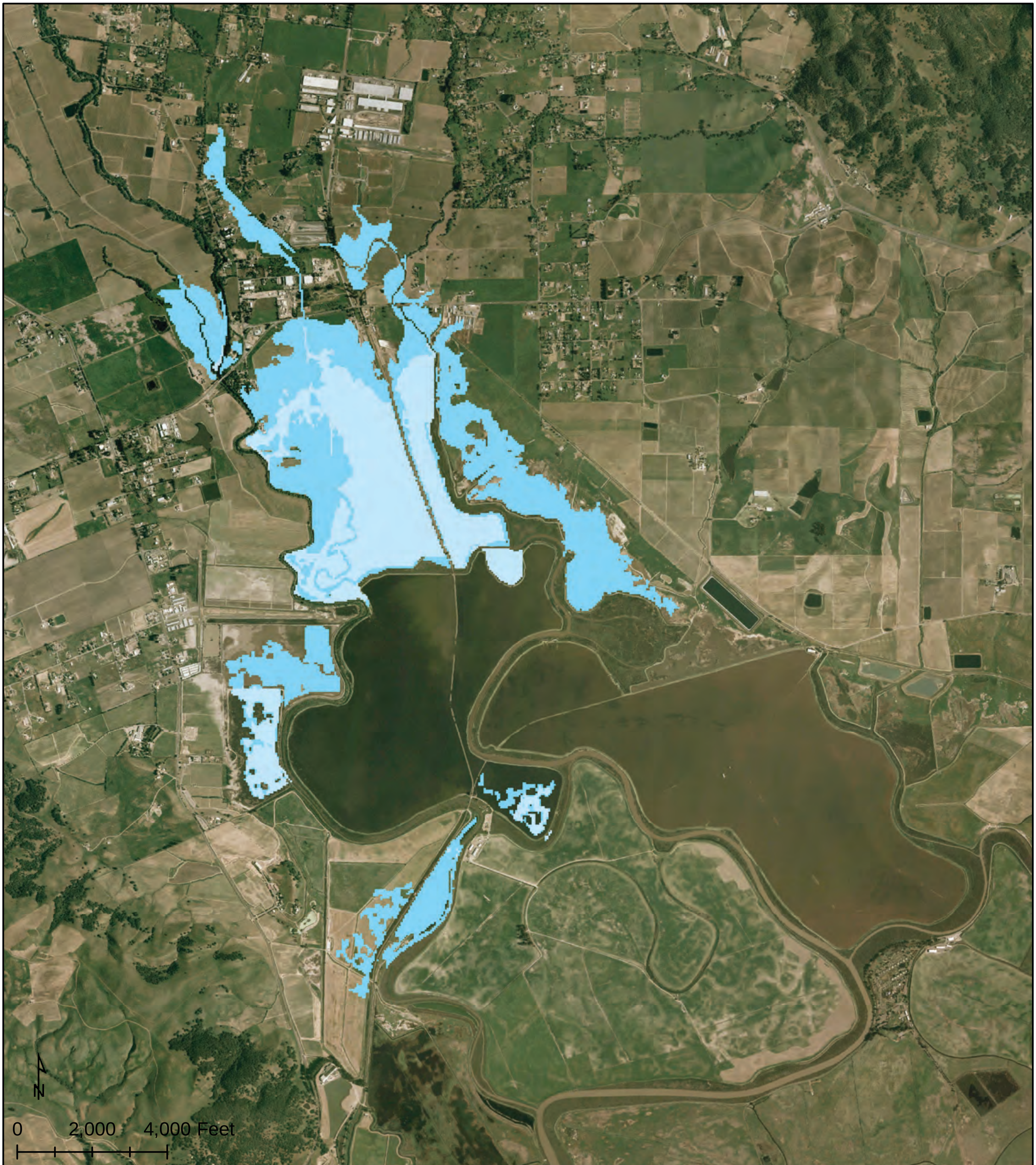

Alt3B 2-yr Flood Inundation Extent with Medium SLR

Alt3B 10-yr Flood Inundation Extent with Medium SLR

figure ***A1-9***

Lower Sonoma Creek Flood Management and Ecosystem Enhancement

Alternative 3 Inundation Extents for the 2- and 10-Year Design Storm Events Under Medium SLR

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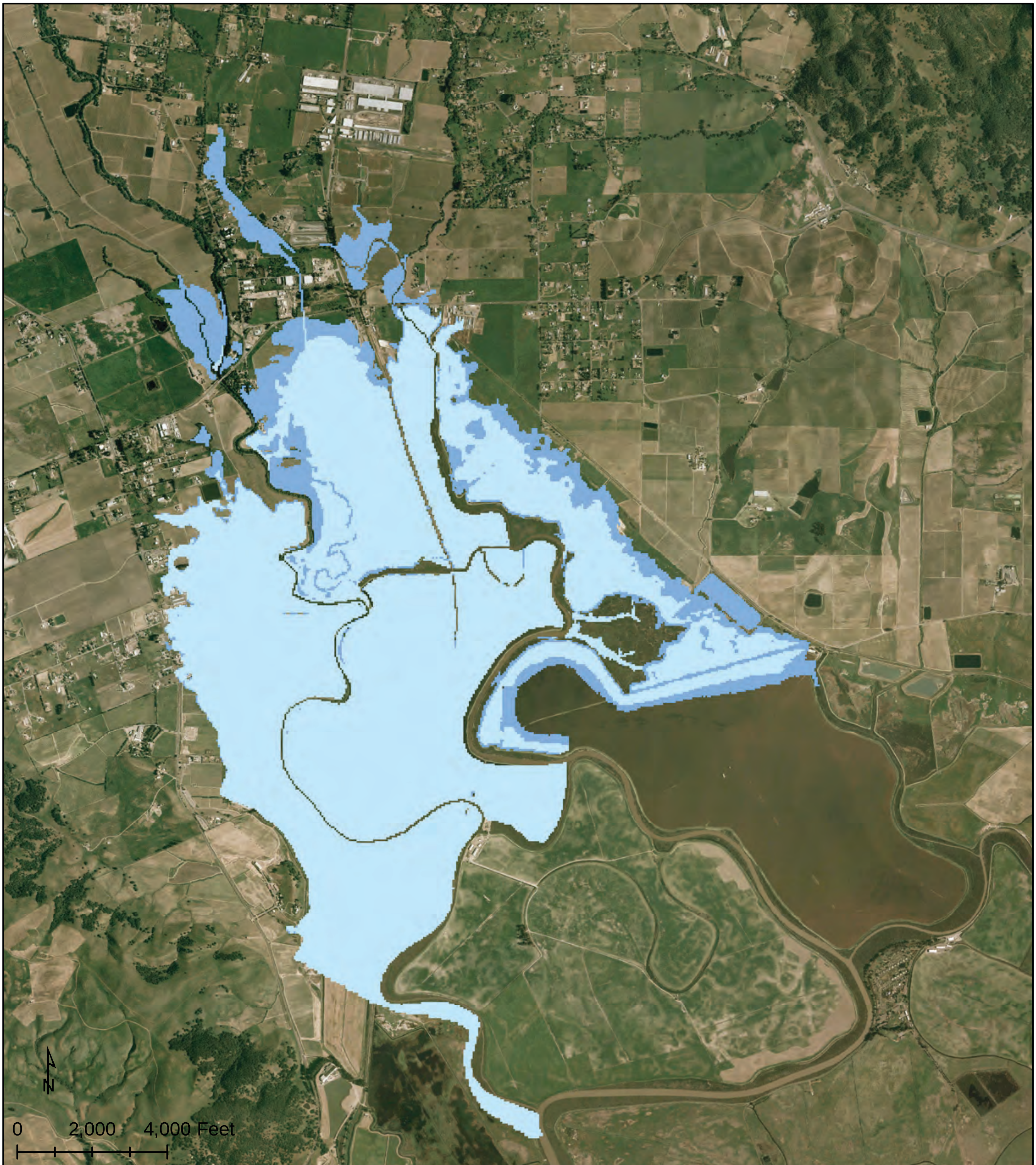

Alt3B 2-yr Flood Inundation Extent with High SLR

Alt3B 10-yr Flood Inundation Extent with High SLR

figure ***A1-10***

Lower Sonoma Creek Flood Management and Ecosystem Enhancement

Alternative 3 Inundation Extents for the 2- and 10-Year Design Storm Events Under High SLR

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4.3 GEOMORPHIC CONSIDERATIONS

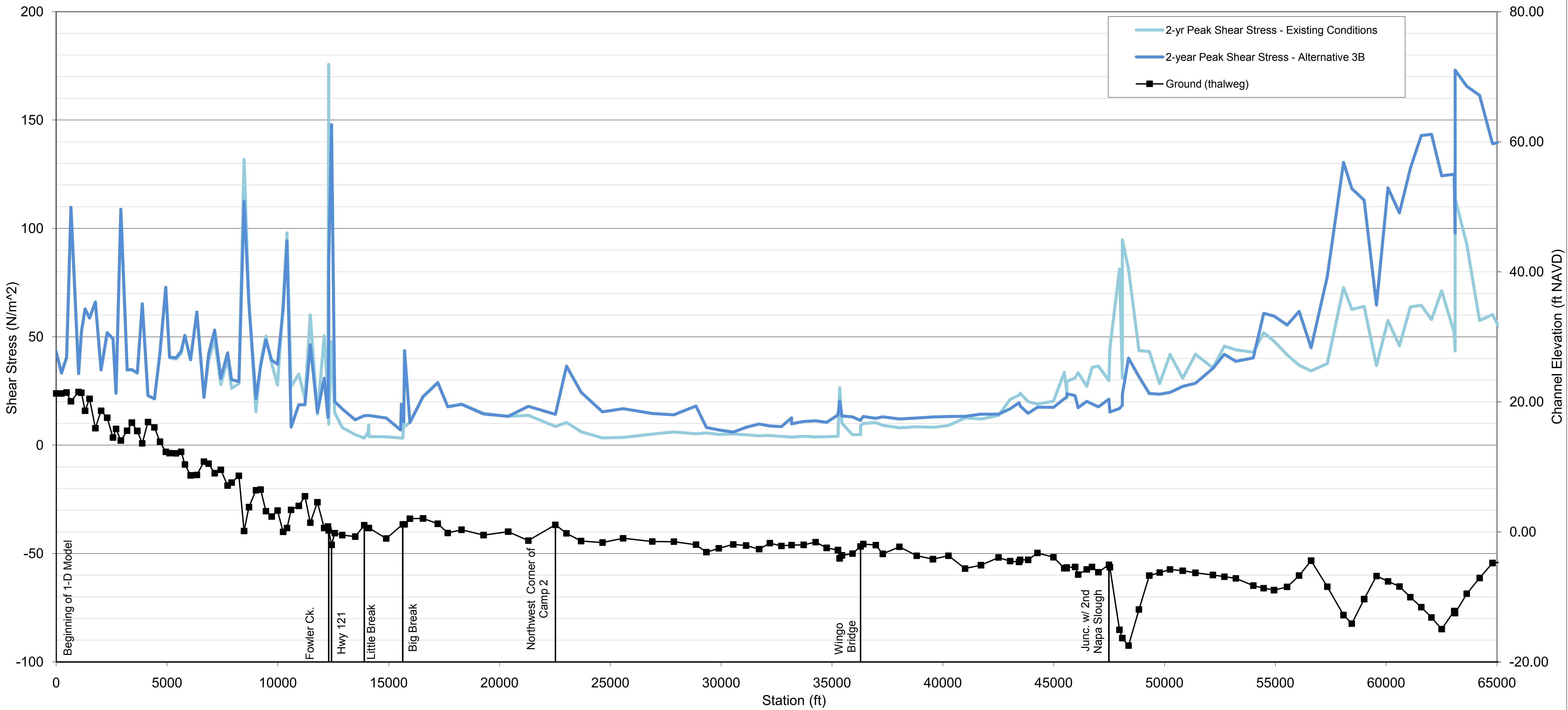
Geomorphic effects are project outcomes related to changes in channel shape or physical characteristics that are induced by changes in physical processes caused by the project. These outcomes are characterized below.

4.3.1 Shear Stress and Erosion Potential

Alternative 3 will produce significant changes in the quantity and hydraulic characteristics of flow that will pass through the Sonoma Creek corridor. Under this alternative, the channel corridor will have increased ability to convey flow, and more flow will be directed through it. These changes will occur through four mechanisms:

1. Direct enlargement of the Sonoma Creek channel through excavation of a channel terrace in the vicinity of Highway 121;
2. Direct reduction in overbank flows escaping to the east upstream of Highway 121 by means of a short length of engineered levee upstream of Highway 121, and therefore the routing of additional water down Sonoma Creek; and
3. Generation of additional tidal scour through the creation of the excavated floodplain terrace together with reconnection of 400 acres of tidal marsh to Sonoma Creek, thereby enlarging the lower Sonoma Creek channel; and
4. Incidental Sonoma Creek channel enlargement through increased scour: mechanisms 1 through 3 above will induce more water to pass through lower Sonoma Creek -- and less through lower Schell Creek, thereby increasing the overall shear stress and erosion potential in the channel.

Under Alternative 3, sediment transport dynamics would evolve over time as the channel adjusted to the new hydrologic and hydraulic conditions triggered by the initial project construction. Shear stresses for Alternative 3 have been evaluated as an indicator of the level of sediment transport, as transport for a given particle size typically increases when shear stresses increase. Shear stresses for Alternative 3 have been evaluated for simulated conditions: the constructed modified channel cross section and levee features, together with the long-term assumptions for equilibrium conditions in the tidal channels. The results of this analysis are presented graphically in Figure A1-11. Under Alternative 3, shear stresses (and sediment transport) would be reduced upstream of Highway 121 due to the channel enlargement, and increased downstream nearly to 3rd Napa Slough, as a result of tidal scour-driven channel enlargement and more flow being routed through that system. A detailed analysis of the evolution of sediment dynamics that would result from the interplay of the initial construction assumptions has not been conducted.



Source: MIKE Flood model
Notes: Model results for Existing Conditions and Alternative 3B with 400 and 1000 acres of tidal restoration
Scenario 3B - Highway 121-focused with Narrow Terrace

figure ***A1-11***

Lower Sonoma Creek Flood Management and Ecosystem Enhancement

2-Year Peak Shear Stress for Existing Conditions and Alternative 3

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Options associated with the reconnection and restoration of tidal marsh could have a significant effect on the evolution of the Sonoma Creek channel. For example, the channel downstream of the marsh connection could be partially excavated at the outset of the project. Excavated material or even material from other sources could be placed within the restored marsh area to accelerate the creation of marshplain, tidelands able to support planted or naturally recruited vegetation. This would reduce the size of the initial tidal prism that would be created by the project, and therefore reduce the magnitude of the initial scouring flows that would be experienced. Alternatively, the cost of this excavation and placement of material could be avoided by letting the reconnected marsh area fill with tidally-delivered deposits naturally, though the amount of material delivered would be limited until the downstream tidal channel scoured as a result of the increased tidal prism, which could take years. These details of the marsh habitat design will need to be developed during a feasibility or preliminary design phase.

4.3.2 Hydraulic Geometry Calculations

ESA PWA evaluated the potential for tidal wetland restoration to enlarge the Sonoma Creek channel through the tidal flushing that would be associated with a larger tidal prism. To estimate equilibrium channel dimensions for various restoration scenarios, we applied empirical hydraulic geometry equations, which relate marshplain area or tidal prism with channel depth, width, and cross sectional area. We assumed theoretical restoration acreage of 400 acres in the vicinity of Wingo, with the connection to existing channels at the west end of Wingo Slough downstream of Camp 2.

The following assumptions were made in the hydraulic geometry analysis:

1. Equilibrium channels are approximately parabolic in shape, with the channel banks and marshplain at the elevation of mean higher high water (MHHW), or 6.3 ft NAVD88.
2. Channel scour occurs downstream from the connection between the restored area and the Sonoma Creek channel.
3. Upstream of the connection location, there will be a transition from existing channel dimensions to equilibrium (scoured) dimensions extending upstream to approximately the location of Railroad Slough.
4. Assumed no effect from fluvial flows.

A 400-acre tidal wetland restoration element connected on the west side of Wingo is estimated to increase channel capacity downstream of the connection by approximately 8 times for a typical cross section. It should be noted that much of the expanded channel cross section lies below the mean tide level, reducing its effectiveness for conveying fluvial flood flows. The results of the hydraulic geometry analysis are more completely presented in Appendix F.

4.4 BASIS FOR REJECTION OF ALTERNATIVE 3

In discussions with stakeholders, the SSCRCD determined that the flood management accomplishments of Alternative 3, reduction in flooding across Highway 121/12 during minor flood events, was not of sufficient perceived value to warrant further investigation or development. Without reductions in the magnitude of flood flows reaching lower Sonoma Creek, significant measures are required to accomplish even limited and localized flood hazard reduction benefits such as these. In addition, it became clear during discussions with stakeholders that solutions for landowners downstream of Highway 121 was the primary flood issue of concern within the study area. Most of these lands are reclaimed former tidelands. Without new levees, it is not possible to significantly improve the protection of existing land uses in former tidelands during even minor flood events due to the influence of tide levels in San Pablo Bay. Thus, a solution set to protect existing land uses downstream of Highway 121 does not exist if extensive new levee systems are excluded.

APPENDIX A2

HYDRAULIC MODEL DEVELOPMENT REPORT
April 30, 2008

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SONOMA CREEK FLOOD MANAGEMENT AND ENHANCEMENT PROJECT
Hydraulic Model Development

Interim (Partial) Deliverable
Task 2.1 – Hydraulic Modeling

Prepared for

Southern Sonoma County RCD

Prepared by

Philip Williams & Associates, Ltd.

June 30, 2008

PWA Ref. # 1844.01-int

Services provided pursuant to this Agreement are intended solely for the use and benefit of the Southern Sonoma County RCD.

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1. INTRODUCTION AND PROJECT DESCRIPTION

As part of the flood management and ecological enhancement project for Lower Sonoma Creek, PWA created a 1D/2D MIKE FLOOD model that will include the project area from about 2.5 miles upstream of Highway 121 to San Pablo Bay along Sonoma Creek and also an area eastward to include the adjacent Napa Salt Ponds and related channels. In addition to including the latest topographic information, the model also included the most recent hydrologic and other boundary condition data. This memo describes the model development up through existing conditions, to include hydrodynamic verification, and prior to any alternatives analysis.

1.1 PROJECT DESCRIPTION

The Sonoma Creek Flood Management and Enhancement Project is being undertaken to address flooding issues and ecosystem enhancement opportunities in the Schellville area. As presently conceived, this project would alleviate flooding at the fire station, improve road access during flood events, and reduce flood-related damage to structures, roads, the railroad tracks, and crops. The project design will incorporate habitat restoration and enhancement strategies and elements to improve ecological functions in the region.

The specific boundaries of the project area generally lie within the reach of Sonoma Creek south of Watmaugh Road.

The project may include such elements as reconfigured levees, new designated flow areas, modified channels, detention areas and maintenance strategies, as well as habitat features such as new and/or enhanced freshwater and tidal wetlands and a restored floodplain and riparian corridor.

Conceptual design and environmental review of the proposed project is expected to be completed by the end of 2010.

No specific level of protection or project cost has been identified as a criterion for the project or the development of the conceptual design. Designs that might represent different levels of flood hazard reduction and habitat enhancement, different areas of protection, or different approaches to providing protection must be constrained within the level of effort supported by current funding for conceptual design.

2. MODEL DEVELOPMENT

For this project, PWA used, as a basis for the current model development, the 1D/2D MIKE FLOOD (MF) model that we, with the support of DHI Water and Environment (DHI), initially developed for the Napa-Sonoma Marsh Restoration (NSMR) project for the US Army Corps of Engineers (USACE) and the California State Coastal Conservancy (SCC) (PWA, 2002a; PWA, 2002b). The MF model, reflective of the planning stages for NSMR Ponds 3, 4, and 5 (PWA, 2002b), has since been provided to and modified by URS Corporation (URS) to support their design of NSMR Ponds 6, 7, and 8 for the SCC. Modifications by URS to the MF model included updating the model for as-built conditions for other NSMR components and converting the 2D ponds to 1D stage-storage elements. The MF model was updated by URS for breaches at Ponds 3, 4 and 5 per the technical drawings (PWA, 2005), but not so for the breaches labeled “by others (NIC)” and the levee lowering (the breach excavation and levee lowering occurred in 2006 and the breach excavation by others occurred in 2007). The MF model was modified by URS by converting Ponds 3, 4, and 5 from 2D to 1D to significantly reduce run times and including Ponds 6, 7, and 8 in 1D. URS subsequently provided PWA with a version of the MF model sufficient to meet their 50% design for Ponds 6, 7 and 8 (URS et al., 2007).

2.1 MODEL DOMAIN

Figure 1 shows the extent of the current MF model. From the NSMR project, the MF model included the following 1D channels (PWA, 2002a):

- Napa River from Oak Knoll Ave. to the confluence of Mare Island Strait with Carquinez Strait;
- Sonoma Creek from the Highway 121 Bridge to its outlet at San Pablo Bay;
- All major tidal slough channels between the Napa River and Sonoma Creek:
    - Napa Slough;
    - Dutchman Slough;
    - South Slough;
    - China Slough;
    - Devils Slough;
    - Mud Slough;
    - Napa Slough;
    - Hudeman Slough;
    - Second Napa Slough;
    - Third Napa Slough.

The MF model also included several former salt ponds originally represented in 2D. The former salt ponds included in the current MF model, now as 1D stage-storage elements (URS, 2007), are Ponds 3, 4, and 5 (reflective of as-built conditions) and Ponds 6, 7, and 8 (reflective of 50% design conditions).

For this project, the MF model included additional 1D channels:

- Extension of Sonoma Creek upstream to Watmaugh Road;
- Schell Creek from San Luis Road to the tide gate at Schell Slough;
- The lower 2,600 feet of Fowler Creek;
- Extension of the tidal slough network:
  - Schell Slough;
  - Railroad Slough;
  - Steamboat Slough;
  - Wingo Slough.

The MF model for this project also included in 2D the floodplains and diked islands neighboring Sonoma Creek. The floodplains of Sonoma and Schell Creeks extend from Watmaugh Road south to the northern perimeters of Camp 3 and Camp 4 as bounded by Highway 121 on the west and the Southern Pacific Railroad on the east (to include that portion of Camp 1 north of McGill). The diked islands known as Camp 2 and Camp 4 are also included in the model because they flooded during the historic New Years Eve (NYE) 2005 flood. The portion of Camp 1 south of McGill is not in the model, as it is outside the project limits (despite flooding during NYE 2005 due to levee failures south of McGill). Camp 3 is also not in the model because it did not flood during NYE 2005.

2.2 BATHYMETRY AND TOPOGRAPHY

For the NSMR project (PWA, 2002a), the bathymetry and topography for the MF model was mostly derived from a digital terrain model (DTM) prepared by Towill (2001) under contract with the USACE. The DTM was developed from a combination of photogrammetry and cross section surveys of the slough channels, rivers, marshplains, and inundated ponds. The DTM has a horizontal projection of NAD 83 (CCS 83, 1991.35 Epoch, Zone 2) and a vertical datum of NAVD 88.

The NSMR MF model also included data for the Napa River and Sonoma Creek from other sources. Additional data for the Napa River (PWA, 1996) included cross sections from the Napa County RCD (circa 1995) from Oak Knoll Ave. to Trancas St., cross sections from the USACE (circa 1992) from Trancas St. to Horseshoe Bend, and limited soundings from the USACE (circa 1995) from Horseshoe Bend to the Southern Pacific Railroad. Additional data for Sonoma Creek (PWA, 2002a) included cross sections from the SSCRCD (circa 1998) from the Highway 121 Bridge to the Camp 2 Pumping

Station. No cross section data was available for Sonoma Creek from the Camp 2 Pumping Station to just upstream of its confluence with Second Napa Slough.

For this project, the MF model was updated with newer bathymetry and topography that was derived from a DTM prepared by Towill (2007) specifically for this project under contract with the USACE. The DTM was developed from a combination of photogrammetry and cross section surveys (see Figure 2). The photogrammetry excluded the interior of Camp 2 because it was still inundated from the NYE 2005 flood. The surveys included cross sections on Sonoma Creek from Watmaugh Road to Wingo, cross sections on Schell Creek from San Luis Road to the tide gate at Schell Slough, and cross sections for a small section of Fowler Creek. Additionally, Towill provided detailed bridge cross sections for Sonoma Creek at Highway 121 and Wingo; for Schell Creek at San Luis Road, 8th Street, the railroad near 8th Street, Highway 121, and the railroad near Highway 121; and for the railroad crossing on Railroad Slough immediately north of Camp 2. The DTM has the same horizontal projection and vertical datum as the 2001 DTM.

The MF model was also updated with newer information (see Figure 3) to span the cross section data gap between the 2001 and 2007 DTMs and expand the topographic limits of the 2007 DTM. PWA surveyed cross sections on Schell Slough, Railroad Slough, Steamboat Slough, Wingo Slough, and Sonoma Creek from Wingo to just upstream of its confluence with Second Napa Slough. PWA obtained topographic data from Ducks Unlimited (DU) for the area west of the railroad (circa 2000). PWA obtained topographic data from the North Coast Railroad Authority Program (as surveyed by Towill) for the existing railroad bed from just north of Highway 121 to approximately 2,500 feet southwest of Wingo (2007). PWA obtained “bare-earth” IFSAR (Interferometric Synthetic Aperture Radar) from Intermap Technologies for Camp 3 and areas west, east, and internal to the 2007 DTM to provide overlapping floodplain coverage for the FEMA effective flood limits (circa 2003). A 30 meter DEM surface was obtained from USGS for the western half of Camp 4 and integrated with the other sources of surface data. A cross section at the bridge spanning the eastern end of Wingo Slough in Wingo was surveyed by PWA.

Hydraulic features that were implemented in the model based on topographic data of sufficient accuracy and resolution included:

- Highway 121 and Wingo bridges over Sonoma Creek;
- Highway 121, 8th Street, San Luis Road, and railroad bridges over Schell Creek
- Wingo Bridge;
- Existing (and proposed) railroad bed, bridge, and breaches;
- Camp 2 “overtopping” failures located immediately south of the Railroad Slough / Schell Slough junction.

Hydraulic features that were estimated in the MF model due to missing topographic data from the above sources included:

- Silt farm breaches on Sonoma Creek upstream of the Highway 121 Bridge;
- Little Break;
- Big Break;
- Camp 2 levee break adjacent and west of the railroad (not included in the model based on anecdotal evidence);
- ”Overtopping” failures for the eastern perimeter of Camp 2;
- Levee profiles for Camp 1, Camp 3, and Camp 4;
- Levee breaks for Camp 1 and Camp 4;
- Internal levee or berm profiles;
- Cross sections along Wingo Slough (only one cross section was surveyed by PWA).

Up to this point, the MF model bathymetry and topography is consistent with conditions that occurred during the NYE 2005 flood event, which was useful for verifying the flood performance of the model. To predict the flood patterns under existing (or baseline) conditions, the MF model was further updated with the following assumptions:

- The railroad breaches will have been repaired;
- The western 2/3^{rds} of Camp 2 will have been drained and reclaimed by the California Department of Fish and Game (CDFG);
  The eastern 1/3rd of Camp 2 will have been abandoned by the CDFG and allowed to remain tidal following the NYE 2005 levee breaks;
- The levee break at Sue Smith’s property was fixed.

2.3 BOUNDARY CONDITIONS

The MF model primarily relied on historical flood information (e.g. Collins & Leising, 2004; NYE 2005 anecdotal observations) and the *Sonoma Creek & Tributaries Basin Hydrologic Investigation* (PWA, 2004) to predict patterns of flooding on Sonoma Creek and its tributaries. The historical flood information was used for verification of the MF model. The hydrologic investigation, completed by PWA under contract to the USACE and in cooperation with the SSCRCD for the purpose of informing development of flood management and ecosystem enhancement strategies for Lower Sonoma Creek, provided the 2-, 10-, 25-, and 100-year design flood events that were (and will be) used to assess the performance of existing (and proposed) conditions.

Subsequent to PWA completing the hydrologic investigation, Sonoma Creek experienced the largest flood on record (NYE 2005). As a result, PWA revisited our prior hydrologic analysis to 1) update the flood frequency analysis to determine if an update of the design floods was warranted, and 2) generate flood hydrographs for Lower Sonoma Creek and its tributaries for the purposes of verifying the MF model.

2.3.1 Flood Frequency Analysis Update

PWA updated the flood frequency analysis developed in the prior hydrologic investigation (PWA, 2004) from a historic record spanning 72 years (66 peaks with record extension) to one spanning 76 years by including data through the recent flood of record. We used the same methodology (i.e., Log Pearson III analysis as stipulated in Bulletin 17B of the Water Resource Council, 1982) as was used in the hydrologic investigation (PWA, 2004). Figure 4 and Table 1 show the results of the updated flood frequency analysis based on the appended gauge record.

Table 1. Bulletin 17B Flood Frequency Comparisons for Sonoma Creek at the Agua Caliente Gauge

Return Period (years)	**Exceedance Probability**	**Bulletin 17B (PWA, 2004)**	**Bulletin 17B (this study)**	**Percent Increase**
1.05	0.95	971	1,009	3.9
1.11	0.90	1,441	1,495	3.7
1.25	0.80	2,227	2,308	3.6
1.5	0.67	3,206	3,329	3.8
2.0	0.50	4,523	4,697	3.8
2.3	0.43	5,185	5,354	3.3
5	0.20	7,887	8,237	4.4
10	0.10	9,978	10,460	4.8
25	0.04	12,340	13,000	5.3
50	0.02	13,880	14,680	5.8
100	0.01	15,240	16,170	6.1
200	0.005	16,440	17,510	6.5
500	0.002	17,830	19,060	6.9

The NYE 2005 flood event had an estimated (published) instantaneous peak discharge of 20,300 cfs. This peak discharge was estimated by the US Geological Survey (USGS) using indirect methods (i.e. slope-area) and was assigned a “fair” rating which means this value is within ±15 percent (*pers. comm.* Richard Hunrichs, USGS).

The analytical procedures used to compute the flood frequency estimates (i.e., fitting the Log Pearson III curve to the observed data) as shown by Figure 4 identify the observed discharge rate for the flood of record (20,300 cfs) as considerably larger than the estimated 100-year event (16,170 cfs) and inconsistent with the statistical fit of the rest of the data. According to Table 1, the historic flood of record would have an approximate return period > 500 years based on the updated analysis, but could be on the order of at least > 200 years based on the fitted curve’s error bounds, as indicated by Figure

4. It should be recognized that the Bulletin 17B methodology is a “curve-fitting” analysis that provides a “best-fit” through the data points. In this case, the NYE 2005 flood was significantly larger than prior floods, and the analysis therefore assumes that it had a long recurrence interval but can only estimate the size of that recurrence interval based on the length of the record.

Also shown by Table 1 is that the updated estimates for the 2- through 100-year flood events increased by about 4 to 7 percent over the previous estimates. This is not an extreme change in predicted discharges.

It is interesting to note that the USGS (2006) estimated the NYE 2005 flood event on Sonoma Creek near Agua Caliente to have a return period > 100 years. This estimate relied on a preliminary (unpublished) peak discharge estimate of 17,600 cfs and 29 years of record (without the benefit of record extension, as applied here and in the earlier hydrologic investigation). Even in the USGS investigation, however, the flooding on Sonoma Creek stands out from other north coast streams that generally had return periods in the range of 10 to 25 years for this same rainfall event.

The changes to the estimated flood frequency that have been identified in this study and described above do not require any modification to our 2004 hydrology report recommendations. Our reasoning is as follows:

1. As identified in the 2004 hydrologic investigation (PWA), the recommended design flood peak discharges, which were generated from a hydrologic model, are generally higher than the statistical flood frequency estimates, likely due to our use of a conservative rainfall distribution approach.
2. The recommended 10- and 25-year design peak discharges are consistent, if not slightly more conservative, with the updated flood frequency peak flow estimates.
3. The recommended 100-year design peak discharge is significantly more conservative than the updated flood frequency peak flow estimate, but is quite similar to the peak discharge for the flood of record (20,300 cfs).

2.3.2 NYE 2005 Flood Hydrographs

PWA revisited the prior hydrologic modeling (PWA, 2004) to generate flood hydrographs for Sonoma Creek and its tributaries with the intended purpose to verify the flood performance of the MF model during the NYE 2005 flood event. The prior calibration of the hydrologic model was further tuned using observed rainfall data leading up to and during the NYE 2005 flood, as shown by Figure 5. Note that the rainfall was spatially distributed through 2 am on December 31st, moving from west to east with more rainfall occurring in the north than in the south. Due to the spatially distributed rainfall pattern inferred from hourly rainfall data, only three of the five gauges (see Table 2 and Figure 5) were used as input to the hydrologic model; St. Helena rainfall was applied upstream of

Kenwood, Bennett Valley rainfall was applied between Kenwood and Agua Caliente, and Petaluma East rainfall was applied downstream of Agua Caliente.[1]

Table 2. Active Rainfall Gauges During the 2005 December 31st Flood Event

Gauge Name	ID	Latitude	Longitude	Elevation (ft)	MAP (in)	Source
Carneros	109	38.218889	-122.353889	5	26.5	CIMIS
Petaluma East	144	38.267222	-122.616111	97	28.0	CIMIS
Oakville	77	38.433889	-122.409722	190	37.0	CIMIS
Bennett Valley	158	38.419444	-122.656944	270	29.5	CIMIS
St. Helena 4WSW	SH4	38.4920	-122.5330	1780	41.5	CDEC

Notes: CDEC = California Data Exchange Center (http://cdec.water.ca.gov/); CIMIS = California Irrigation Management System (http://wwwcimis.water.ca.gov/); MAP = Mean Annual Precipitation derived from SCWA (1983) isohyetal map.

Figure 6 shows the predicted streamflow response of the hydrologic model using the previously estimated curve number parameters for wet antecedent moisture conditions with reasonable assumptions for recession baseflow. It is noted that the peak discharge is within 0.3 percent of observed and that the cumulative flow volume is within 0.5 percent for the period shown. The satisfactory fit was primarily achieved by using the Bennett Valley rainfall and fine tuning the recession baseflow parameters globally.

Recession baseflow as implemented in the hydrologic model is described as $Q = Q_o K^t$, where Q is discharge, Q_o is the initial baseflow, K is the recession constant, and t is time. The recession constant K was set at 0.008 and Q_o was automatically reset on the falling limb of the hydrograph by the model when the discharge-to-peak ratio fell below 85 percent. A recession constant set significantly less than 1 is characteristic of baseflow generated from surface runoff, indicating that significantly more rainfall was converted to runoff than provided by the previously estimated curve number parameters due to overly wet soil moisture conditions leading up to and during the storm. Figure 7 shows the estimated cumulative rainfall depth compared to the observed cumulative runoff volume (in inches) and demonstrates that greater than 85 percent of the rainfall (through 12 pm on the 31st) was converted to runoff.

For the Napa River and its tributaries, flood hydrographs were generated from observed USGS flow data at the Napa River near Napa gauge (11458000) located at Oak Knoll Ave. Flood hydrographs for the tributaries were based on scaling factors for the Napa River gauge derived from the General Design Memorandum (GDM) for the Napa River/Napa Creek Flood Protection Project (USACE, 1998).

[1]Only the St. Helena gauge was used in the prior (PWA, 2004) calibration.

2.3.3 Design Flood Hydrographs

Analysis of existing (and project) conditions relied on design floods developed for Sonoma Creek and its tributaries as part of the prior hydrologic investigation (PWA, 2004) and for Napa River and its tributaries as part of the GDM (USACE, 1998). The MF model was supplied with flood hydrographs at the upstream boundaries and major tributaries. The flow boundaries on Sonoma Creek included Sonoma Creek at Watmaugh Road, Fowler Creek at Highway 121, and Schell Creek at Highway 121. The flow boundaries on Napa River included Napa River at the following locations: Oak Knoll Avenue, downstream of Milliken Creek, downstream of Napa Creek, downstream of Tulucay Creek, and downstream of Carneros Creek.

As demonstrated by the section above, the ability of the Sonoma Creek hydrologic model to reproduce observed flows during the NYE 2005 flood using observed rainfall data with only minor changes gives us even greater confidence in the model to simulate actual conditions during large flood events. In addition, the hydrologic model remained consistent with the updated flood frequency analysis of recorded flows at the Agua Caliente gauge. Based on these findings, previously developed design floods of 48 hours in duration for Sonoma Creek (see Table 3) were used directly from the 2004 hydrologic investigation for future conditions.

Table 3. Sonoma Creek 48-hour Design Peak Discharges at Agua Caliente

Return Period (years)	Existing Peak Discharge (cfs)	Future Peak Discharge (cfs)	Updated Bulletin 17B Peak Discharge (cfs)
2	2,654	2,913	4,697
10	10,055	10,643	10,460
25	13,905	14,607	13,000
100	19,821	20,663	16,170

For the Napa River and its tributaries, design floods of four (4) days in duration from the GDM (USACE, 1998) were used. The relative timing of the design floods on Sonoma Creek and Napa River were guided by the NYE 2005 flood event. The lag time between the hydrograph peaks of Sonoma Creek at Agua Caliente and Napa River at Oak Knoll Ave was assumed to be 7.5 hours (see Figure 8).

2.3.4 Downstream Boundary Conditions

The MF model was supplied with time-varying water levels (representative of tidal conditions) at the downstream boundaries at San Pablo Bay and Mare Island Strait. For the verification period (NYE 2005), the MF model used water levels computed by PWA for Mare Island as derived from the NOS gauge (http://tidesandcurrents.noaa.gov/) at San Francisco (9414290); these water levels were also applied at the mouth of Sonoma Creek. The NYE 2005 water levels were computed based on correlation of observed water levels between San Francisco (9414290) and Mare Island (9415218) for the January 1997 flood event (this was the only flood of significance for Mare Island due to data gaps).

For analysis and comparison of existing (and project) conditions using design flood hydrographs, the MF model used observed water levels from USGS gauges (http://sfbay.wr.usgs.gov/) at USCG Channel Marker 9 (GM9) and Mare Island Causeway (MIC). The observed water levels from July 2001 were used as this month is representative of the range of tidal conditions typically present. The design flood hydrograph peaks were made to coincide with the proposed tide peak at a time when the proposed tide peak has reached its modeled maxima at the Highway 121 Bridge.

For the purposes of accounting for the potential effects of sea level rise on the function of project alternatives, we propose that alternatives be evaluated with respect to both present sea level conditions and those representing a future sea level condition within a reasonable planning time horizon. For this purpose, we propose to use an estimate of a fixed amount of sea level increase that is consistent with expected conditions approximately 50 -100 years into the future. Current estimates of sea level rise from 1990 to 2050 and 2100 have recently been identified using the latest science for the State of California's Delta Risk Management Strategy (URS, 2007) and for planning purposes by the CALFED Independent Science Board (2007). Both documents identify the same value as a high-end estimate for 2100 for planning purposes: 1.4m rise from 1990 values. The former document identifies an estimate for 2050 using the same source study (Rahmstorf, 2006): 0.41m, or about 16 inches. Both documents also acknowledge the potential for even much higher rates of sea level rise, due to potential ice-dynamical processes that are not accounted for in this estimate. Even so, the 0.41m value exceeds the outer bounds of the recent estimates for 2050 produced by the Intergovernmental Panel on Climate Change (2001)[2] by approximately 0.1 meter and is marginally higher than the outer bounds on the estimate for 2060 suggested by the same source. While considerable uncertainty exists for the increment of sea level rise that will have occurred 50 years after the construction of a Sonoma Creek project, it likely lies between 0.41 meter and 1.4 meter.

We propose to use a 0.5 meter increment of sea level rise for the purpose of conceptual project design and alternatives evaluation. We believe it to be a reasonable estimate for planning purposes of future conditions at the project site. To encompass conditions that may occur over the course of a longer planning timeframe, we will also evaluate conditions that would exist in the event of a 1.5 meter increase in sea level rise. Bracketing anticipated sea level conditions in this fashion will help to frame the range of potential sea level conditions that may exist, despite the uncertainty of when such conditions may actually come into play.

[2] See IPCC TAR Intergovernmental Panel on Climate Change, Ed. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the IPCC (Cambridge University Press, Cambridge, 2001), available at http://www.grida.no/climate/ipcc_tar/ and published by the Cambridge University Press, or the summary in URS (2007), cited above.

2.4 HYDRAULIC ROUGHNESS

During the NSMR project (PWA, 2002a), calibration and verification of the MF model was performed by adjusting the hydraulic roughness to achieve the best fit between observed and simulated water levels and velocities. A total of eight (8) water level gauges and nine (9) velocity gauges were used during calibration and verification of the MF model. The gauges were distributed in the channels and sloughs between Sonoma Creek and the Napa River. The adopted Manning's n-values range from 0.015 to 0.03 (see Table 4) and generally decrease from the channels towards the interior of the slough network.

For this project, Manning n-values for Steamboat Slough, Railroad Slough, Schell Slough, Schell Creek, and Fowler Creek were assigned a value of 0.03. These values are slightly conservative and no data was available to verify these assignments. For the 2D portions of the MF model, a single Manning's n-value of 0.03 was applied; this value is consistent with recent USACE (2007) estimates for agricultural fields.

Table 4. Manning's n-values

Channel or Slough	**Manning's n-values**
Napa River	0.03
Dutchman Slough	0.02
South Slough	0.015 – 0.02
China Slough	0.015 – 0.02
Devils Slough	0.02
Mud Slough	0.02 – 0.03
Napa Slough	0.015 – 0.02
Hudeman Slough	0.015
Second Napa Slough	0.015 – 0.03
Third Napa Slough	0.02
Steamboat Slough (new to model)	0.03
Railroad Slough (new to model)	0.03
Schell Slough (new to model)	0.03
Schell Creek (new to model)	0.03
Fowler Creek (new to model)	0.03
Sonoma Creek	0.02 – 0.03

3. MODEL RESULTS

Figure 9 shows a place name map that will be referenced when discussing the NYE 2005 and existing conditions flooding.

3.1 MODEL VERIFICATION

Should there have been extensive data on concurrently measured streamflows and water levels, it would have been preferable to initially use part of the data set for model calibration and the remainder of the data set for verification. However, there was very limited historical flood information to support detailed hydrodynamic model calibration. As such, PWA conducted a limited verification of the MF model for the NYE 2005 flood event. This flood event was the largest on record as observed on Sonoma Creek at Agua Caliente and resulted in Sonoma Creek overtopping Highway 121 near Schellville and the inundation of Camp 2 via multiple agricultural berm failures.

For this project, the flooding patterns of the updated MF model were verified for the NYE 2005 flood event. Verification of the MF model to the NYE 2005 flood event primarily relied upon the anecdotal observations of the local landowners (e.g. Shannon Kiser) communicated during a 9/12/2007 stakeholder meeting with the SSCRCD. These anecdotal observations are provided in Table 5 and Figure 10. The base map to Figure 10 also shows the pattern of historic flooding and failure locations (Collins & Leising, 2004).

Table 5. NYE 2005 Flood Anecdotal Observations

Individual (Affiliation)	**Observations**
Shannon Kiser (landowner)	• Flooding started first in the town of Sonoma • She was sand bagging the low spot on her easement road at 2 am (she indicated coincident with high tide) • Camp 3 did not flood (and has never flooded), but came within inches • Camp 1 flooded not only adjacent to Sue Smith's property (Area 8) but also due to breaches on Sonoma Creek downstream of Second Napa Slough • Camp 2 East flooded first via overtopping of the northeast levee which has five "overtopping" breaches • Sonoma Creek at the southern lobe of Camp 2 East (east of Wingo) was overtopping into Camp 2 along eastern levee (approximately 5 am, but she can't see low spot from her house) • The southern lobe of Camp 2 East was spilling back into Sonoma Creek between Wingo bridge and her easement road at approximately 1:30 pm • Unsure when the Camp 2 West levee breach near the railroad bridge formed (perhaps at dawn break, but typically spills via RR bridge first) • The railroad bed breaches in Camp 2 developed from east to west and began spilling across the railroad tracks around 9 am

Individual (Affiliation)	Observations
	• Camp 2 was full by 10 am to 11 am
Sue Smith (landowner)	• Her land (Area 8) flooded via a levee failure along Sonoma Creek that scoured out the railraod bed (which has since been repaired) and by overtopping at the southeast corner • The greater Camp 1 area flooded because of levee failure and water moving down the road on the east side of the railroad tracks
Norm Yenni (landowner)	• Camp 4 flooded and was sheeting over when he woke up; suspects it started flooding sometime between 5 am and 6 am (which coincides with timing of flood peak) • Skaggs Island only had minor overtopping, nothing significant • Northeast of Infineon Raceway was flooding via drainage from hillslopes to the west • Had minimal flooding near Tubbs Island near Caltrans easement • Indicated Sonoma Creek mouth is constricted due to formation of mud delta and vegetation encroachment • The area around the Airport flooded • The area to the north of the Airport flooded via drainage from the hillslope to the west
Tom Huffman (CDFG)	• A mud berm at Highway 37 limits flow draining into Sonoma Creek • Breaches along the northeast corner of Camp 2 are only overtop and currently only spill in extreme high tides, unlike the levee breach near railroad bridge which is fully tidal • Periodic log jams occur in Sonoma Creek all along Camp 2
Mitch Mulas (landowner)	• There are five breaks through the railroad bed about 10 feet wide and scoured down to the surrounding ground surface; these are south of the position directly opposite of Big Break

Based on the MF modeling of the NYE 2005 flood, the simulated timeline of flooding was prepared and is presented in Table 6 and Figure 11. These patterns of flooding are consistent with anecdotal observations during the NYE 2005 flood (see Table 5) and the locations of previously mapped levee breaks and levee overtopping (Collins & Leising, 2004).

Table 6. Model Results for the NYE 2005 Flood Event

Point No.	Date / Time	Occurrence	Comment
1	12/30/05 18:30	Little Break and Big Break start to spill onto floodplain	
2	12/30/05 18:40	Sonoma Creek overtops to the north into Railroad Slough	
3	12/30/05 19:10	Sonoma Creek spills through historic levee break opposite Hauto's Landing	

Point No.	Date / Time	Occurrence	Comment
4	12/30/05 19:50	Sonoma Creek starts to spill through the railroad adjacent to Area 4	It is unclear when these breaks in the railroad bed fully formed
5	12/30/05 20:20	The breaches just upstream of the Highway 121 bridge on Sonoma Creek in Area 1start to spill and Fowler Creek starts to spill	
6	12/30/05 21:20	Schell Creek starts to spill to the west through historic levee break upstream of the tide gate	
7	12/30/05 23:10	Sonoma Creek starts to flood area adjacent to Airport via a low spot	Low spot is mapped by Collins & Leising (2004)
8	12/31/05 01:00	Schell Creek starts to flood to the east in the vicinity of prior levee breaks and head southeast	Prior levee breaks mapped by Collins & Leising (2004)
9	12/31/05 01:50	Northeast corner of Camp 2 overtops and floods Camp 2 East	This is coincident with high tide; low spots in the levee identified in the 2007 DTM
10	12/31/05 02:10	Sonoma Creek starts to flood area south of Airport in the vicinity of a prior levee break	Prior levee break is mapped by Collins & Leising (2004)
11	12/31/05 02:30	The northwest lobe of Camp 4 starts flooding from Steamboat Slough	
12	12/31/05 03:20	The Camp 2 West starts to flood (via #9) from east to west	According to Shannon Kiser, the railroad began to overtop around 9 am; it is unclear when these breaks in the railroad bed fully formed
13	12/31/05 03:20	The southern lobe of Camp 2 East starts flooding from Wingo Slough	According to Shannon Kiser, this occurred around 5 am (note: inadequate levee profile)
14	12/31/05 04:30	Camp 1 (adjacent to Area 8) starts to flood via failure in railroad bed	
15	12/31/05 05:00	Flood waters start overtopping Camp 4 access road (via #8)	This concurs with the observation by Norm Yenni
16	12/31/05 07:00	Levee overtops at low spot and starts to flood Area 7 (via #7 and #11) and spill towards Area 8	Prior levee overtopping has been mapped by Collins & Leising (2004)

Point No.	Date / Time	Occurrence	Comment
17	12/31/05 07:00	Area north of Airport starts to flood, but just barely	Prior levee break has been mapped by Collins & Leising (2004); according to Norm Yenni, this area flooded via drainage from the westerly hillslope
18	12/31/05 10:00	Camp 2 completely inundated	This concurs with the observation by Shannon Kiser
19	12/31/05 11:30	Camp 4 completely inundated	

3.2 EXISTING CONDITIONS FLOODING

The baseline MF model, in conjunction with the 2-, 10-, 25-, and 100-year design flood events, was used to assess potential flooding under an existing condition post NYE 2005 and representative of pre-project conditions. Under this existing condition, it was assumed that the railroad bed will have been repaired, the western 2/3^rds^ of Camp 2 will have been drained and reclaimed by the CDFG, the eastern 1/3^rd^ of Camp 2 will have been abandoned by the CDFG and allowed to remain tidal following the NYE 2005 levee breaks, and the levee break at Sue Smith's property was fixed. The results of the existing conditions flood are shown graphically in Figures 12, 13, and 14 and are summarized below.

During the 2-year design flood:

- Figure 12 shows that most of the flooding (approximately 360 acres) occurred on Area 4 as a result of flood waters spilling through Little Break, Big Break, and the previously mapped low spot opposite Hauto's Landing;
- Sonoma Creek was spilling over a low spot in its left levee into Railroad Slough near the northwest corner of Camp 2 West;
- Depending on the tides, there was up to 3 feet of head between Sonoma Creek and Railroad Slough at this location; and
- Depending on the tides, there was up to 5 feet of head across Wingo Slough.

During the 10-year design flood (in addition to the 2-year flood effects):

- Figure 12 shows that an additional 1850 acres is flooded;
- In addition to 2-year spilling, the breaches just upstream of the Highway 121 bridge on Sonoma Creek in Area 1 were also spilling;
- The railroad between Area 4 and Area 5 property begins to selectively overtop;

- The area south of the Airport and north of Camp 1 completely floods via flood waters entering the previously mapped low spot adjacent to the Airport and 1955 levee breaks and moving south towards Area 8;
- Camp 2 East floods up to 2.5 feet deep via overtopping of the low spots along the northeastern levee;
- Schell Creek begins to flood upstream of Highway 121;
- Schell Creek just upstream of the tide gate spills west and floods Area 5;
- Schell Creek either side of the tide gate spills east, travels southeast through Area 6, and begins to stack up against the Camp 4 access road; and
- The Camp 4 access road just begins to overtop.

During the 25-year flood (in addition to the 10-year flood effects):

- Figure 12 shows that an additional 650 acres is flooded;
- Fowler, Sonoma, and Schell Creek flood waters comingle upstream of Highway 121;
- Camp 2 East floods up to 6 feet deep;
- Camp 2 West begins to have shallow flooding when the railroad is overtopped from the east; and
- The northwestern lobe of Camp 4 begins to flood and move through breaks in the access road.

During the 100-year flood (in addition to the 25-year flood effects):

- Figure 12 shows that an additional 1820 acres was flooded;
- The area to the north of the Airport floods via previously mapped levee breaks;
- The entire Camp 2 West experienced shallow flooding;
- Most of Camp 4 experienced shallow flooding; and
- Figure 13 and Figure 14 show that water levels in Sonoma Creek along Camp 3 are lower than they were during the NYE 2005 flood.

3.3 EXTENT OF TIDAL INFLUENCE

Flood impacts on Sonoma Creek and Schell Creek are thought to be directly correlated with tidal conditions in San Pablo Bay. Several month-long simulations were conducted to better understand how far upstream the tides influence water levels on Sonoma Creek and Schell Creek.

3.3.1 Tidal Datum Analysis

Using the month-long July 2001 tides, the MF model was run with two different upstream boundary conditions to bracket the expected range of tidally-influenced water levels under dry-weather and minor flood conditions. Under the dry weather scenario, the upstream inflows into the MF model from the creeks were assumed to be zero. Under the minor flood scenario, the upstream inflows into the MF model from the creeks were assumed to correspond to the 2-year peak discharge. The 2-year peak discharge was used for the entire month-long simulation, rather than the flood hydrograph, so as to reasonably predict the relative change in the tidal datums under a flood scenario. Using the model results from these scenarios, tidal datums (i.e. MHHW, MHW, MTL, MSL, MLW, and MLLW) were computed for the modeled reaches of Sonoma Creek and Schell Creek, including the sloughs between the two creeks (i.e. Steamboat Slough, 3rd Napa Slough, and 2nd Napa Slough). By observing how the elevations of the different datums change moving upstream, the relative influence of the tides and creek flows can be compared. For the dry weather scenario, there was little change in the elevation of MHHW and MLLW (i.e. the mean upper and lower tidal bounds, respectively) on Sonoma Creek upstream of San Pablo Bay to the northwest corner of Camp 2 (see Figure 15) and on Schell Creek upstream of San Pablo Bay to the tide gate (see Figure 16). Upstream of Camp 2 on Sonoma Creek, MLLW and MLW are influenced by the channel bed and begin to increase in elevation, while MHHW stays relatively constant to Highway 121. For the minor flood scenario, the tidal datums on Sonoma Creek (see Figure 17) begin to collapse on each other (i.e. MHHW equals MLLW) between 2nd Napa Slough and Wingo and are completely collapsed at the upstream corner of Camp 2. On Schell Creek (see Figure 18), the relative difference between MHHW and MLLW is less under the flood scenario than under the dry weather scenario for the entire length of the creek. These datums are almost, but not completely, collapsed at the tide gate.

This analysis showed that during a minor flood event, the maximum influence of tidal fluctuations on peak flood levels in Sonoma Creek do not extend beyond the northwest corner of Camp 2. The extent of tidal influence would likely move downstream during larger, less frequent flood events, as further demonstrated by Figure 13 with the successive collapse of the n-year peak water levels downstream of 2nd Napa Slough. For Schell Creek, the predominant extent of tidal influence under both dry weather and minor flood conditions is approximately the tide gate; however, relative differences between MHHW and MLLW are much lower during flood conditions. This difference, along with the location of tidal influence, would most likely propagate downstream during higher flood events (as similarly demonstrated by Figure 14).

3.3.2 Sea Level Rise Analysis

An additional minor flood scenario was simulated to assess the affect of sea level rise on the extent of tidal influence in Sonoma Creek and Schell Creek. To simulate sea level rise, 0.5 meter was added to the July 2001 tides for the entire month-long time series. The MF model was re-run and the tidal datums were computed from the model results, as shown by Figures 19 and 20.

In general, the extent of tidal influence moved upstream with an increase in the San Pablo Bay tide levels. For Sonoma Creek (see Figure 19) with a 0.5 meter increase in sea level, the maximum extent of tidal influence is still near the northwest corner of Camp 2, but the predominant fluvial-tidal interface moved upstream approximately 1.5 miles in the vicinity of Wingo. For Schell Creek (see Figure 20), the maximum extent of tidal influence moved upstream beyond the tide gate, but the predominant fluvial-tidal interface still remained at the tide gate.

We conducted some additional tests to gauge the influence of even higher levels of sea level rise on tidal conditions, a 1.5 meter rise in sea level. Based on a simplified model run, we expect that under even greater sea level rise (up to 1.5 meters) and minor flood conditions that the predominant fluvial-tidal interface would not extend much further upstream than the northwest corner of Camp 2. However, in the absence of flood flows and based on an extrapolation of Figure 15, it is expected that MHHW under 1.5 meters of sea level rise would translate even farther upstream, or approximately 1.3 miles upstream of Highway 121. Based on a simplified model run, we expect that under even greater sea level rise (up to 1.5 meters) for minor flood conditions that the predominant fluvial-tidal interface would extend just upstream of Highway 121. However, in the absence of flood flows and based on an extrapolation of Figure 16, it is expected that MHHW would translate even farther upstream: approximately 1.7 miles upstream of the tide gate, or 1.1 miles upstream of Highway 121, with 1.5 meters of sea level rise. Thus, a 1.5 meter increase in sea level is expected to push tidal fluctuation effects and MHHW more than a mile upstream of Highway 121 on both Sonoma and Schell Creeks, though the tidal range would be small on Sonoma Creek upstream of Camp 2 and on Schell Creek upstream of Highway 121.

Additionally, the effects of about 1 meter of sea level rise on water levels during a large flood event can be estimated by comparing peak water levels for the 100-year and NYE floods, which were two floods of near equal discharge, but the NYE downstream peak water level was roughly 1 meter higher due to storm surge. As depicted in Figure 13 and Figure 14 for Sonoma Creek and Schell Creek, respectively, the sea level rise moved the predominant extent of tidal influence under a large flood with approximately upstream on the order of 2 miles on both creeks, terminating upstream of Wingo on Sonoma Creek and midway along Camp 2 on Schell Creek.

In summary, the predominant fluvial-tidal interface shifts further downstream as flood magnitude increases, but in the presence of sea level rise, this shift is offset in the upstream direction. Thus, sea level rise will essentially push the effects of the tides upstream, moving both the opportunities for tidal wetland restoration and flood hazard reduction upstream. For the purposes of long-term planning, the simulated dry-weather conditions with 0.5 meters of sea level rise represent the future tidal conditions that should be anticipated for habitat planning. In flood events, some of this tidal fluctuation will be overwhelmed by the effects of creek flows. However, the effects of sea level rise on water levels during large flood events appear to be minor in the creek reaches upstream of Camp 2. If flood hazard planning is limited to the reaches upstream of Camp 2, the potential effect of even significant sea level rise on flood stages in those reaches is expected to be minor.

3.4 ASSUMPTIONS AND LIMITATIONS

The numerical simulation model described in this document contains a number of assumptions and limitations, as described above. Key assumptions and limitations are summarized as follows:

- Estimated tides (with storm surge) were used for simulation of the NYE 2005 flood.
- Estimated flood hydrographs for the NYE 2005 flood for Sonoma Creek and its tributaries were based on recorded precipitation data.
- Limited validation data existed for the NYE 2005 flood.
- The simulated downstream boundary condition all recurrence-interval flood conditions is based on recorded tidal data that is reasonably representative of typical bay conditions.
- Estimated flood hydrographs for simulation of all recurrence-interval flood conditions for Sonoma Creek and its tributaries were based on assumed precipitation patterns.
- Topographic descriptions for Big and Little breaches and for Silt Farm breaches along Sonoma Creek and for the eastern portion of Camp 2 along Steamboat Slough were estimated.
- Only IFSAR or USGS data was available for some areas modeled in 2D (near Mulas property north of Camp 2, areas east of Schell and Steamboat Sloughs, and Camp 4).

3.5 CONCLUSIONS

The MF numerical simulation model prepared by PWA for use in developing and evaluating the conceptual design of the Sonoma Creek Flood Management and Enhancement Project is based on the best information available at this time and represents the hydrodynamic conditions along Sonoma Creek, its floodplain, and its tributaries at a level that is certainly sufficient for conceptual design of the project. It is consistent with our current understanding of reasonably foreseeable future hydrologic and hydrodynamic conditions and is capable of evaluating the expected effects of potential conditions of sea level rise. It was successful in reasonably reproducing the conditions observed in the record NYE 2005 flood event.

As the project evolves, enhancement to the simulation model may be desirable. For example, a less ambitious flood management goal may heighten the value of model verification during a less severe flood event. In addition, as project elements are identified, it is possible that some of the coarser elements of the model’s description of system geometry may warrant refinement. At this time, however, we believe the model has been refined and verified to a level that warrants its use for development of the conceptual project design. The baseline flood condition simulations that have been developed to represent without-project conditions are ready for use as a standard against which with-project effects may be evaluated.

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5. LIST OF PREPARERS

This report was prepared by the following PWA staff:

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Matt Wickland
Betty Andrews

6. FIGURES

Legend	*figure 1*
NSMR MIKE Flood model (1-D channels)	*Sonoma Creek Conceptual Design*
Highways	Extent of Current MIKE Flood Model from NSMR Project
Note: "P" stands for "Pond" (e.g. P1 refers to Pond 1)	*PWA Ref.# 1844.00* PWA

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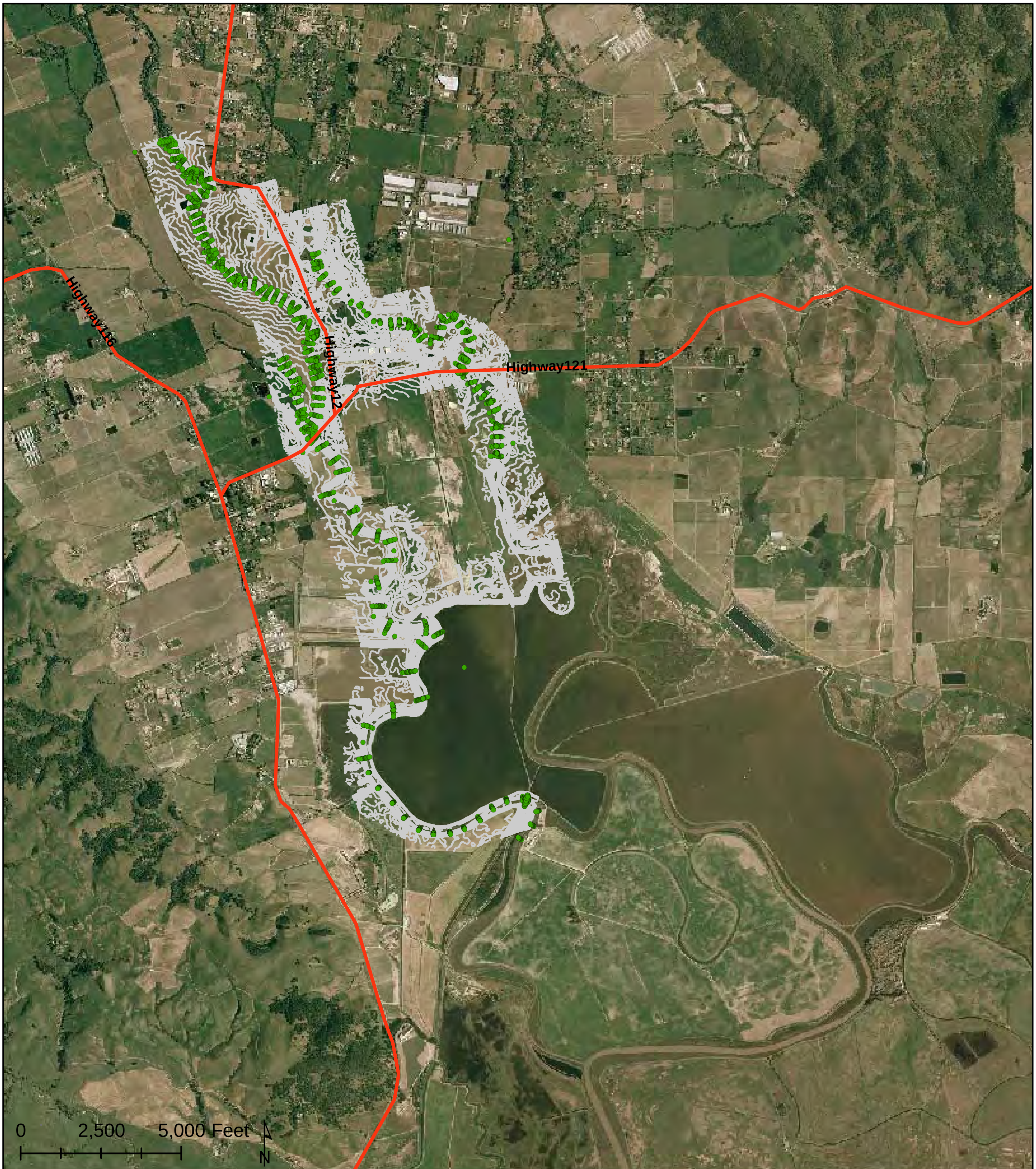

Legend

Ground Survey Point Locations

Aerial Survey Extent

Highways

figure 2

Sonoma Creek Conceptual Design
Towill Aerial and Ground Survey Extents

PWA Ref.# 1844.00

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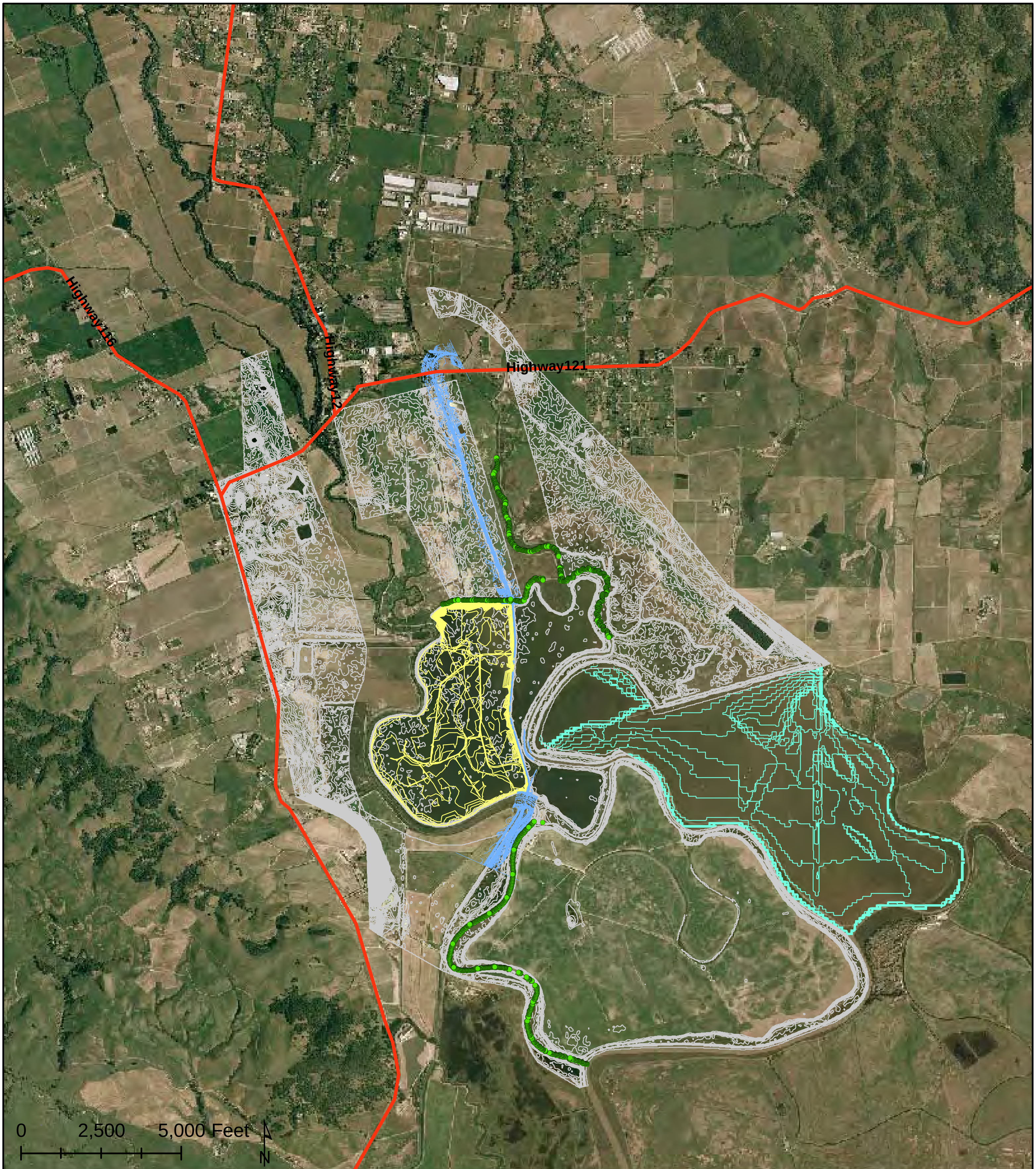

Legend

- Highways
- PWA Ground Survey Points
- Railroad Elevation Contours (North Coast Railway Authority Program)
- Camp 2 Elevation Contours (Ducks Unlimited)
- IFSAR Contour Data (converted from TIN)
- Camp 4 Contour Data (converted from USGS DEM)

figure 3

Sonoma Creek Conceptual Design

PWA Ground and IFSAR Aerial Survey Extents

PWA Ref.# 1844.00

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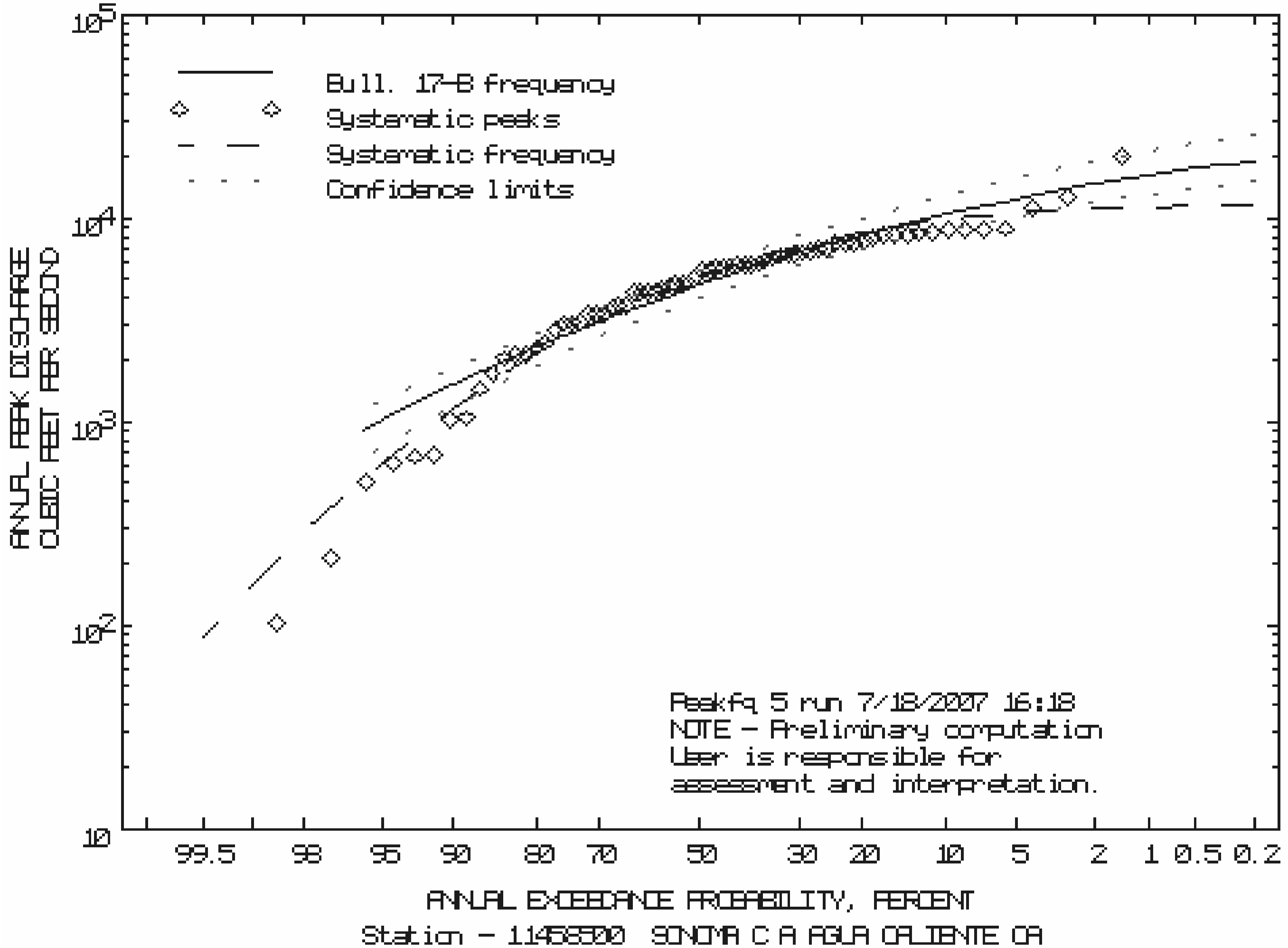


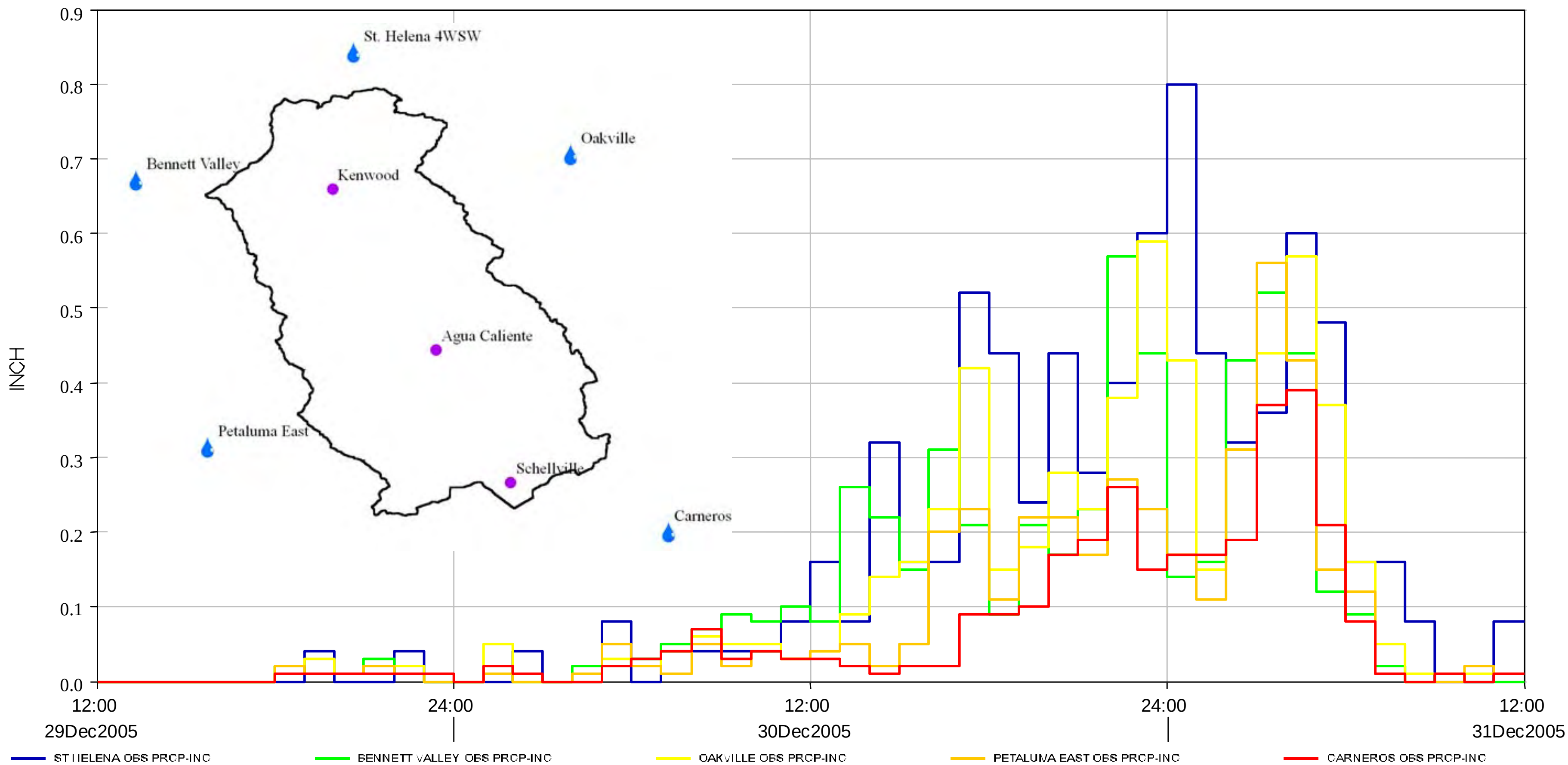
Notes: the Agua Caliente gauge record was extended from 29 peaks to 70 peaks between water years 1930 to 2006 through statistical correlation with the St. Helena gauge on the Napa River
Source: PWA (this study)

figure 4
Sonoma Creek Conceptual Design

Flood Frequency at Agua Caliente

PWA Ref# 1844.00

PWA



Source: rainfall from CDEC (http://cdec.water.ca.gov/) and CIMIS (http://wwwcimis.water.ca.gov/)

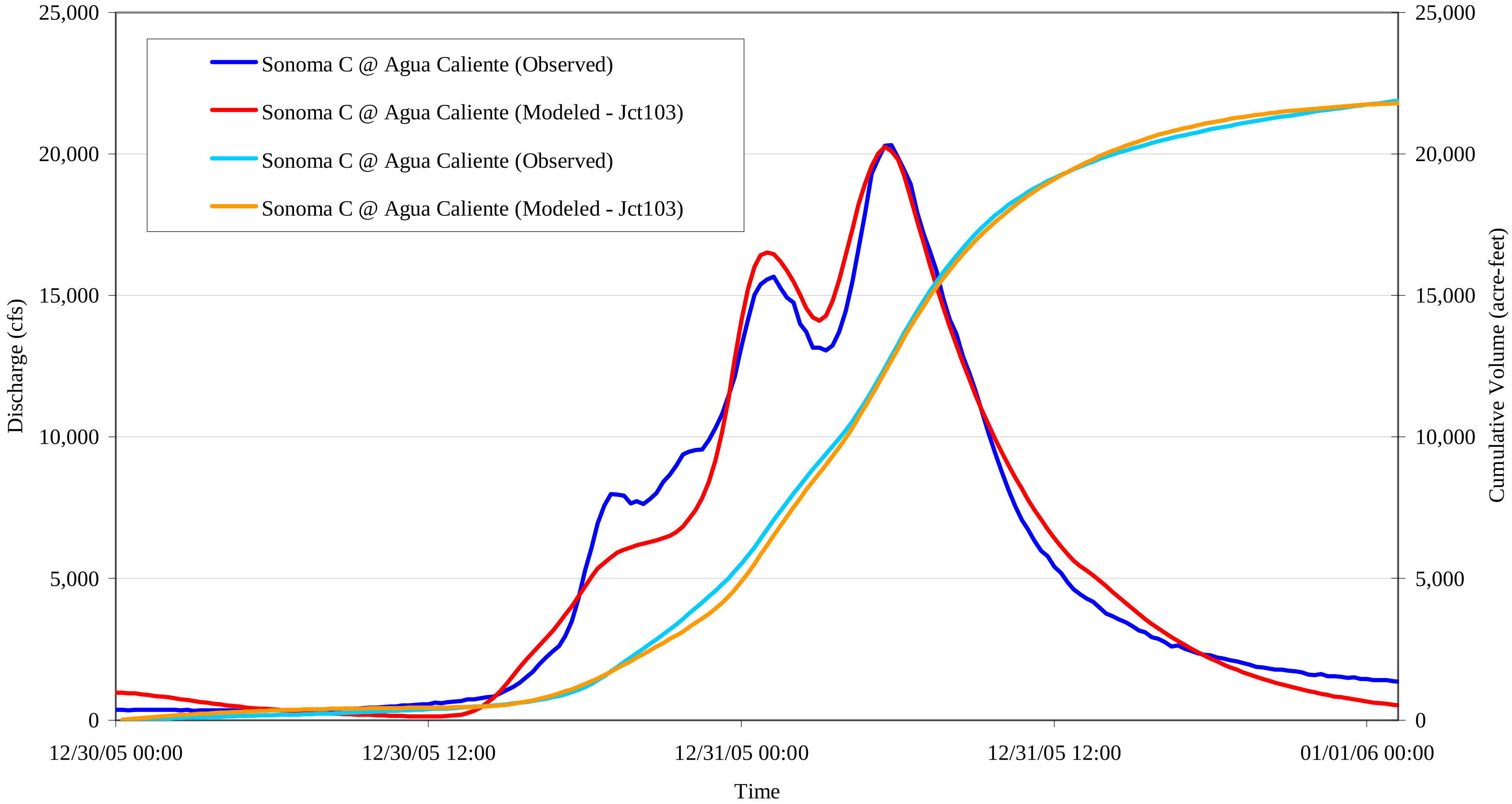
figure 5

Sonoma Creek Conceptual Design

2005 December 30th to 31st Observed Rainfall

PWA Ref# 1844.00

PWA



Source: USGS gage records and HMS model output

figure 6

Sonoma Creek Conceptual Design

Calibration of December 31st Flood Event

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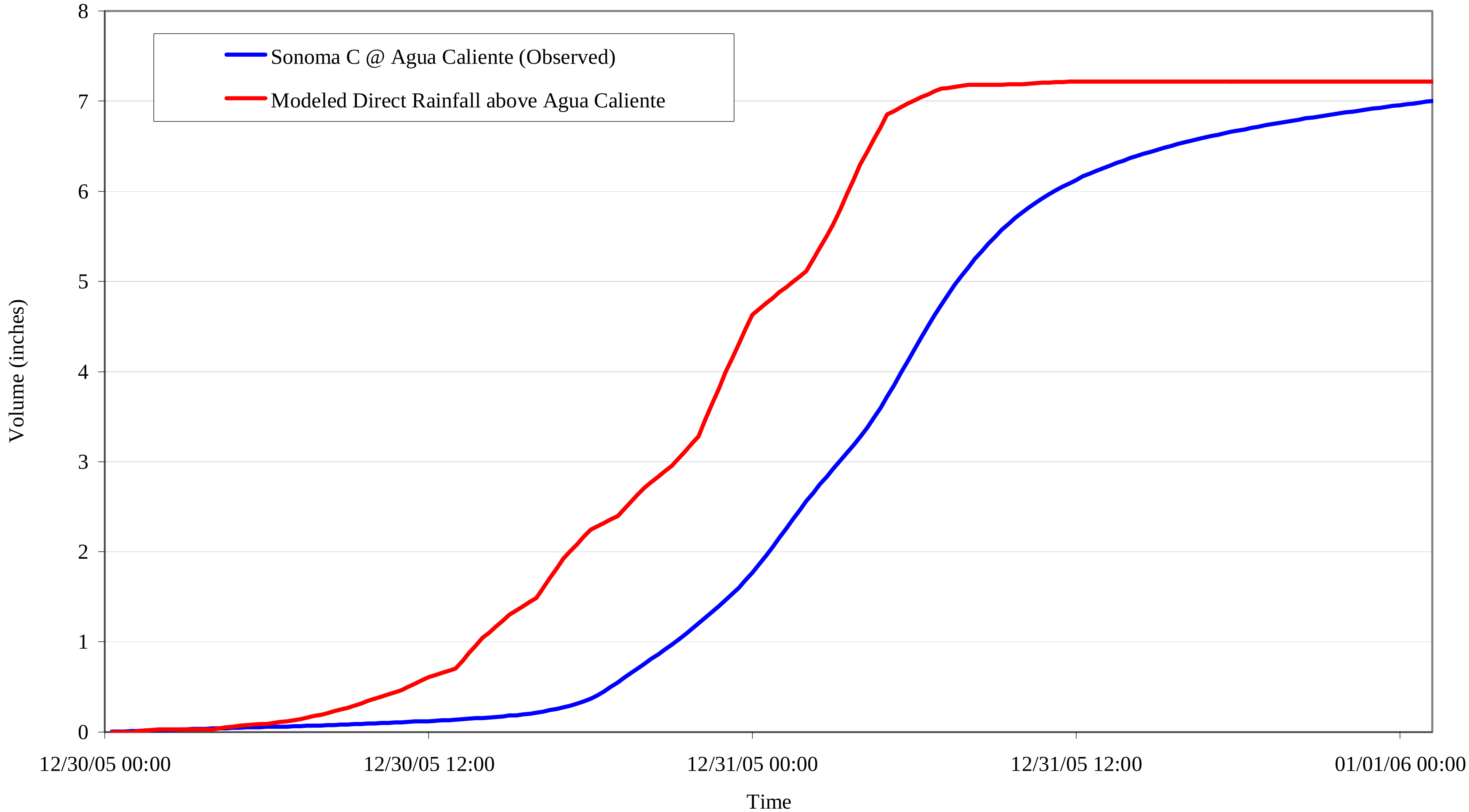

Source: USGS gage records and HMS model output

figure 7
Sonoma Creek Conceptual Design

Comparison of Cum. Rainfall and Runoff Depths

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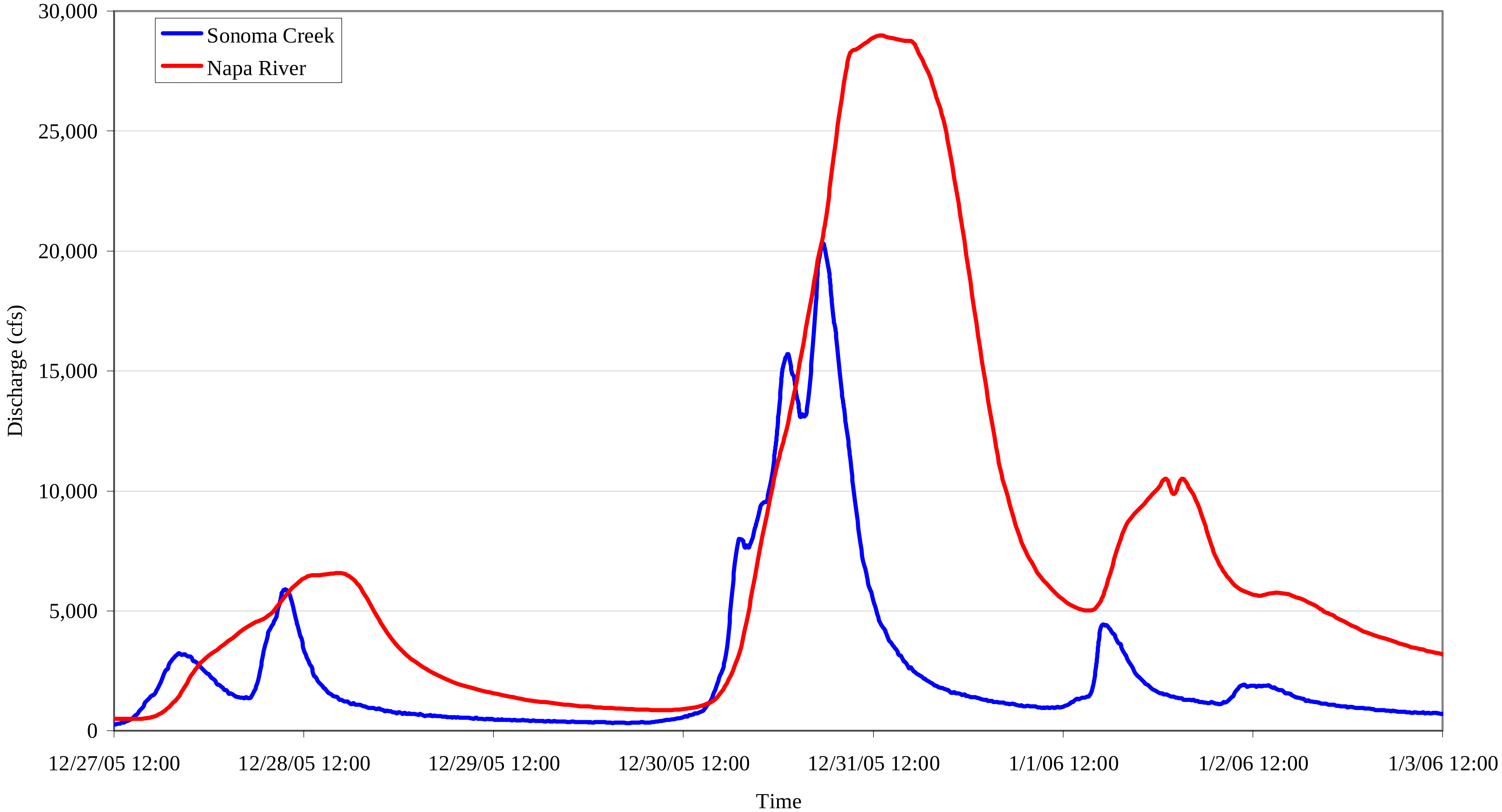

Source: USGS gage records; Sonoma Creek at Aqua Caliente (11458500) and Napa River near Napa (11458000)

figure 8
Sonoma Creek Conceptual Design

Sonoma Creek and Napa River Flood Hydrographs

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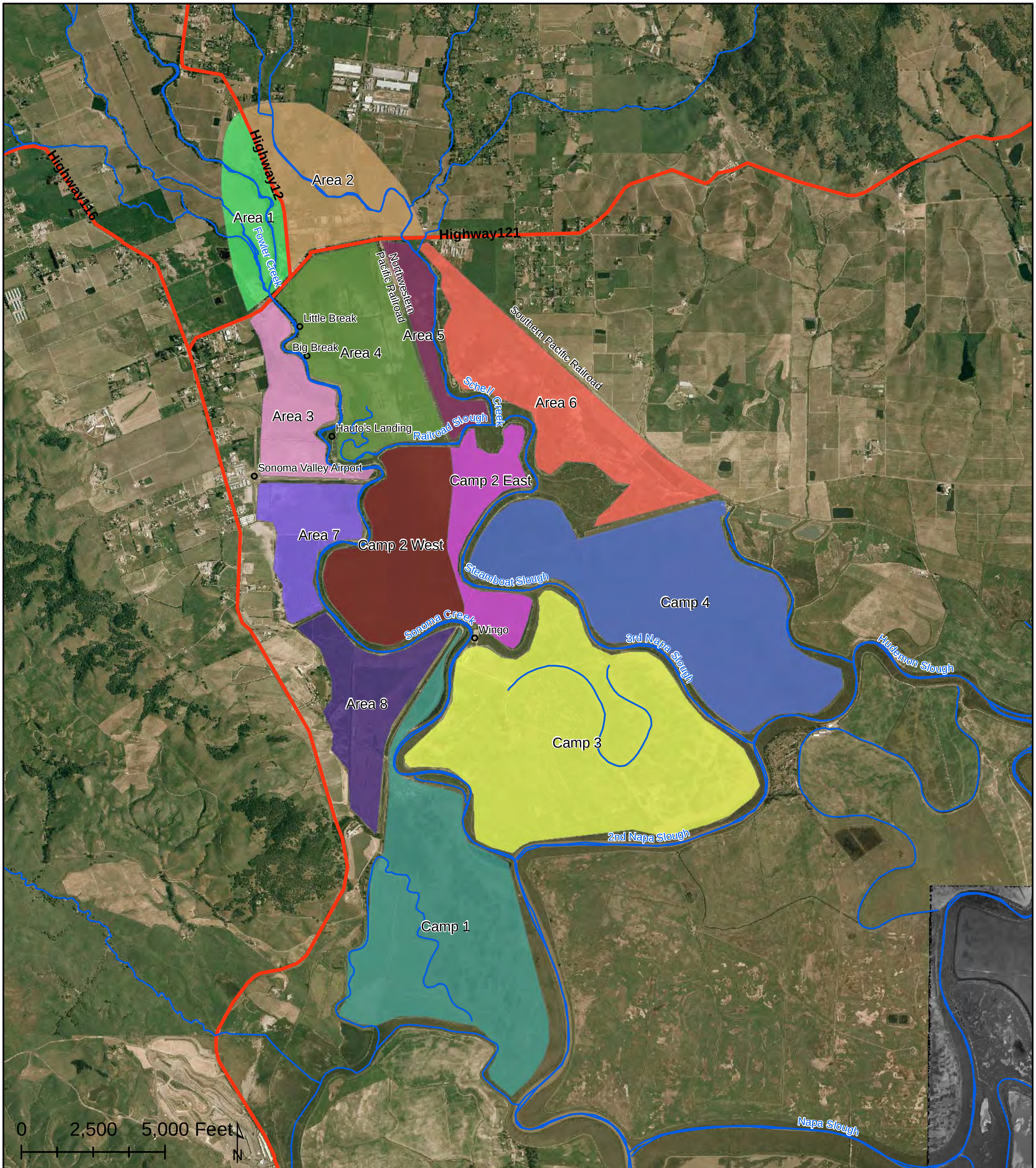

Legend

■	Camp 1	■	Area 1	■	Area 5
■	Camp 2 East	■	Area 2	■	Area 6
■	Camp 2 West	■	Area 3	■	Area 7
■	Camp 3	■	Area 4	■	Area 8
■	Camp 4				

figure 9

Sonoma Creek Conceptual Design
Area, Stream, and Place Names

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PWA

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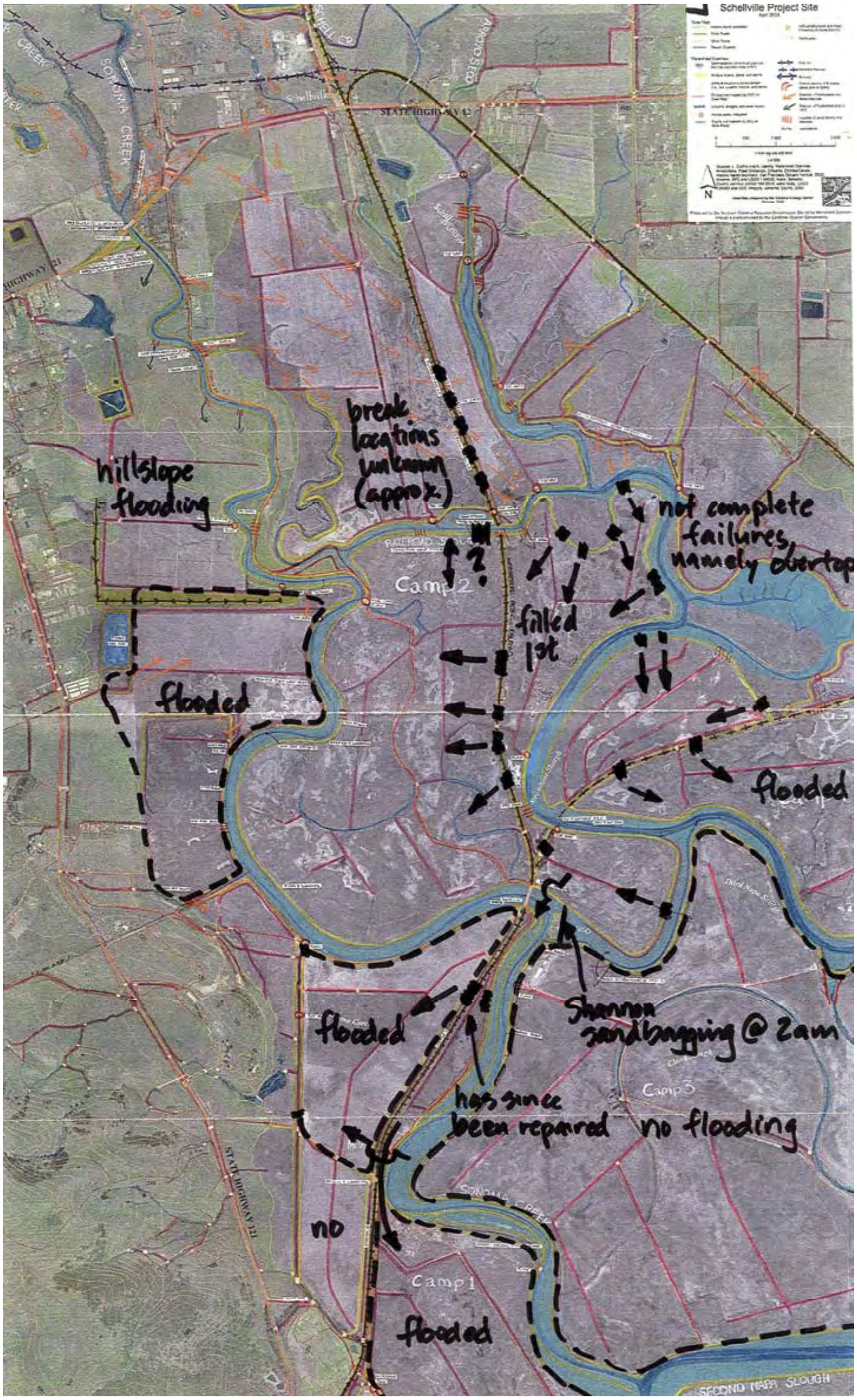

Source: Base map from Collins and Leising, 2004
Notes: Annotations indicate flooding patterns and levee overtopping locations as specified by local landowners during the 9-12-07 stakeholder meeting

figure 10
Sonoma Creek Conceptual Design

Flooding and Levee Overtop Locations for NYE 05' Flood Event

PWA Ref# 1844.00

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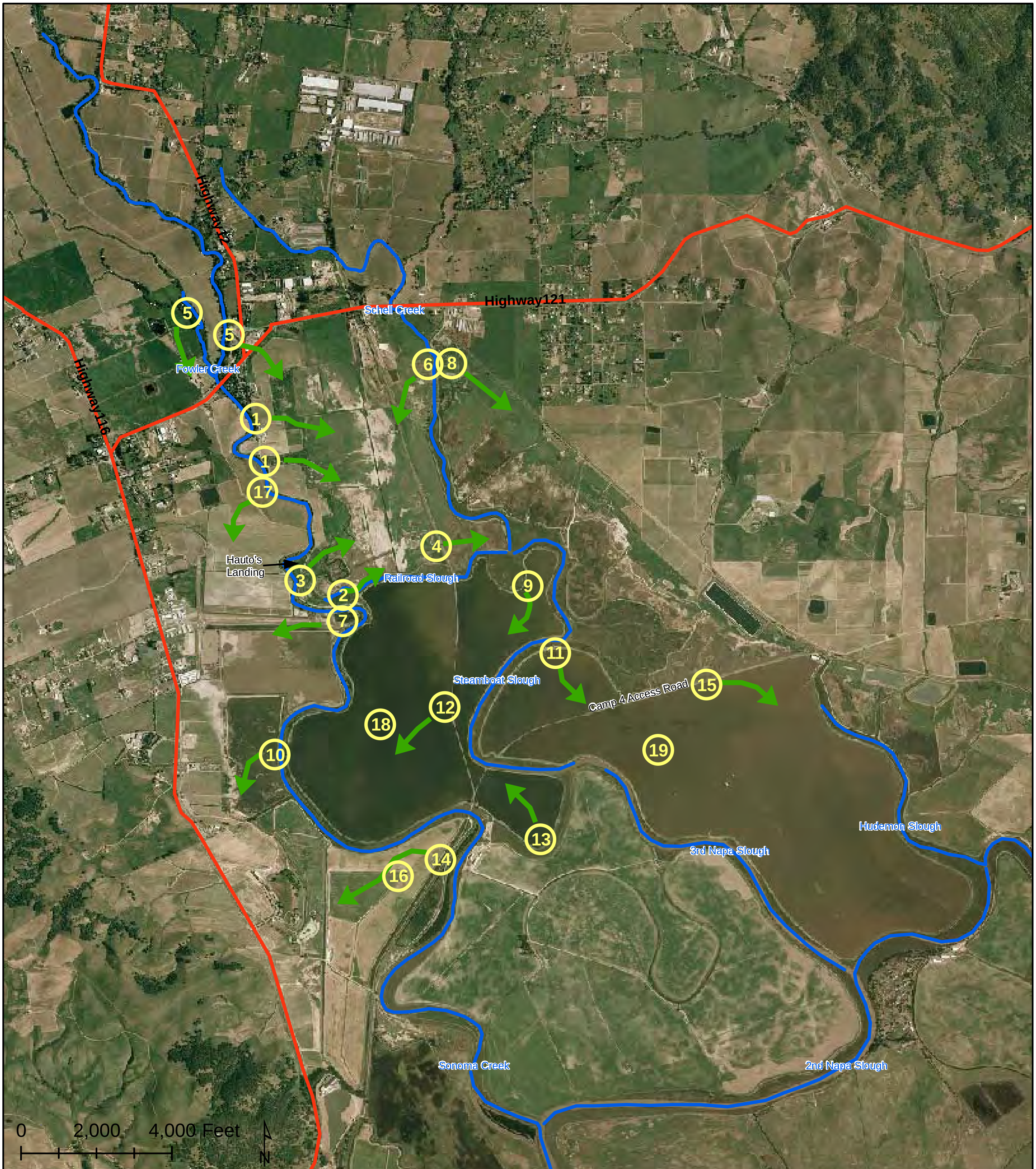

Legend

Aproximate Flow Direction

Breakout Points (See Table 6)

Modeled Reaches

Highways

figure 11

Sonoma Creek Conceptual Design

NYE Flood Breakout Locations and Flow Paths

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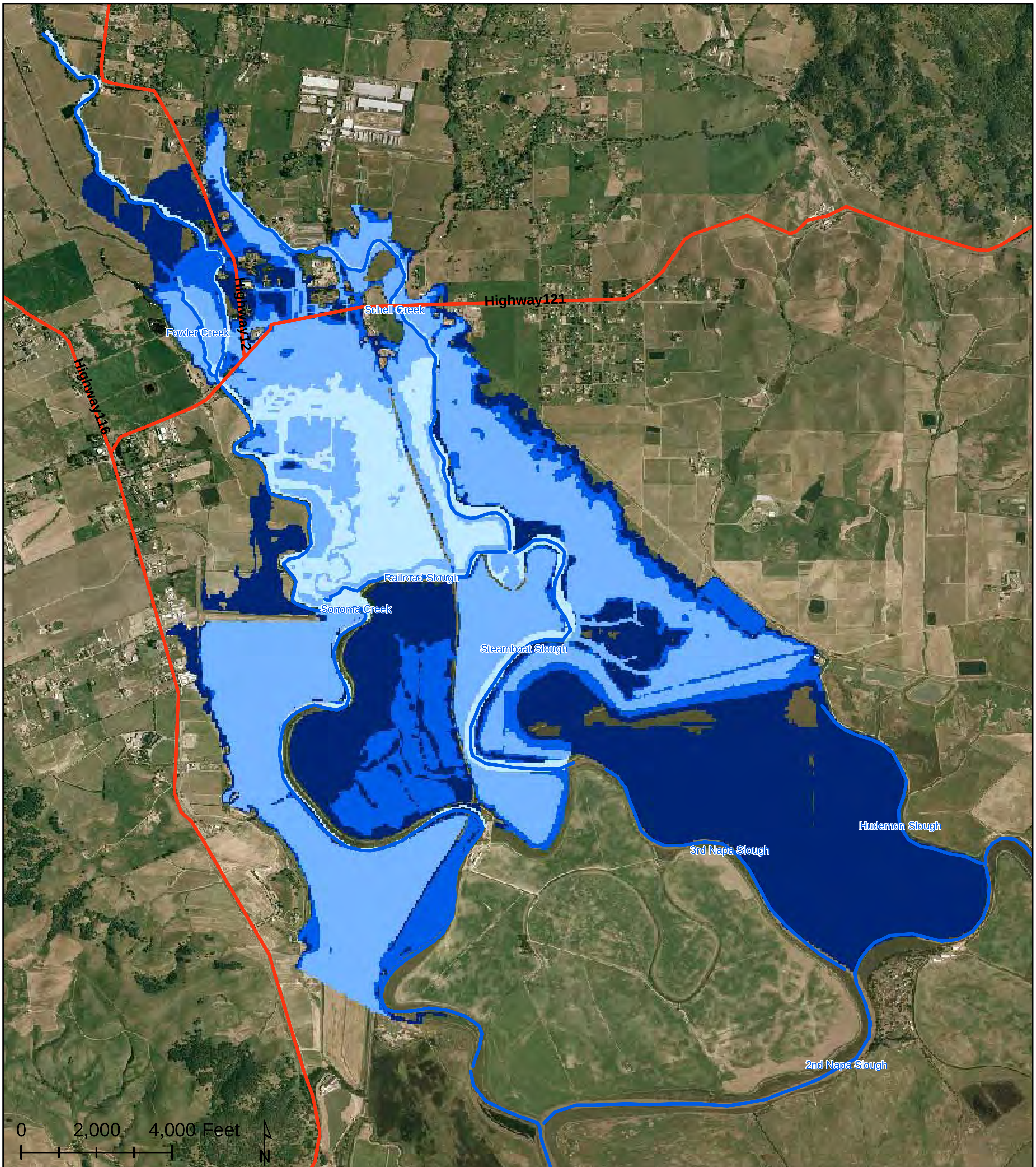

Legend

- 2-yr Flood Inundation Extent
- 10-yr Flood Inundation Extent
- 25-yr Flood Inundation Extent
- 100-yr Flood Inundation Extent
- Modeled Reaches

figure 12

Sonoma Creek Conceptual Design

2-, 10-, 25-, and 100-yr Flood Inundation Extents

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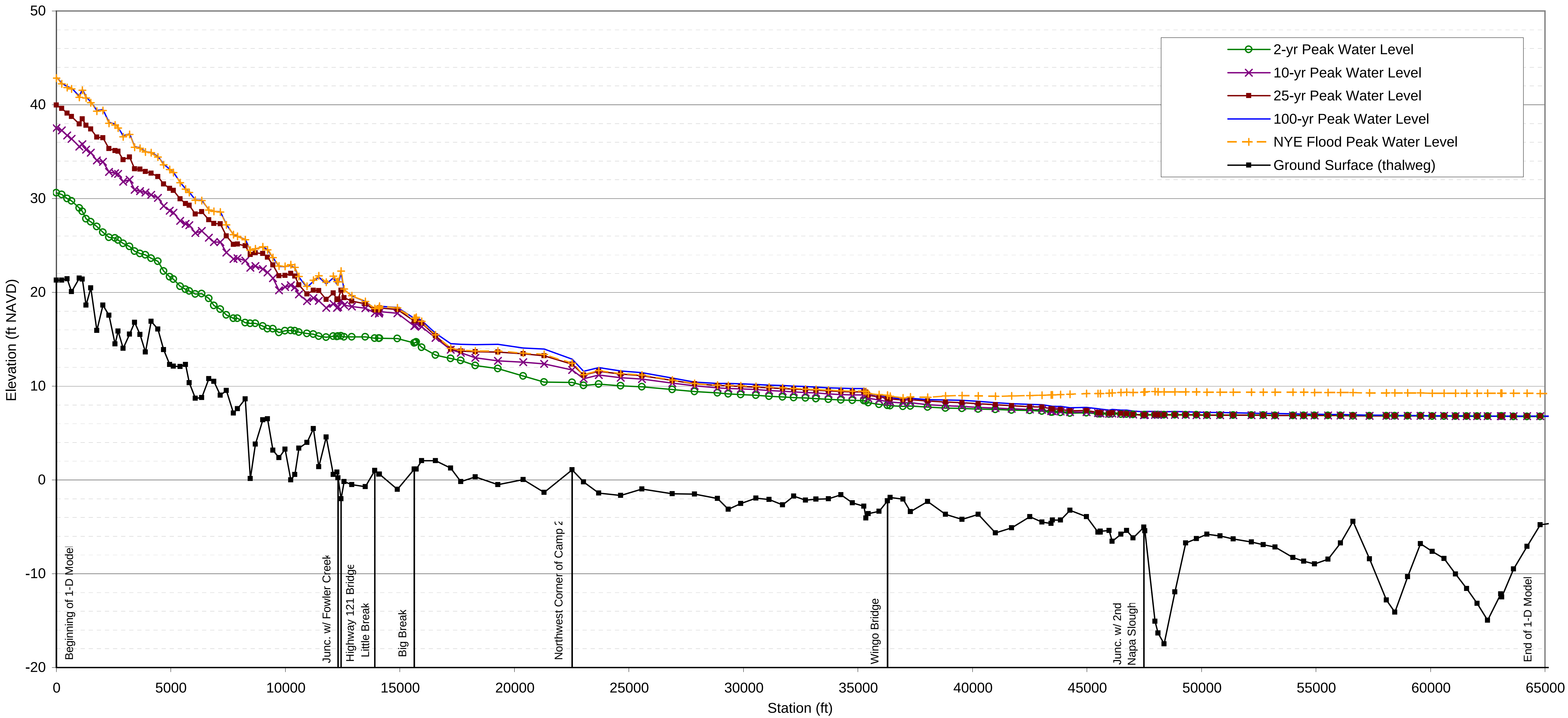

Source: MIKE Flood model

figure 13

Sonoma Creek Conceptual Design

Sonoma Creek Flood Model Results for the NYE 2005 Storm and the 2-, 10-, 25-, and 100-yr Events

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PWA

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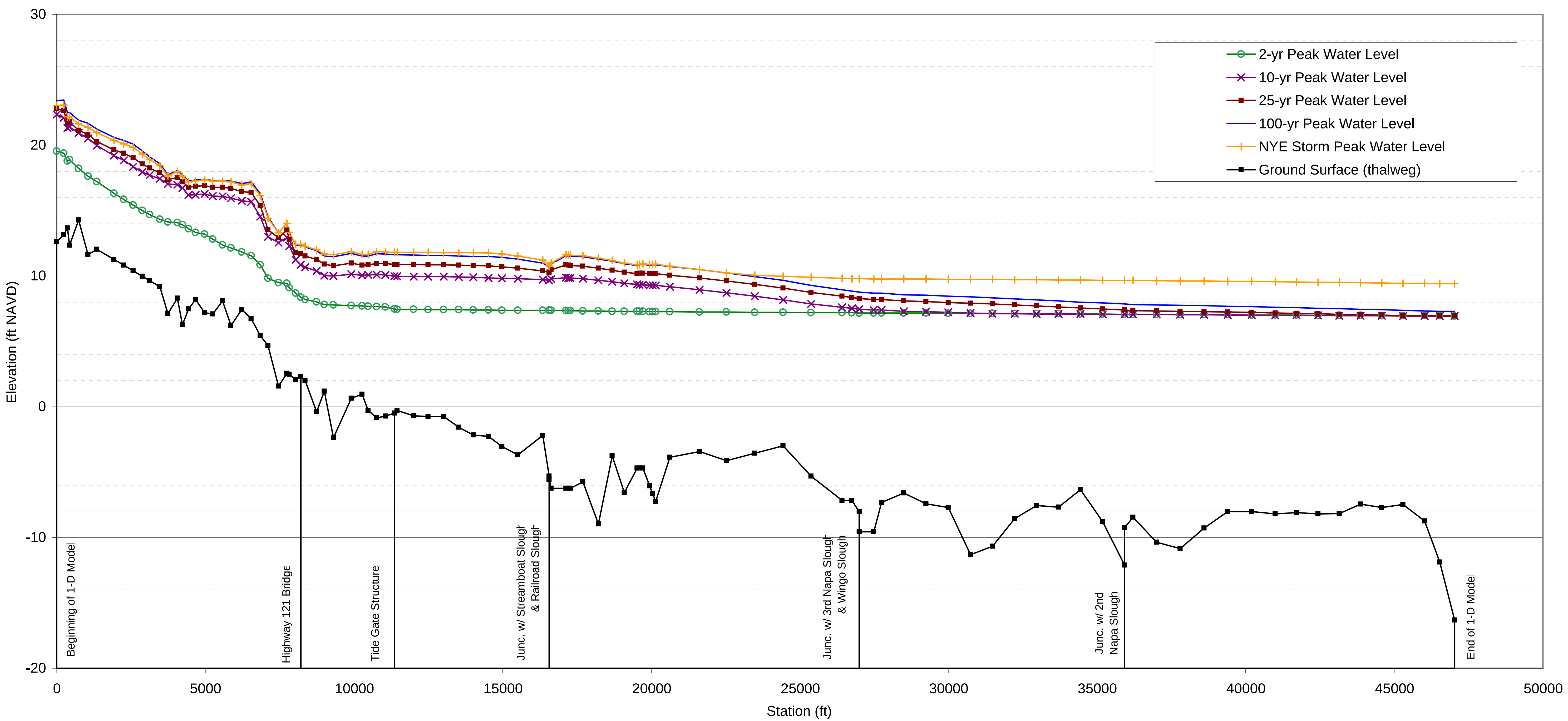

Source: MIKE Flood model

figure 14

Sonoma Creek Conceptual Design

Schell Creek Flood Model Results for the NYE 2005 Storm and the 2-, 10-, 25-, and 100-yr Events

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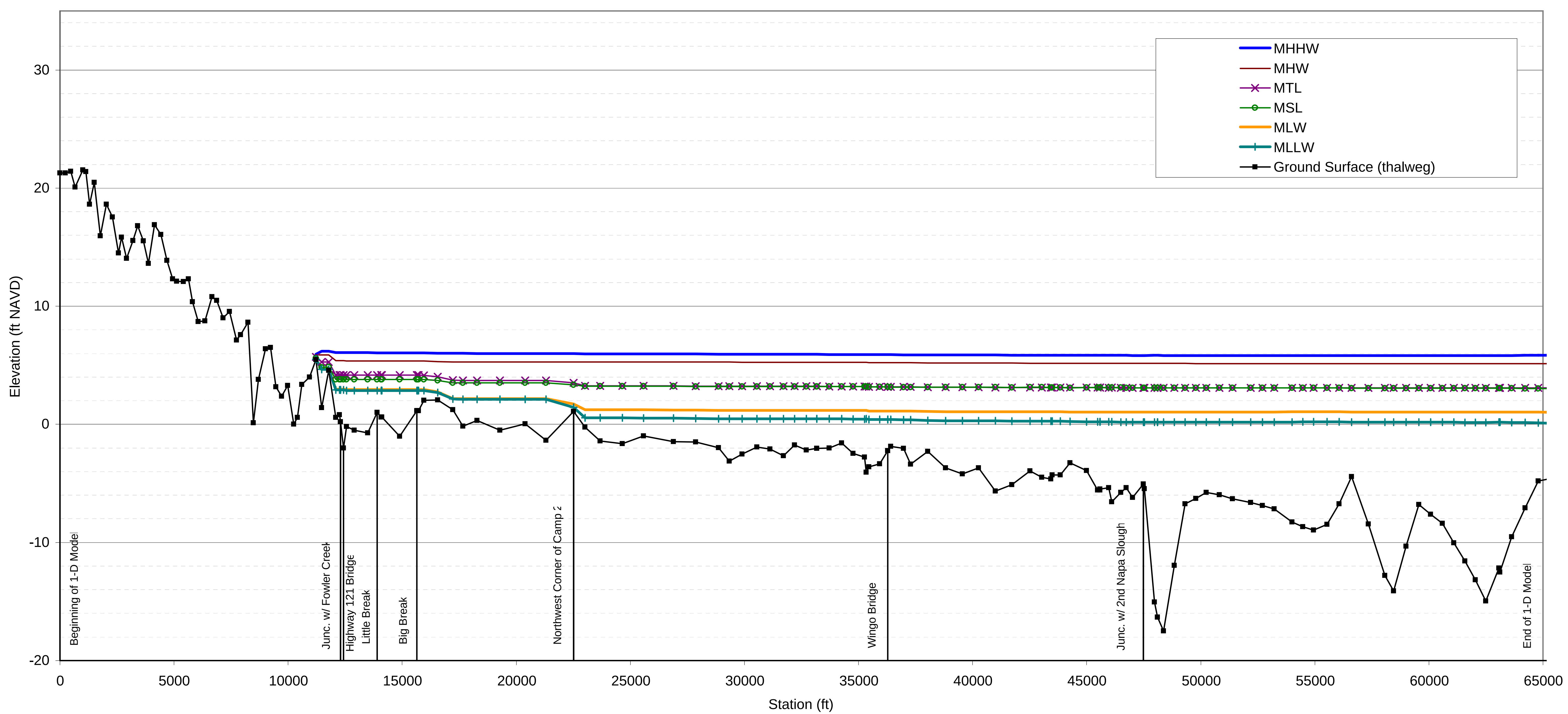

Notes: MIKE Flood model

figure 15

Sonoma Creek Conceptual Design

Tidal Datums for Sonoma Creek - Zero Inflow and No Sea Level Rise

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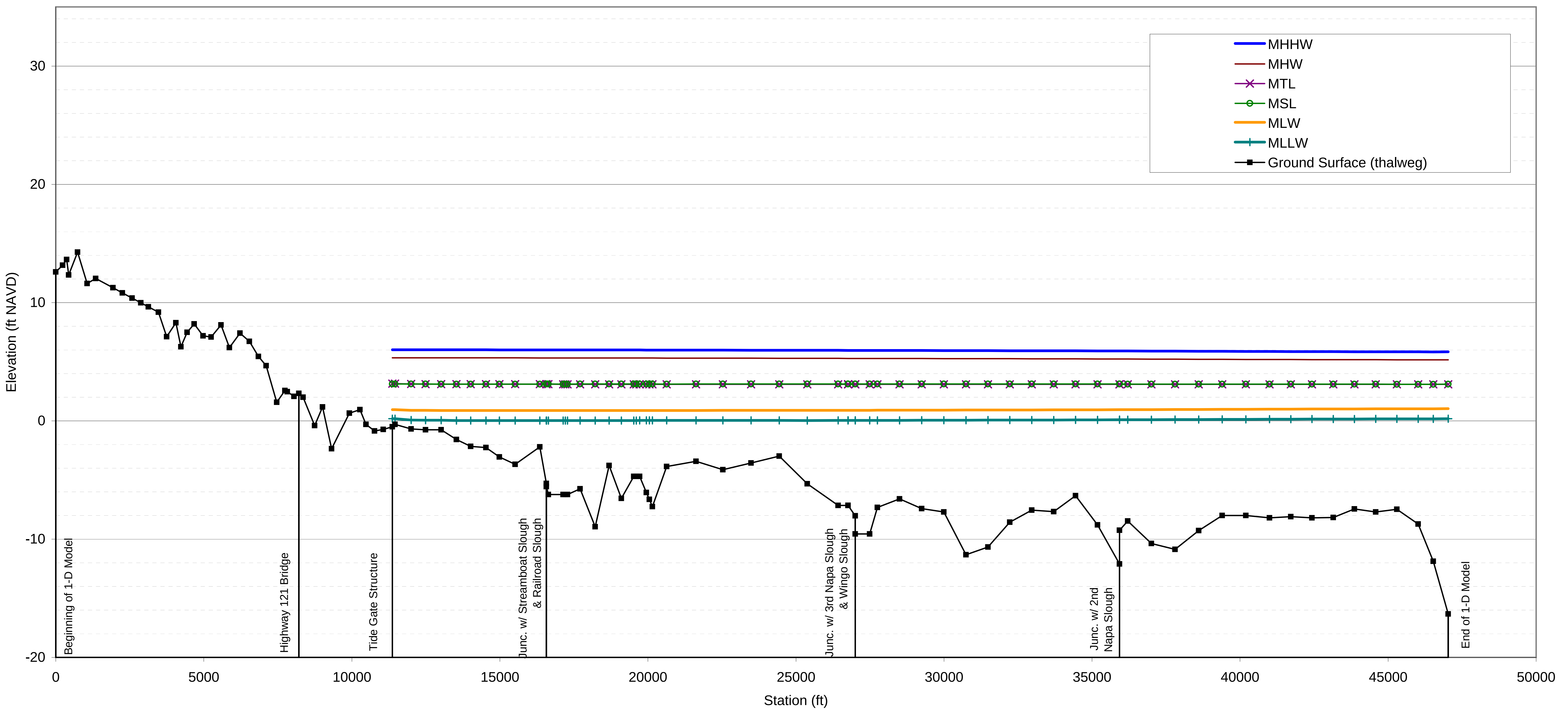
PWA

1844_TidalDatums_fromM11.xls / SC - Run1all - LPfig



Notes: MIKE Flood model

figure 16

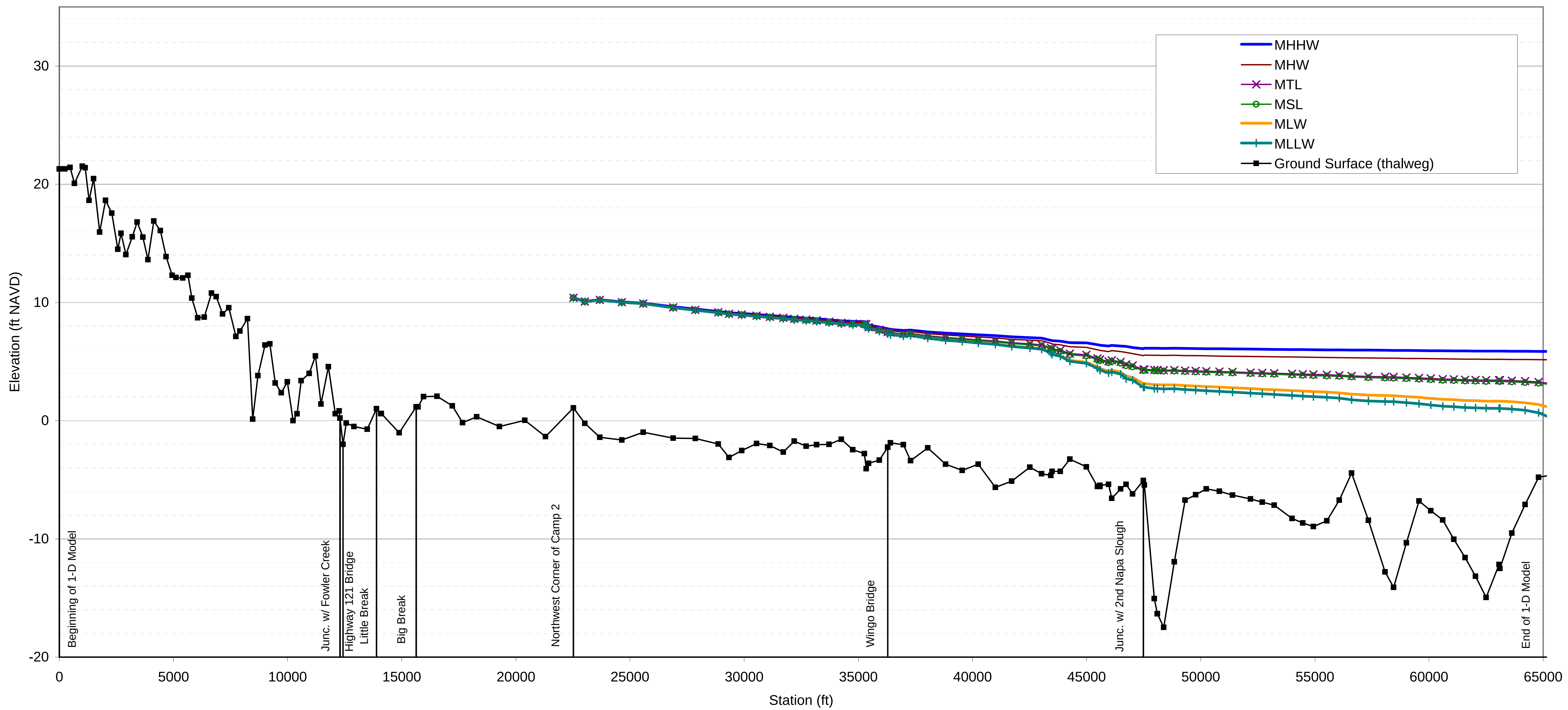
Sonoma Creek Conceptual Design

Tidal Datums for Schell Creek - Zero Inflow and No Sea Level Rise

PWA Ref# 1844.00

PWA

1844_TidalDatums_fromM11.xls / Sch - Run1all - LPfig



Notes: MIKE Flood model

figure 17

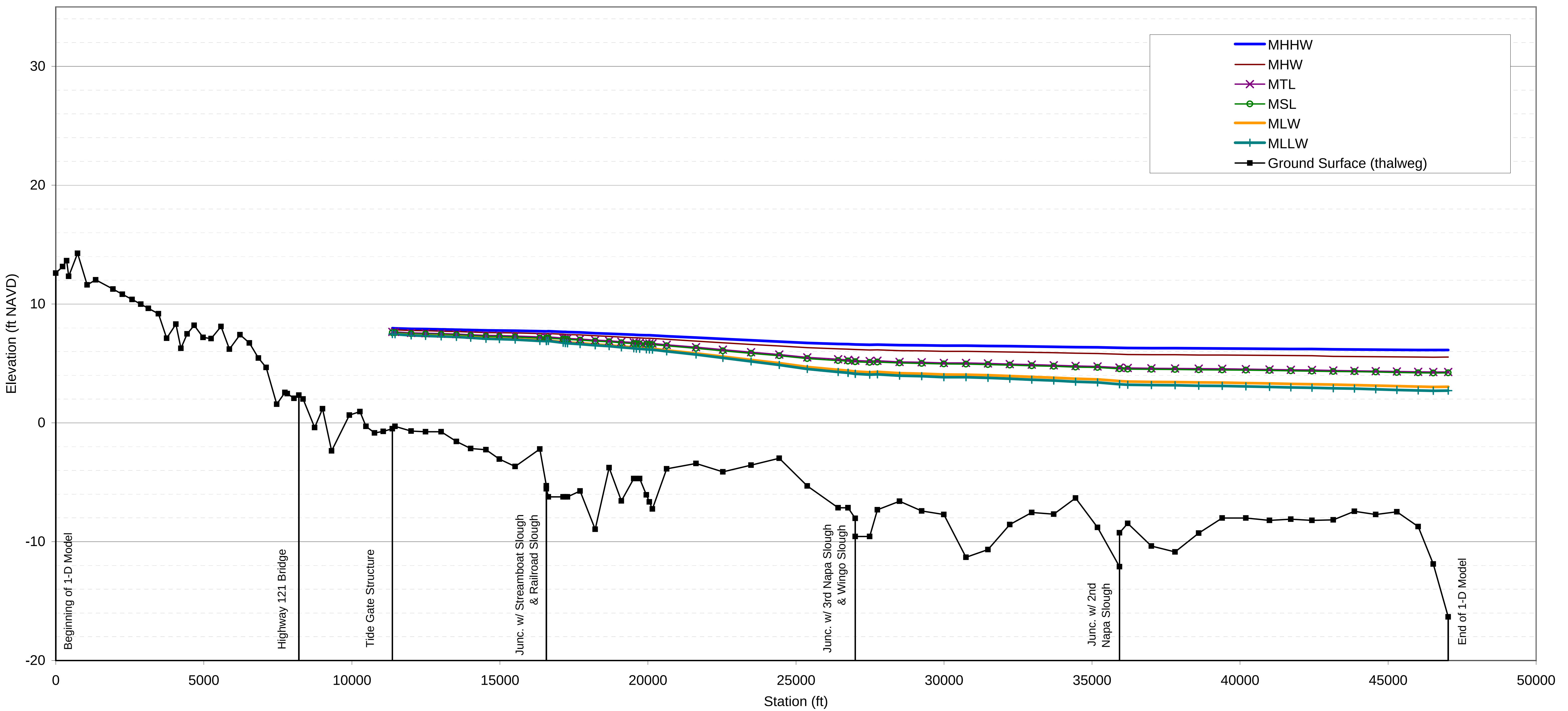
Sonoma Creek Conceptual Design

Tidal Datums for Sonoma Creek - Q2 Inflow and No Sea Level Rise

PWA Ref# 1844.00

PWA

1844_TidalDatums_fromM11.xls / SC - Run2all - LPfig



Notes: MIKE Flood model

figure 18

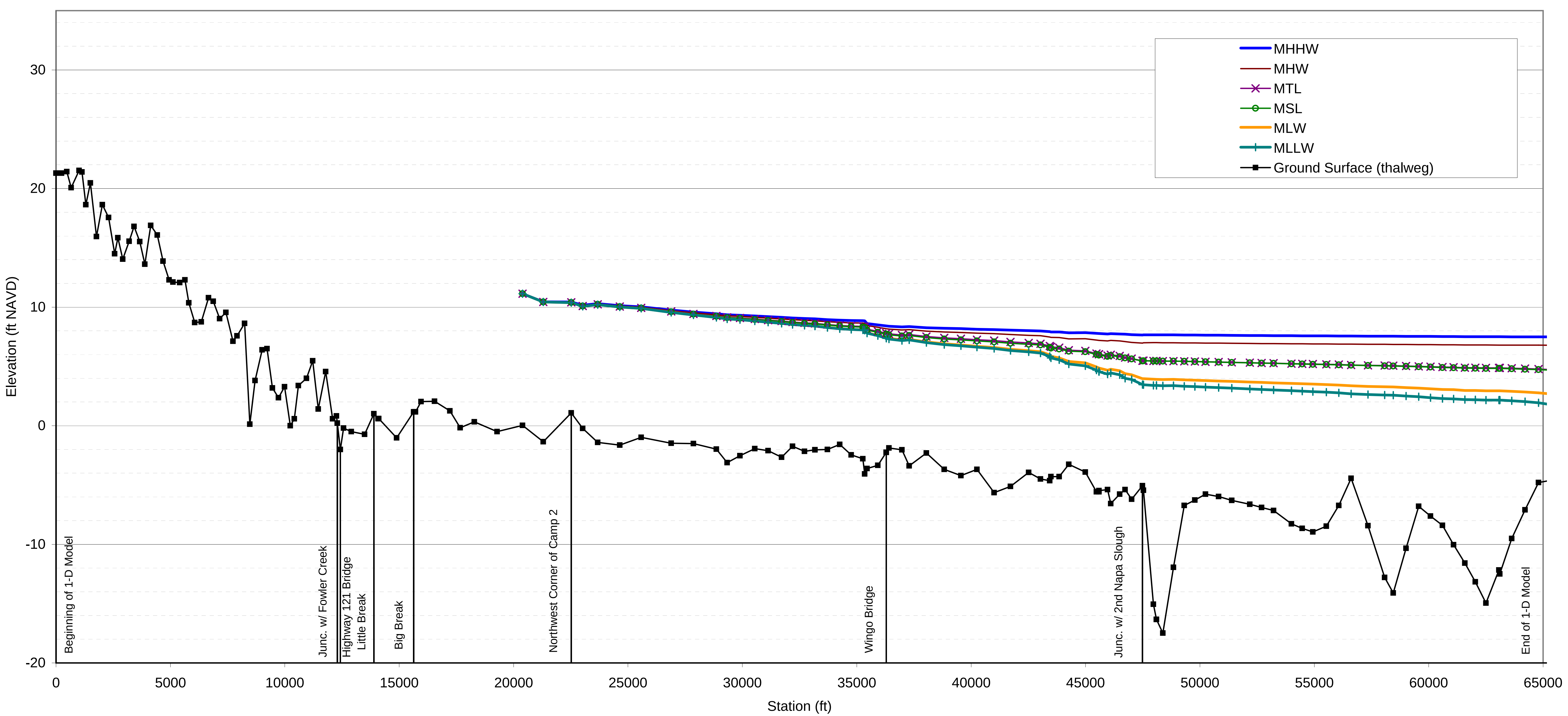
Sonoma Creek Conceptual Design

Tidal Datums for Schell Creek - Q2 Inflow and No Sea Level Rise

PWA Ref# 1844.00

PWA

1844_TidalDatums_fromM11.xls / Sch - Run2all - LPfig



Notes: MIKE Flood model

figure 19

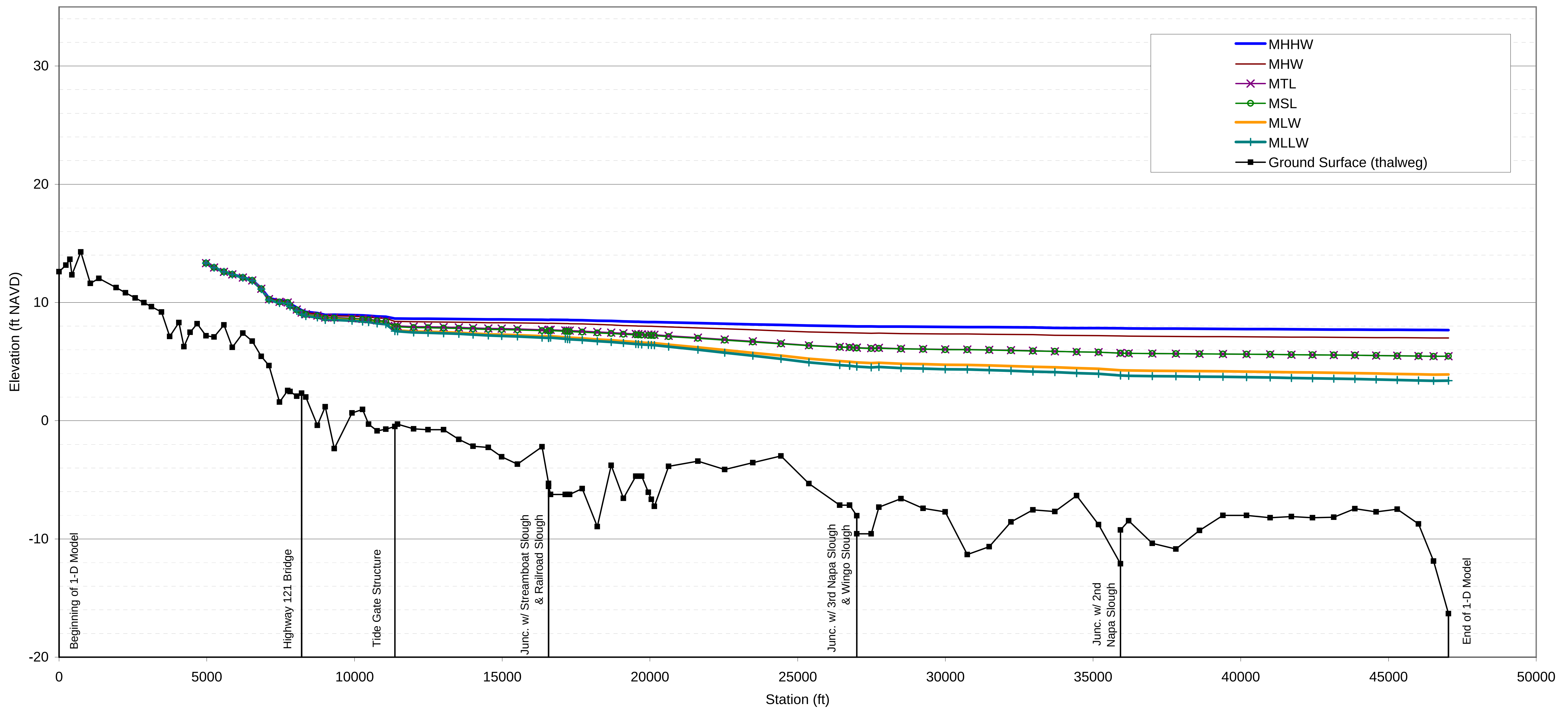
Sonoma Creek Conceptual Design

Tidal Datums for Sonoma Creek - Q2 Inflow with 0.5 m Sea Level Rise

PWA Ref# 1844.00

PWA

1844_TidalDatums_fromM11.xls / SC - Run3all - LPfig



Notes: MIKE Flood model

figure 20

Sonoma Creek Conceptual Design

Tidal Datums for Schell Creek - Q2 Inflow with 0.5 m Sea Level Rise

PWA Ref# 1844.00

PWA

1844_TidalDatums_fromM11.xls / Sch - Run3all - LPfig

APPENDIX B

PHOTOS OF RECENT FLOOD EVENTS

PHOTOS OF RECENT FLOOD EVENTS

NYE 2005 Flood (December 31, 2005 – January 1, 2006) – approximately a 100-year event

Photo 1. After the flood: Highway 12 at Highway 121. (Photo from Sonoma Ecology Center website)

Photo 2. Jan 1, 2006. Looking south to Highway 121 at the Sonoma Creek Bridge. The area at the intersection of Highways 12 and 121 visible on the left floods due to multiple levee breaks in the eastern levee along Sonoma Creek. Fowler Creek is visible on the right. (Photo by Jeff Haltiner, PWA)

Photo 3. Jan 1, 2006. View from the south of Big Break, a low spot in the eastern Sonoma Creek levee south of the Larson Winery and north of Camp 2. (Photo by Jeff Haltiner, PWA)

Photo 4. Jan 1, 2006. Looking south along Arnold Drive, downstream of Highway 121. Sonoma Creek and the corner of Camp 2 is visible in the upper left. The airport runway is the swath of dry ground visible mid-left. In the foreground is inundation from an unnamed stream flowing from the Sonoma Mountains. (Photo by Jeff Haltiner, PWA)

January 4, 2008: approximately a 5-year flood event

Photo 5. View south along Highway 12 to Highway 121. Note rootwad in the roadway. (Photo by Betty Andrews, PWA)

Photo 6. View south along Sonoma Creek at levee breaks just upstream of Highway 121. (Photo by Betty Andrews, PWA)

Photo 7. Looking upstream at the Highway 121 Bridge across Sonoma Creek. (Photo by Betty Andrews, PWA)

Photo 8. Intersection of Millerick Road with Highway 121. Note root wad visible to the left on the highway. (Photo by Betty Andrews, PWA)

Photo 9. Looking downstream at the Highway 121/12 Bridge across Schell Creek. (Photo by Betty Andrews, PWA)

Photo 10. View across the Viansa wetlands northeast across Camp 2. (Photo by Betty Andrews, PWA)

APPENDIX C

SCREENING ANALYSIS MEMORANDUM
June 30, 2008

PWA
PHILIP WILLIAMS & ASSOCIATES, LTD
ENVIRONMENTAL HYDROLOGY
550 Kearny Street, Suite 900
San Francisco, California 94108-2404
TEL 415.262.2300 FAX 415.262.2303
www.pwa-ltd.com

MEMORANDUM

Date:	June 30, 2008
To:	Susan Haydon
Organization:	Southern Sonoma RCD
From:	Betty Andrews and Matt Wickland
PWA Project #:	1844.01
PWA Project Name:	Sonoma Creek Conceptual Design – Hydraulic Modeling
Subject:	Task 5 - Screening Analysis
Copy(ies) To:	Leandra Swent, SSRCD

The Southern Sonoma County Resource Conservation District (RCD) has contracted with Philip Williams & Associates, Ltd. (PWA) to develop a conceptual design for a project that achieves the dual goals of flood management and ecosystem enhancement in Lower Sonoma Creek in the vicinity of Schellville. The project reach extends generally from Watmaugh Road downstream to the mouth of Sonoma Creek at the Bay. As the first step towards defining a project concept, PWA developed some simple approaches for evaluating the broad nature of the flood management opportunities posed by several schematic project elements. This memorandum provides a text summary of what we learned from these screening analyses. **Attachment A** provides a print version of a presentation made to the RCD on this material and **Attachment B** provides notes to the files documenting our methodology for each analysis.

Background

PWA has developed a hydrodynamic model (MIKE FLOOD) of the Sonoma Creek system to evaluate flooding mechanisms and test alternatives for flood management. Prior to developing full-blown project alternatives in this model, we have conducted a series of simpler screening analyses to test potential project elements for their effectiveness. A variety of simpler hydraulic models and other hydraulic analysis methods, as well as one application of the MIKE FLOOD model, were used to test the potential for a range of management approaches to reduce flood levels in Sonoma Creek. The results of these initial screening analyses are briefly summarized below.

The elements examined in this analysis include the following:

1. Highway 121 Bridge capacity
2. Widened channel corridor
3. Storage at Camp 2
4. Railroad Slough overflow
5. Enhanced tidal scour

Screening Analyses

Highway 121 Bridge capacity

PWA created a HEC-RAS hydraulic model of a limited reach of the Sonoma Creek channel to test whether the Highway 121 Bridge limits the conveyance of flood flows in Sonoma Creek. The results of this test indicate that the Highway 121 Bridge structure itself has greater potential conveyance capacity than the creek channel itself and therefore does not constitute a significant flow restriction. The model was used to test the effect of expanding the channel width to provide a 100- or 130-foot bottom width through the bridge, which greatly increased the conveyance capacity of the existing bridge. Widening of the channel through the bridge up to 130 feet appears to be feasible based on the available sheets from the original bridge plans. These results indicate that expanding the Sonoma Creek channel capacity through the bridge and some distance downstream would be necessary to achieve a significant improvement in conveyance capacity. If the channel is expanded to a 130-foot bottom width, the bridge is capable of passing up to approximately 22,000 cfs, a value approaching the estimated 100-year design discharge at the bridge.

Widened channel corridor

A simple HEC-RAS model was developed to further assess how an increase in channel area would affect peak water levels in Sonoma Creek. We tested two channel modification scenarios for the reach downstream of Highway 121/12: *existing* channel cross sections with an excavated floodplain terrace of 100 to 200 feet in width and *widened* channel cross sections (100 to 250-foot wide bottom width down to the junction with 2nd Napa Slough) with a floodplain terrace of 100 to 250 feet in width (modified USACE design). The water depth above the existing levees can be considered a rough estimate of how much higher a levee would need to be to contain the 100-year flood event on Sonoma Creek for each of the two scenarios. For the widened cross section with a floodplain terrace, the maximum increase required to contain the 100-year flood is less than 2 feet, or about 1.5 feet for a 10-year flood event. This widened channel design, however, would be expected to act as a sediment trap, and the channel would most likely fill in to a size similar to existing conditions over time. For the scenario using existing cross sections with a widened terrace, levee heights would need to be extremely high to contain the 100-year event: up to approximately 16 feet, or up to 13 feet to contain a 10-year event.[1] This result suggests that increasing the channel capacity alone may not be a practical approach to contain a 100- or even a 10-year

[1] For comparison, if we were hypothetically to contain the 100-year flow in its entirety in the present channel *without* an excavated floodplain, the levees would need to be up to (an entirely unrealistic) 29 feet higher, demonstrating the significant flow area provided by the excavated floodplain.

flood event, or that a channel corridor significantly wider than the 100- to 200-foot width evaluated here would be required.

A simple Manning's analysis of required channel area to convey various recurrence interval discharges in the reach downstream of Highway 121 was then conducted to further explore this option. The analysis suggests that the present channel area can convey about a 2-year peak flow. The flow area would need to be more than 3 times as large to convey a 10-year peak flow, and 5 times as large to convey a 100-year peak flow, assuming a roughness value of n = 0.045, representative of some degree of vegetation in the channel.

Storage at Camp 2

The influence on upstream peak water levels in Sonoma Creek of offline flood water storage in Camp 2 was analyzed using a simplified spreadsheet model and results from the MIKE FLOOD hydraulic model of Sonoma Creek. The two storage area options analyzed were the entire western half of Camp 2 (east of the railroad tracks) and a 500-foot wide strip along the western levee of Camp 2. Stage-discharge relationships from the model in combination with standard weir flow relationships were used to estimate the effect of a weir located on the left bank (eastern levee) of Sonoma Creek near the northwest corner of Camp 2, allowing flow over the weir into Camp 2. By comparing the water surface elevation that would exist in the channel with and without the flow across the weir, a potential reduction in peak water levels was calculated.

Making the entire western half of Camp 2 available for flood storage offers a greater potential reduction in water levels than a 500-foot buffer in Camp 2, due to the greater storage volume available. The larger area produced maximum reductions in peak water levels ranging from 2.8 to 3.4 feet. The smaller area required a higher weir elevation to maximize peak water level reductions, but only showed reductions of little more than one foot, which would most likely not cause a significant effect upstream in the vicinity of Highway 121.

Railroad Slough overflow

The MIKE FLOOD model for Sonoma Creek was adapted to include a connection between Sonoma Creek and Railroad Slough near the northwest corner of Camp 2. A weir was added to the model that would allow water to spill from Sonoma Creek during small flood events and be routed to the east through Railroad and Steamboat Sloughs. During the 10-year flood event, a trivial reduction in peak water elevations resulted from the connection of Sonoma Creek and Railroad Slough, as water levels in each system were similar in floods of this size. A more significant decrease in peak water levels occurred during the 2-year event, with a maximum decrease of 0.71 feet for the weir set at an elevation of 6.6 ft

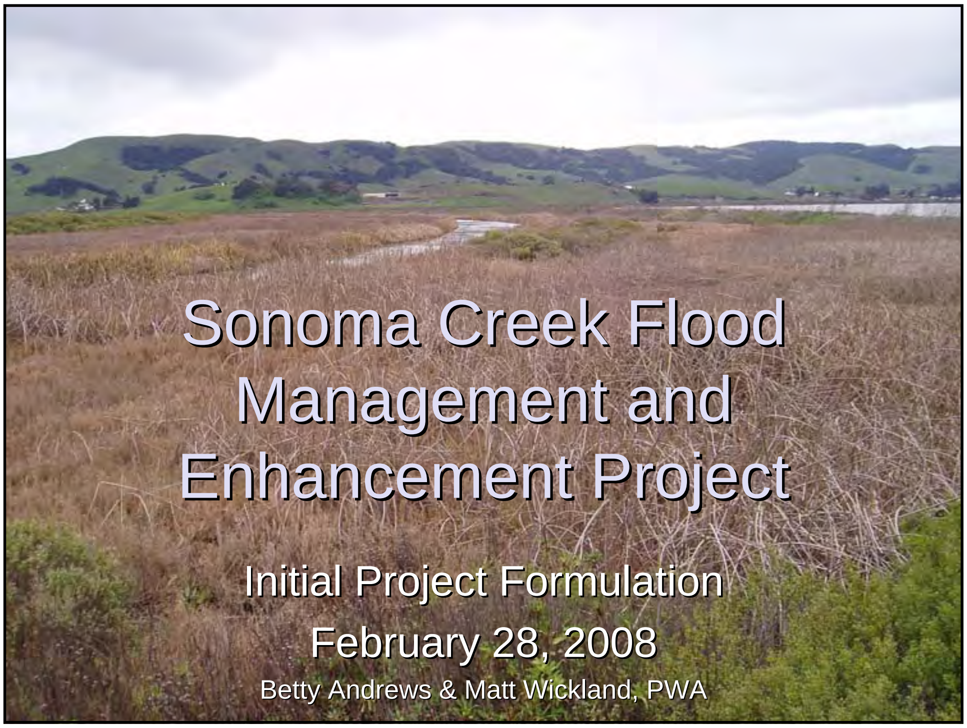
NAVD 88. This maximum reduction in water levels, however, occurs right at the northwest corner of Camp 2 near the airport runway and does not extend very far upstream.

Based on this screening-level analysis, connecting Sonoma Creek and Railroad Slough with a weir would only affect water levels during higher frequency (lower flow) events and would not cause reductions in peak water levels upstream near Highway 121.

Enhanced tidal scour

PWA used hydraulic geometry relationships to estimate how natural scour associated with the restoration of former tidal marsh lands at Camp 2 might affect the capacity of the Sonoma Creek channel downstream of a connection to Camp 2. Two restoration scenarios were evaluated: the portion of Camp 2 west of the railroad tracks and a 500 foot-wide strip in Camp 2 along the course of Sonoma Creek. Hydraulic geometry relationships for tidal marshes in the San Francisco Bay area (Williams, et al, 2002) were used to estimate the long-term channel geometry for each scenario.

The results of the hydraulic geometry analysis indicate that both restoration options could cause a significant increase in channel area compared to existing conditions. This increase in channel area results in an increase in channel capacity compared to existing conditions of approximately 7 to 13 times for Option 1 and approximately 2 to 3.5 times for Option 2. The effect of increased channel capacity in the vicinity of Camp 2 on water levels at Highway 121 has not been assessed; however, based on the results of the Railroad Slough overflow analysis, it is not expected to be significant.


Sonoma Creek Flood Management and Enhancement Project
Initial Project Formulation
February 28, 2008
Betty Andrews & Matt Wickland, PWA

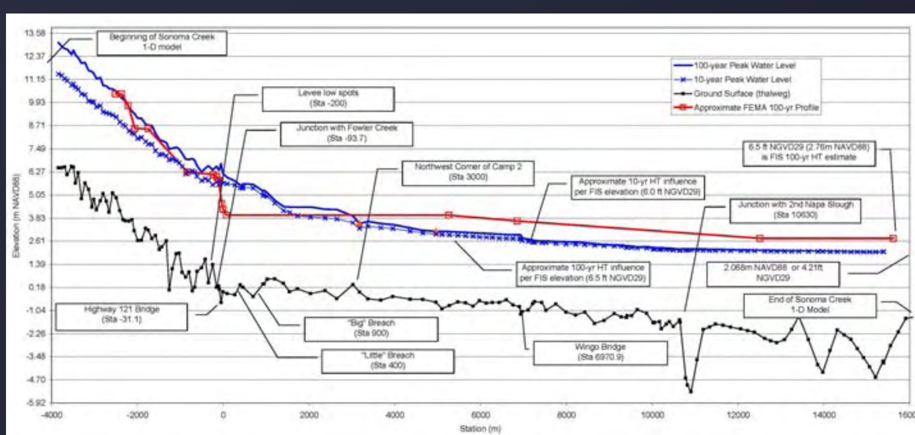

Presentation
1. Background (flood setting)
2. Screening analyses findings
3. Priority objectives
4. Design principles
5. Strawman initial alternatives

Flooding Analysis: Background

The influence of fairly routine high tides controls the maximum water surface elevation during floods up to ~NW corner of Camp 2

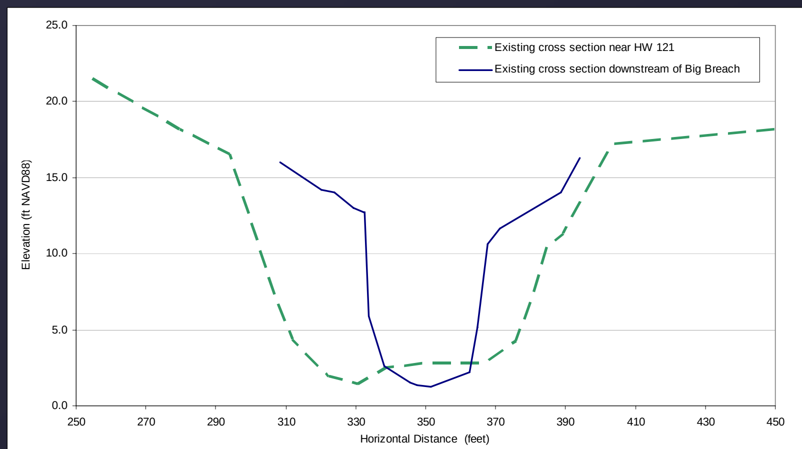
- Current channel capacity is significantly reduced below “Big Break” (by ~2/3) and remains very constrained down to the junction with 2nd Napa Slough
- Overbank flows and flooding of Hwy 121 will result from a flood event that is > 2-yr and < a 10-yr event under present conditions (~Q5?).

Flooding Analysis: Background



Long profile

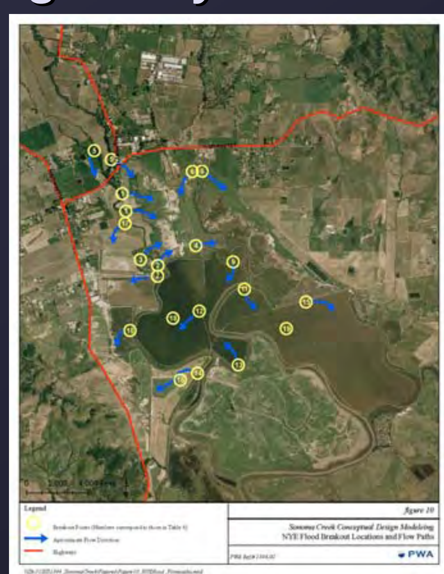
Flooding Analysis: Background



Cross section
comparison

PWA

Flooding Analysis: Background



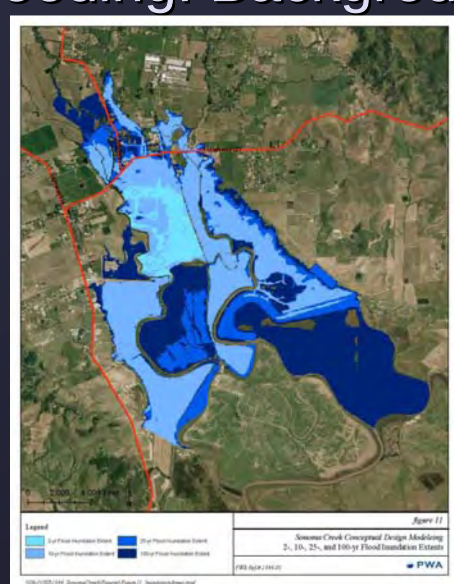
NYE flow paths

PWA

Flooding: Background

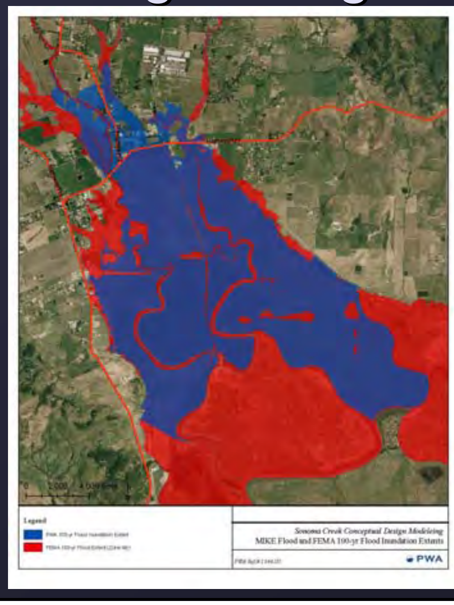
10-yr event movie

Flooding: Background



PWA flood extents

Flooding: Background



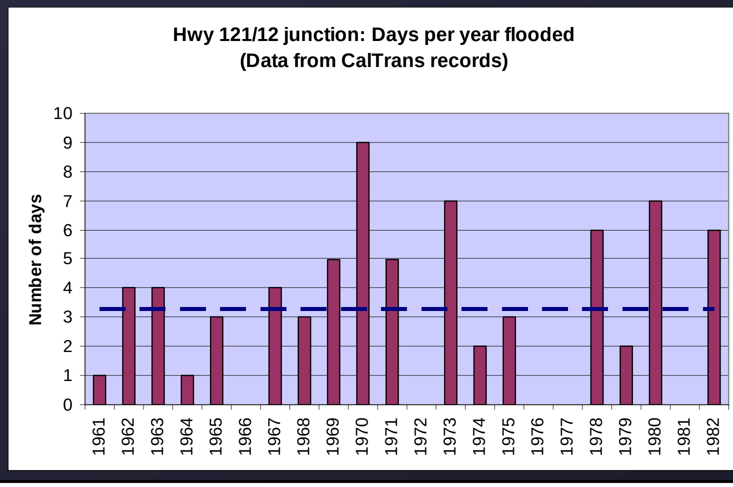
FEMA and PWA 100-year flood extents

Flood Setting - Hydrology

Return period (years)	Peak discharge at Agua Caliente (design flow, cfs)	Estimated discharge at Hwy 121 (cfs)
2	2,910	3,600
10	10,640	12,500
25	14,610	17,000
100	20,660	23,700

Flood Setting

Depths of 4 – 48 inches recorded in WY 1961-1982

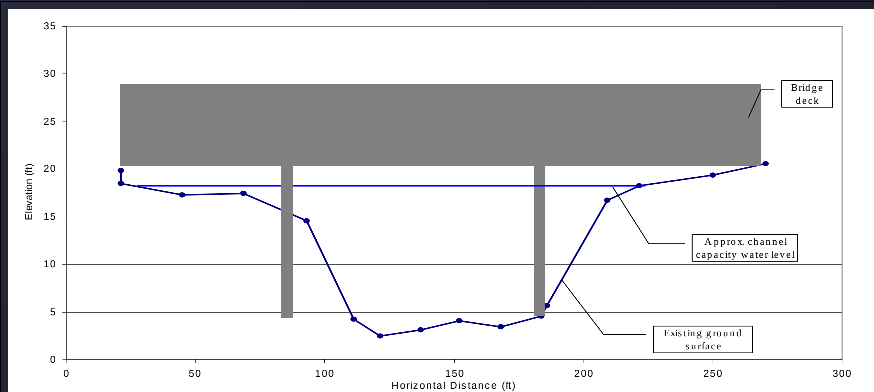


Screening Analyses: Specific

1. Hwy 121 bridge capacity
2. Conveyance corridor
3. Camp 2 detention storage
4. Tidal channel scour
5. Flow routing into Railroad Slough

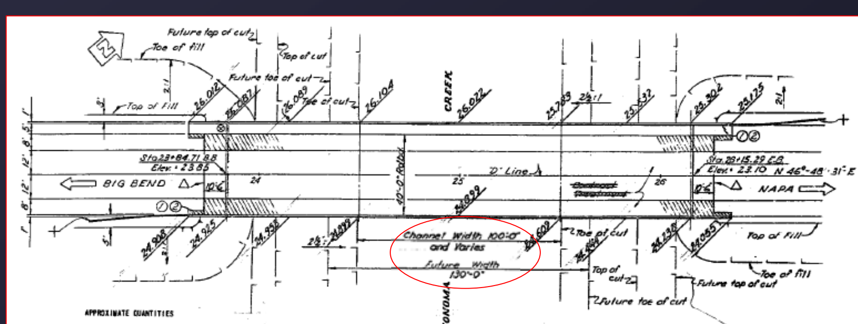
Screening Analyses: Hwy 121 Bridge

- Can pass up to ~4,000 cfs in existing channel to top of banks



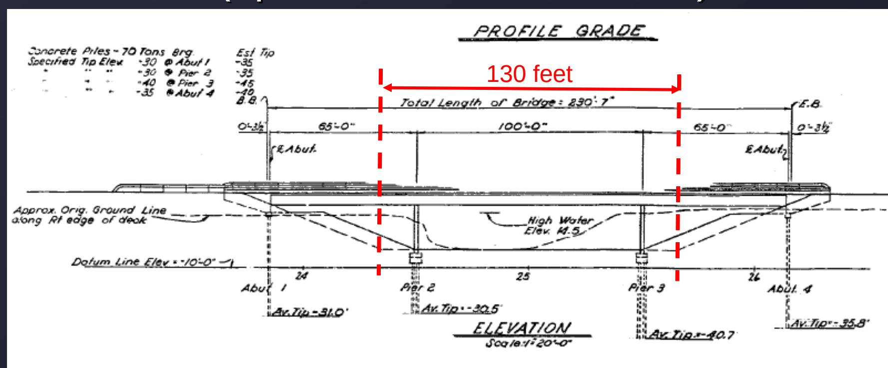
Screening Analyses: Hwy 121 Bridge

- Appears to have been designed to accommodate a significantly wider channel

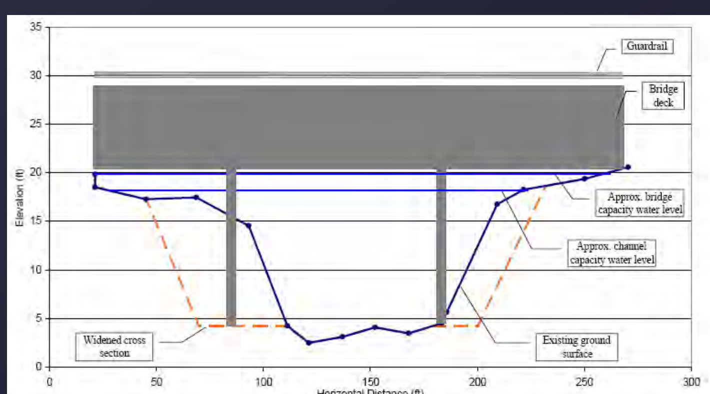


Screening Analyses: Hwy 121 Bridge

- Appears to have been designed to accommodate a significantly wider channel (up to 130 ft bottom width)



Screening Analyses: Hwy 121 Bridge



Could pass up to ~22,000 cfs (~Q100) with significant channel widening downstream and through the bridge and little freeboard

PWA

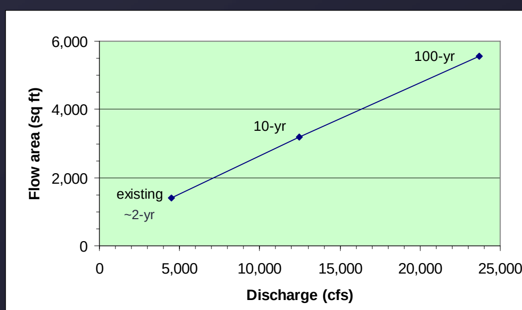
Screening Analyses: Conveyance Corridor

Widened channel corridor concept

- Existing channel area bottleneck occurs downstream of Hwy 121 after flow breakouts (e.g., “Big Break”)
- For habitat enhancement and better sediment transport, use terraced channel or flood terrace concept

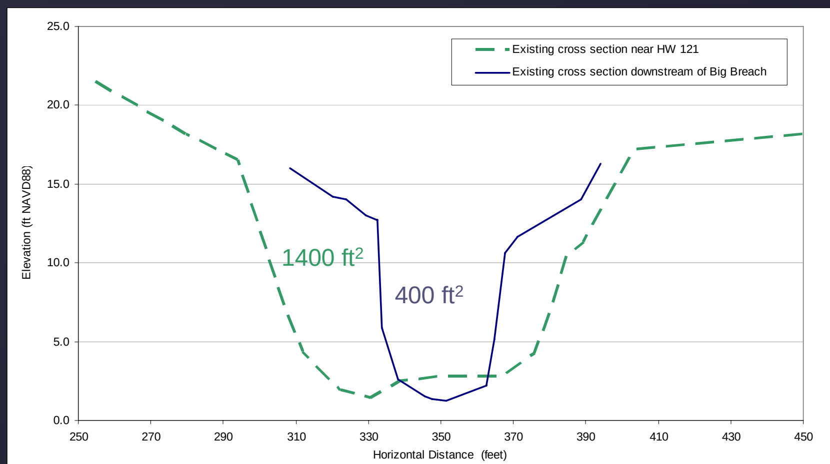
Screening Analyses: Conveyance Corridor

Widened channel corridor concept: how much area would you need?



Area-discharge relationship between Hwy 121 and “Big Break” (at n=0.045)

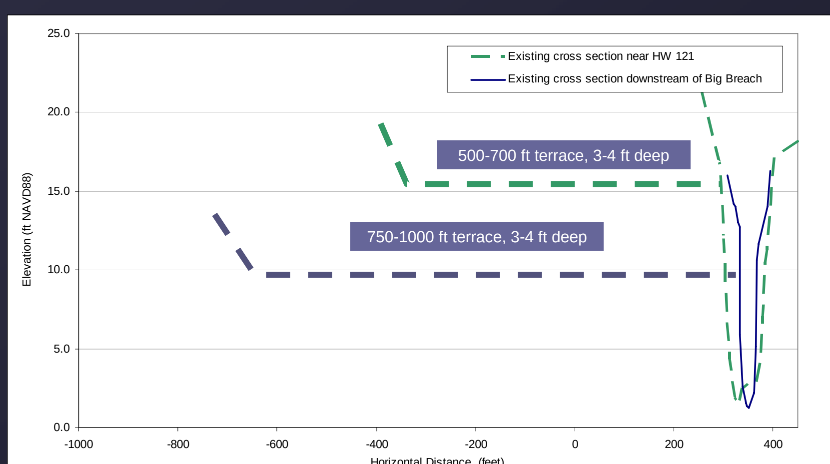
Screening Analyses: Conveyance Corridor



…therefore would need to add on the order of 2,000 – 3,000 ft^2 to accommodate 10-year peak flow.

PWA

Screening Analyses: Conveyance Corridor



Corridor required would need to be quite large even to convey a 10-year flood.

PWA

Screening Analyses: Camp 2 Detention Storage

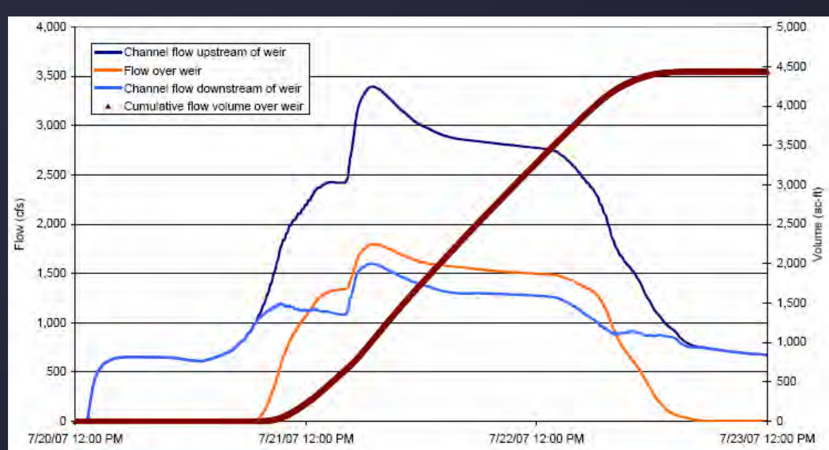
- Evaluated storage volume in
  - Option 1: 500-foot wide corridor in Camp 2
  - Option 2: entire western half of Camp 2
- Used a spreadsheet model to estimate the effect of simulated weir flow into Camp 2

Found:

- Option 1 would reduce water levels ~ 1 foot
- Option 2 would reduce water levels ~ 3 feet

PWA

Screening Analyses: Camp 2 Detention Storage



PWA

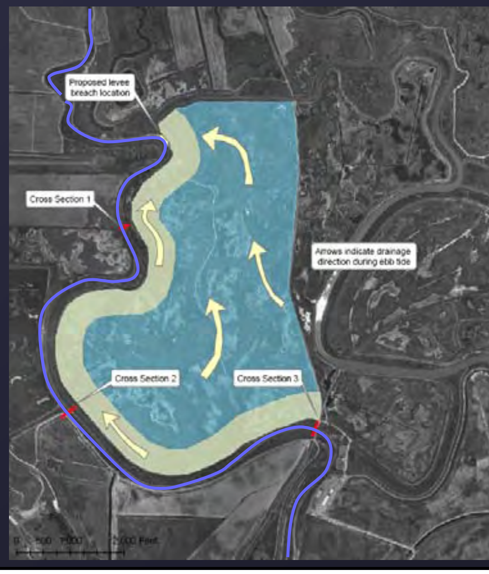
Screening Analyses: Tidal Channel Scour

- Reduction in tidal prism has significantly reduced the natural scouring of lower Sonoma Creek
- Assuming channels have reached ~equilibrium dimension, estimated potential channel area increase if some of Camp 2 were opened up to tidal exchange

Screening Analyses: Tidal Channel Scour

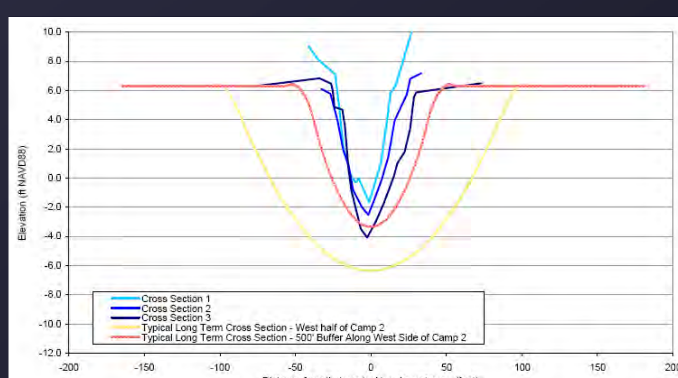
- Option 1: 500-foot corridor at western edge
- Option 2: all of western Camp 2
- For each: connected to Sonoma Creek at upstream end

Screening Analyses: Tidal Channel Scour



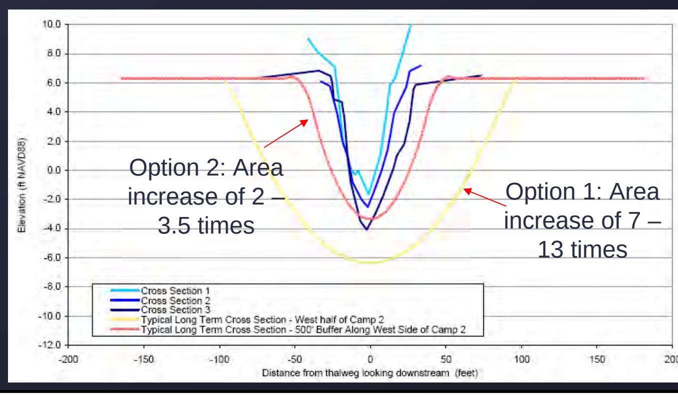
Screening Analyses: Tidal Channel Scour

- Found potential for significant increase in Sonoma Creek channel size through natural tidal scour



Screening Analyses: Tidal Channel Scour

- Found potential for significant increase in Sonoma Creek channel size through natural tidal scour



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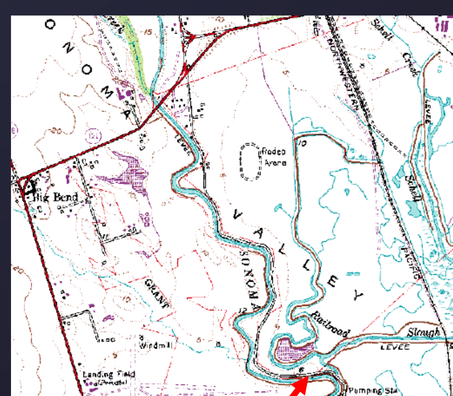
Screening Analyses: Flow routing into Railroad Slough

- Tested connection at northern end of Camp 2
- Simulated a weir link

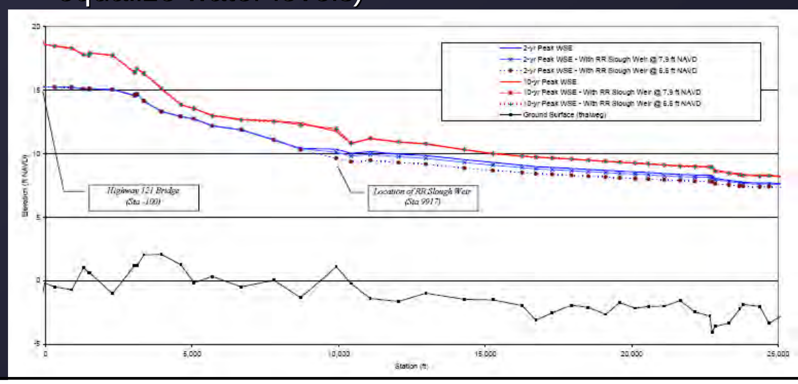


Simulated weir location

PWA

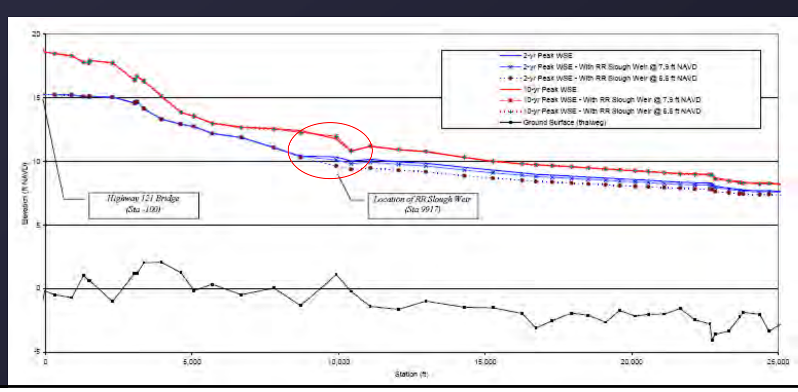
Screening Analyses:
Flow routing into Railroad Slough

- Water level reduction in Sonoma Creek was minimal except in small (e.g., Q2) floods
  - (Larger floods connect these two drainages and equalize water levels)



Screening Analyses:
Flow routing into Railroad Slough

- Even when water level reduction achieved, little persistence of effect upstream



Screening analysis summary

1. Hwy 121 bridge: channel capacity is more of a constraint on conveyance than the bridge structure
2. Conveyance corridor: need >2x channel area for Q10; ~4x for Q100
3. Camp 2 storage: significant stage reduction would require most of the area
4. Tidal scour: could increase lower Sonoma Creek channel size by 2-13x
5. Routing to RR Slough: minor local stage reduction in very small floods (~Q2)

PWA

Priority Objectives

Flood Management

- Reduce flooding of Hwy 121/Schellville

Ecosystem Enhancement

- Consistent with regional plans (e.g., SF Goals Project?)
- Complementary to flood management components

Is this list complete? Is it right??

PWA

Design Principles

- Design for resiliency with respect to sea level rise (2 ft – 5 ft)
- Design for modest ongoing maintenance costs (e.g., avoid building an effective sediment trap)
- Avoid extensive new levee systems?

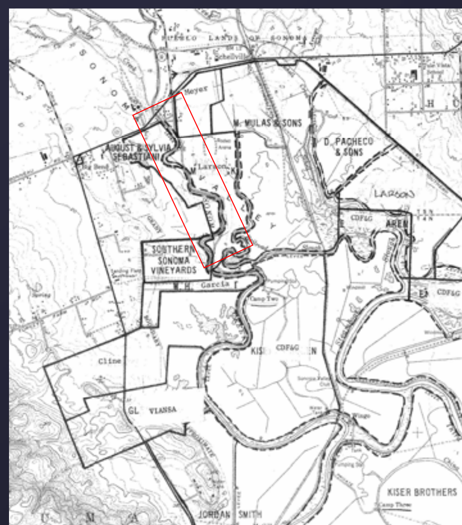
PWA

Strawman Initial Alternatives

- Option 1: Moderate flood conveyance with habitat creation, minimum additional project elements
  - Reach downstream of Hwy 121
  - ~1.5 miles in length (to just upstream of Camp 2)
  - Inset vegetated floodplain terrace

PWA

Strawman Initial Alternatives



PWA

Strawman Initial Alternatives

- Option 2: Multi-faceted, multi-location habitat enhancement while reducing routine flood hazards
  - Western half of Camp 2 converted to tidal wetlands
  - Additional lands converted to tidal wetlands (criteria to identify?)
  - Riparian corridor lands (assume any?)

PWA

ATTACHMENT B

Project ID: Project #1844.01, Sonoma Creek Concept Design: Hydraulic Modeling
Record for the project file
Subject: Documentation of methodology and results
Prepared by Matt Wickland, December 2007
Compiled by Betty Andrews, February 28, 2008

The elements examined for PWA’s Screening Analysis include the following:

1. Highway 121 Bridge capacity
2. Widened channel corridor
3. Storage at Camp 2
4. Railroad Slough overflow
5. Enhanced tidal scour

Each of these analyses is described in turn on the following pages.

1. Highway 121 Bridge capacity

The capacity of the Highway 121 Bridge over Sonoma Creek for existing and widened conditions was estimated using a simple HEC-RAS model. The model was created by adapting data from the MIKE-11 hydraulic model and converting the geometry to US units. Existing conditions cross sections were added to the model for several hundred feet upstream and for several thousand feet downstream of Highway 121.

Two alternatives were modeled that assumed a bottom width between the right and left toes of the channel of 100 and 130 feet, respectively. Bank and thalweg elevations were not changed compared to the existing cross sections. For the existing and widened models, the downstream boundary was set at the lowest bank elevation of the most downstream cross section. Two different flow values were applied at the upstream end of the modeled reach and were adjusted until 1) no channel banks were overtopped and 2) the water surface elevation just reached the low chord of the bridge. For this reach of Sonoma Creek, the channel capacity is much lower than the Highway 121 bridge capacity. The summary of the HEC-RAS results are summarized in Table 1.

Table 1.

	Existing Conditions	100’ Widened Conditions	130’ Widened Conditions
Channel capacity between banks (cfs)[1]	4,000	12,000	16,000
Bridge capacity below low chord (cfs)[1]	6,500	17,500	22,000

[1] - Modeling results are preliminary and should be viewed relative to one another and not as absolute channel or bridge capacities. A more detailed analysis should be used to determine these values with a higher level of confidence.

The results from the screening-level HEC-RAS model analysis shows that the Highway 121 Bridge does not cause a significant restriction of flows in Sonoma Creek. The capacity of the channel is more of a constriction than the abutments or low chord of the bridge. By expanding the channel to 100 or 130 feet, channel capacity is greatly increased and would cause a much more significant change than a redesign of the Highway 121 Bridge.

2. Widened channel corridor

A simple HEC-RAS model was developed to assess how an increase in channel conveyance would affect peak water levels in Sonoma Creek. The model extended from approximately 2,000 feet upstream of the Highway 121 Bridge to just downstream of Sonoma Creek's junction with Napa 1st Slough near San Pablo Bay. Two model geometries were created: one with widened cross sections based on the USACE Plan of Improvement from 1963 and a second based on existing cross sections with a widened floodplain terrace. Both geometries were developed by adding several cross sections at key locations and then using the model to interpolate cross sections in between them. The key locations included the model's downstream boundary, just upstream and downstream of Sonoma Creek's junction with Napa 2nd Slough, upstream and downstream of Highway 121, and the model's upstream boundary above Highway 121. Cross sections were interpolated between each of these existing sections at distances ranging between 40 and 400 feet (depending on the severity of the channel shape transition).

The widened model's geometry was adapted from channel cross sections and profile drawings from Plate 3 of the USACE report (1963). The channel slope from the downstream extent of the model to Highway 121 was 0.00025 and the slope upstream of Highway 121 was 0.0162. Cross sections downstream of Sonoma Creek's junction with Napa 2nd Slough has bottom width of 350', side slopes of 4:1, and floodplain terraces 100' in width at an elevation of mean higher high water (MHHW). For cross sections located approximately 2,000 downstream of Highway 121 and upstream of the junction with Napa 2nd Slough, bottom widths were 250', side slopes were 4:1, and the floodplain terrace was 50' wide. The floodplain terrace changed in elevation based on the channel slope in this reach. From 2,000' downstream of Highway 121 to the Highway's bridge, the channel bottom width transitions from 250' to 100' with varying side slopes and no floodplain terrace. Highway 121 was implemented in the model as a bridge, with geometry based on the Towill survey data. Above Highway 121, the channel bottom width is 100' and the side slopes are 2.5:1. The floodplain terrace width expands from 50' wide just upstream of the bridge to a width of 1,000 feet. The width and elevation of this terrace roughly correspond to the existing floodplain terrace between Sonoma Creek and Fowler Creek approximately 2,000 feet upstream of their junction.

The second geometry used in the model was based on cross sections taken from the existing MIKE-11 model at the locations described above. Beginning approximately 2,000 feet downstream of Highway 121 and heading downstream, a 200' wide terrace was added to each cross section. The elevation of this terrace was set at MHHW for cross sections downstream of the junction with Napa 2nd Slough and then increased in elevation at the same slope as the channel bottom moving upstream. At approximately 2,000 feet downstream of Highway 121, the terrace gradually decreases in width until the cross sections correspond to those of existing conditions at Highway 121 where there is no existing terrace. Upstream of the bridge, a terrace was added to the existing cross sections with at a width of 100' and expanding to a width of 1,000' at the upstream boundary of the model. This width and the elevation of this terrace roughly correspond to the existing floodplain terrace between Sonoma Creek and Fowler Creek approximately 2,000 feet upstream of their junction.

Both models were run in steady state with the downstream boundary set as a known water surface elevation equal to MHHW (6.3 ft NAVD). The model was run for 2-yr, 10-yr, 25-yr, and 100-yr flood conditions. The following Manning's n roughness values were assumed in both geometries: 0.035 for the low flow channel, 0.080 for floodplain terraces, and 0.050 for channel sides and banks.

Results from the hydraulic modeling provide an idea of how high levees might need to be with modified cross sections, either the widened cross sections with a floodplain terrace or the existing cross sections with a floodplain terrace. Table 1 summarizes the depth of water above the existing channel banks and the modeled floodplain terraces at key locations in Sonoma Creek during the 100-year flood event.

Table 1 – Depths above the design terrace and existing channel levees during the 100-year flood event at three locations.

Location	Widened Cross Sections w/ Terrace		Existing Cross Sections w/ Terrace	
	Elevation above design terrace	Elevation above existing levee	Elevation above design terrace	Elevation above existing levee
At Junction w/ Napa 2nd Slough	3.8	1.6	6.1	3.8
2,000' downstream of Highway 121	5.0	1.4	20.0	16.4
2,000 upstream of Highway 121	8.0	Below levee crest	22.3	13.2

The depths above the existing levees can be considered rough estimates of how much higher a levee would need to be to contain the 100-year flood event on Sonoma Creek. For the widened cross section with a floodplain terrace (modified USACE design), the maximum increase required to contain the 100-year flood is less than 2 feet. This design, however, would not be geomorphically sustainable, as the low-flow channel would not have enough tidal flow to maintain its wide dimensions. Over time, the channel would most likely fill in to a size similar to existing conditions. For the existing cross sections with a widened terrace, the maximum increase in levee height to contain the 100-year event is approximately 16 feet.

The Hwy 121 model was used to assess how wide the terrace would need to be to accommodate the 10-yr flow. The 100-ft bottom width model was used and it showed that the 10-yr event would not overtop the banks.

Additionally, Flowmaster (a Manning's equation solver) was used to back this up. A cross section downstream of the bridge with a 100-ft terrace was added to the software, with bank and terrace roughness values of 0.08 and in-channel roughness values of 0.03. The elevation of the terrace was taken from the conveyance model for just downstream of HW 121, or approximately 12.5' above the channel thalweg and 7' below the channel banks. With the slope estimated from the long profile, the model was predicting the channel has less capacity than the 10-yr event and a velocity of approximately 2 fps. Because this velocity seemed much too low for a flood event, the slope was artificially increased until the velocity was about 5.5 fps (which is about what might be expected for an event as large as the 10-yr), and the software predicted that the model could contain the 10-yr event of 12,500 cfs.

3. Storage at Camp 2

The influence on peak water levels in Sonoma Creek of offline flood water storage in Camp 2 was analyzed using a simplified spreadsheet model and results from the MIKE-11 hydraulic model of Sonoma Creek. The two storage areas analyzed were the entire western half of Camp 2 (east of the railroad tracks) and a 500 foot wide buffer along the western levee of Camp 2. The proposed weir was located on the left bank (eastern levee) of Sonoma Creek near the northwest corner of Camp 2. At two cross sections in this vicinity, flow-elevation relationships and in-channel water levels and discharges from the 10-year flood event were extracted from the MIKE-11 model and imported into the spreadsheet. A weir elevation and length were assumed in order to calculate the flow over the weir into Camp 2. As water in the channel rose to above the elevation of the weir, flow was initiated on the water and water was transferred to the available storage in Camp 2. Weir flow ceased when either the channel water levels went below the elevation of the weir or when Camp 2 was full. The available storage volume in Camp 2 was assumed to be the area of each region (the entire west half or the 500' buffer) times the available depth. The available depth was calculated by subtracting the average bed elevation of each region from the elevation of the weir. Thus, a lower weir resulted in a smaller available storage volume. The flow that passed over the weir was then subtracted from the flow in the channel. Using the flow-elevation relationships for each cross section, a new channel elevation was calculated at each time step. By comparing the maximum elevation without the weir and the maximum elevation with the weir, a potential reduction in peak water levels was calculated. Because the modeled peak water levels and discharges for existing conditions did not always correspond to the flow-elevation relationships (due to the coupling of the 1-D MIKE-11 model with the 2-D MIKE-21 model and the exchange of flow between the two dynamic models), a theoretical peak water level was calculated for existing conditions based on the peak discharge. This theoretical peak was typically higher than the modeled peak and was used to determine the potential reduction in peak waters levels with Camp 2 storage.

By iterating the length and elevation of the weir, the reduction in peak water levels in the channel varied. A weir too long or too low caused Camp 2 to fill up too soon and stopped weir flow before the peak of the flood wave passed through the channel. A weir too high or too short did not remove enough water to make a significant difference in channel flows. The ideal weir length and elevation caused the entire storage area to fill just to capacity right when the water levels in the channel lowered to below the weir elevation. Table 1 shows the weir elevations and maximum theoretical reductions in peak water levels in Sonoma Creek (note that for simplicity, the weir length was fixed at 115 feet, which was a length that maximized water levels reductions for several of the scenarios).

Table 1 – Weir elevations and potential reduction in peak water surface elevations in Sonoma Creek in near the northwest corner of Camp 2 during the 10-year flood event.

Storage Area	Cross Section #	Weir Length (ft)	Weir Elevation (ft NAVD)	Potential reduction in peak WSE (ft)
Camp 2 west of the railroad tracks	1	115	8.2	2.80
	2	115	7.8	3.41
500’ buffer on west side of Camp 2	1	115	9.5	1.16
	2	115	9.2	1.05

Due to the greater storage volume available, making the entire western half of Camp 2 available for flood storage offers a greater potential reduction in water levels than a 500’ buffer in Camp 2 would. The larger area produced maximum reductions in peak water levels ranging from 2.8 to 3.4 feet. The smaller area required a higher weir elevation to maximize peak water level reductions, but only showed reductions of little more than one foot, which would most likely not cause a significant affect upstream in the vicinity of Schellville.

4. Railroad Slough overflow

The MIKE Flood model for Sonoma Creek, the Napa River, and their surrounding tributaries and ponds was adapted to include a connection between Sonoma Creek and Railroad Slough near the northwest corner of Camp 2. A weir was added to the model that would allow water to spill from Sonoma Creek during small flood events and be routed through Railroad and Steamboat Sloughs. The intent of this exercise was to reduce peak water levels in Sonoma Creek by reducing the amount of water in the channel.

The model was run for the 2-year and 10-year flood events and with weir elevations at 6.6 and 7.9 feet NAVD. The width of the weir corresponded to the levee-to-levee width of Railroad Slough near the northwest corner of Camp 2 (approximately 160 feet). A Manning's n value of 0.05 was assumed for the weir calculations. Results of the MIKE Flood model can be seen in Table 1.

Table 1. Maximum reduction of peak water levels compared to existing conditions (no weir connection between Sonoma Creek and Railroad Slough).

	2-yr Event (existing minus w/ weir conditions)	10-yr Event (existing minus w/ weir conditions)
Weir at 6.6 ft NAVD	0.71 ft	0.17 ft
Weir at 7.9 ft NAVD	0.25 ft	0.13 ft

During the 10-year flood event, a trivial reduction in peak water elevations resulted from the connection of Sonoma Creek and Railroad Slough. A more significant decrease in peak water levels occurred during the 2-year event, with a maximum decrease of 0.71 feet for the 6.6 ft NAVD weir. This maximum reduction in water levels, however, occurs right at the northwest corner of Camp 2 near the airport runway, and does not extent very far upstream. Based on this screening-level MIKE Flood analysis, connecting Sonoma Creek and Railroad Slough with a weir would only affect water levels during higher frequency (lower flow) events and would not cause reductions in peak water levels anywhere near Schellville or Highway 121.

5. Enhanced tidal scour

Hydraulic geometry relationships for tidal marshes in the San Francisco Bay area (Williams, et al, 2002) were used to estimate how natural scour due to tidal exchange would increase the capacity of Sonoma Creek downstream of Camp 2. The effect of the restoration of former marsh lands back to tidal marshes was investigated for two scenarios encompassing the portion of Camp 2 west of the railroad tracks and a 500 foot-wide buffer in Camp 2 along the course of Sonoma Creek (see Figure 1). Using aerial photographs and GIS, the area of these two regions were measured. The long-term channel geometry was estimated using the empirical hydraulic geometry equations, which relate marsh plain area with channel depth, width, and cross sectional area for equilibrium conditions. Estimated long term cross sections were assumed to be parabolic in shape, with the long term channel banks and marsh plain at the elevation of mean higher high water (MHHW), or 6.3 ft NAVD. Additionally, it was assumed the tidal volume exchange due to restoration would benefit the entire reach of Sonoma Creek adjacent to Camp 2 (i.e. the connection between Camp 2 and Sonoma Creek is at the northwest corner of Camp 2) and that fluvial inputs have minimal effect on channel geometry. The existing and expected long term channel capacities were estimated using Manning's equation, and assuming an n-value of 0.030 and channel slope of 0.00025.

Long term cross sections in comparison to existing cross sections can be seen in Figure 2 (existing cross sections locations are shown in Figure 1). A summary of the channel geometry and capacity for existing conditions and for long term post-restoration conditions can be seen in Table 1.

Table 1 – Channel geometry and capacity for existing conditions at three cross sections and for long term conditions for two restoration scenario.

Cross Section	Channel Width at MHHW (ft)	Channel Depth below MHHW (ft)	Cross Sectional Area below MHHW (ft^2)	Channel Capacity below MHHW (ft^3/s)
Existing Cross Section 1	7.9	40	188	403
Existing Cross Section 2	8.8	59	262	536
Existing Cross Section 3	10.4	76	345	715
Option 1 – Camp 2 west of railroad tracks	12.6	215	1,595	5,121
Option 2 – 500' buffer on west side of Camp 2	9.6	102	565	1,367

As seen in Figure 2 and Table 1, Option 1 causes an increase in channel depth at all locations of Sonoma Creek adjacent to Camp 2, and Option 3 causes an increase in channel depth at the upper part of Sonoma Creek and no increase in the lower part of the creek towards Wingo. Both restoration options, however, cause a significant increase in channel width compared to existing conditions. This increase in channel area results in an increase in channel capacity compared to existing conditions of approximately 7 to 13 times for Option 1 and approximately 2 to 3.5 times for Option 2.

References:

Williams, P.B., Orr, M.K., Garrity, N.J. 2002. Hydraulic Geometry: A Geomorphic Design Tool for Tidal Marsh Channel Evolution in Wetland Restoration Projects. Restoration Ecology, Vol. 10 No. 3, pp. 577-590.

APPENDIX D

REPRESENTATION OF ALTERNATIVES IN THE HYDRODYNAMIC MODEL

Representation of Alternatives in the Hydrodynamic Model

A description of the existing conditions hydrodynamic model development is in Appendix A. This appendix briefly summarizes the changes made to the existing conditions MIKE FLOOD (MF) model to simulate the alternative conditions. These changes include:

- The Full Length Floodplain Terrace was simulated in the 2D portion of the MF model (MIKE 21). This was done by lowering the grid cells in the MIKE 21 model and lowering the levee elevations in the 1D portion of the MF model (MIKE 11).
- The Short Narrow Floodplain Terrace was simulated in the MIKE 11 portion of the model by expanding cross section widths. The area covered by the expanded cross sections was eliminated from the MIKE 21 grid by specifying them as 'land' values. (Grid cells set to 'land' values are excluded from the active simulation grid.)
- The Highway Protection Levee Spur was eliminated from the MIKE 21 model simulation grid by setting the grid cells to 'land' values.
- Model runs of alternatives that included tidal restoration were adjusted to include the expected tidal scour by increasing the cross sectional areas in the MIKE 11 model. The sizes of the cross sections were determined from hydraulic geometry relationships. This process is further described in the main report.
- Channel enlargement in the Highway 121 reach was simulated by increasing the MIKE 11 model cross sectional areas. The MIKE 21 model was not adjusted.
- The Camp 2 Flow Bypass weirs were simulated by lowering the left bank levee elevations in the MIKE 11 model at the upstream and downstream connections of Sonoma Creek and Camp 2. The MF model's lateral weirs are based on the MIKE 11 levee elevations. Therefore, the bypass weirs were automatically reflected in the MF model.
- The Schell Creek Overflow Channel was built into the MIKE 21 model bathymetry by lowering a channel path one grid cell wide (15 meters) by 1.5 meters below the existing grade.

APPENDIX E

SHORELINE RESPONSE TO SEA LEVEL RISE

SHORELINE RESPONSE TO RISING SEA LEVELS

This appendix describes our general conceptual model of shoreline response to rising sea levels in southern Sonoma County, including lands along lower Sonoma Creek.

The projected rates of sea level rise over the next century will result in a changes in shoreline processes (tidal and wave processes, sedimentation rates) that will cause evolution of the coastal habitats over time. This evolution will be most apparent at the boundaries and buffers between habitats since the existing patterns of intertidal habitats and upland edges are unlikely to be conserved in modified form in place. Existing habitats and landscape structures are likely to be rearranged, and those habitats will be converted to other types of habitat. Furthermore, some habitats may be may be lost entirely, while non-bayland habitats or areas now treated as “buffers” will likely either be incorporated in bayland habitats or isolated from baylands by flood protection structures (dikes or levees, shore armor, etc.) that will be constructed as a reaction to rising sea levels.

1. GEOMORPHIC CHANGE OF BAYLANDS IN RESPONSE TO SEA LEVEL RISE

Existing tidal marshes accommodate sea level rise with only minor long-term or progressive conversion of tidal habitat types, and a gradual landward shift in position (Figure E.1). Vertical accretion rates will depend upon the sediment supply, rate of organic production, and the rate of sea level rise. If sea level rise continues to accelerate, at some point it will outstrip the rate of accretion and the marsh will start to “drown.” If the vertical accretion of marshes cannot keep pace with sea level rise then the wetlands habitats will tend to migrate (or “transgress”) landward. The horizontal rate of transgression will depend upon the rate of sea level rise and the slope of the upland transition zone. Historic diking of baylands steepened coastal gradients of Sonoma baylands, converting gently sloping bayland edges that rise towards the land into steep linear borders backed by basins. Sea level rise acts very differently on gentle, continuous slopes (where it gradually shifts tidal habitat zones upland and landward) and on discontinuous, artificial diked bayland topography (where it forces either acceleration of maintenance and repair of dikes, or “overstepping” the barrier – abruptly flooding the diked basin and radically shifting the shoreline and shore processes landward). If the marsh is bounded by a steep slope (such as an inboard levee) then the transition zone available for transgression will be much reduced and marsh habitat will be lost through “coastal squeeze” (Figure E.2).

Sediment supply, the availability of space, and hence the response to sea level rise, varies along the Sonoma Bay shore. These differences will need to be accounted for in projecting long-term changes that we can expect in the lands along lower Sonoma Creek or in developing a management plan to address those anticipated changes.

2. HOW WILL TODAY'S TIDAL MARSHES AND DIKED BAYLANDS RESPOND TO SEA LEVEL RISE?

There are a number of (qualitative) evolutionary scenarios relevant to long-term planning in Sonoma baylands:

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a. Equilibration, dynamic stability: existing tidal marshes accommodate sea level rise with only minor long-term or progressive conversion of tidal habitat types, and a gradual landward shift (horizontal displacement or landward estuarine "transgression") in position. This familiar scenario is associated with very gradual (historic) rates of sea level rise and net positive sediment budgets (due in part to effects of diking, artificial loss of tidal prism). This scenario is not likely to occur in a regime of rapidly accelerating sea level rise and neutral or negative sediment budgets, and can be considered optimistic.

b. Gradual evolution: gradual submergence of tidal marsh habitats with marsh type conversion ("downshifting" zones: high marsh to middle marsh, middle to low, low marsh to unvegetated tidal flat); expansion of tidal marsh pans and enlargement of tidal channels; mudflat erosion (loss of elevation); progressive but slow erosional retreat of marsh edges (wave-cut marsh "cliffs" or scarps); and either dike overtopping, erosion, and breaching—or a response of dike raising, armoring, and increased artificial bayland drainage.

c. Collapse (abrupt conversion of ecosystem to alternative modes and habitat types): in this worst-case scenario associated with early onset of accelerated sea level rise at the upper end of projected rates, sea level rise would overstep marsh platforms, causing wholesale drowning of marshes: marshplains initially respond by converting to low marsh (cordgrass), but founder as rapid marsh vegetation dieback forms extensive pans that "swallow" fragmented marshes and expand to tidal flats. This is analogous with contemporary tidal marsh loss in Gulf of Mexico and the Mississippi Delta. Rapid marsh edge and levee erosion (or recurrent "emergency" reactive armoring and repair), increased flooding of diked baylands or undiked adjacent lowlands, and the rapid loss of critical high marsh habitat and upland buffer integrity are likely to occur in this scenario.

There will probably be a variable mix of a) and b) for the first 50 years, unless there is an abrupt, rapid acceleration in sea level rise (i.e., abrupt changes in ocean temperature or ice sheet collapse). Maintaining existing marsh zones with no conversion would be an optimistic projection because as marshplain drainage decreases with submergence, so does marsh plant growth and vegetation height. Reduced marsh vegetation growth will mean less stem height and density for trapping and stabilizing suspended sediment and less production of organic matter in the soil profile.

The major controlling variables are the rate of sea level rise, sediment supply and space for transgression. There are methods for affecting the sediment supply locally, by supplying supplemental resources. Providing additional space for marsh transgression can be accomplished by dedicating lands for this purpose and modifying topography to serve this goal (e.g., eliminating or breaching dikes to facilitate delivery of sediment in the near term for accretion of subsided lands).

The pace of coastal habitat changes due to sea level rise, even in "gradual" scenarios, may not be uniformly gradual. Average sea level represented in models deviates from significant annual fluctuations in sea level, which may reach up to approximately 8 inches above average levels during strong El Niño events, due to thermal expansion of warm Pacific waters. In addition, intense storms also associated with El Niño evens also may be expected to achieve many years or even decades' worth of "average" erosion in extreme storms or series of storms. Thus, the coastal habitat changes expected with sea level rise, regardless of the long-term sea level rise curve being generally followed, may not be expected to occur in a linear or incremental pattern. The biological responses to habitat change caused by sea level rise may similarly be expected to occur in pulses, or reflect dominant influences of extreme storm events. Local extirpation of species with limited dispersal ability, high site fidelity, or close dependence on narrowly distributed critical habitats is a particular concern for threshold changes in habitat driven by storm events during long-term sea level rise.

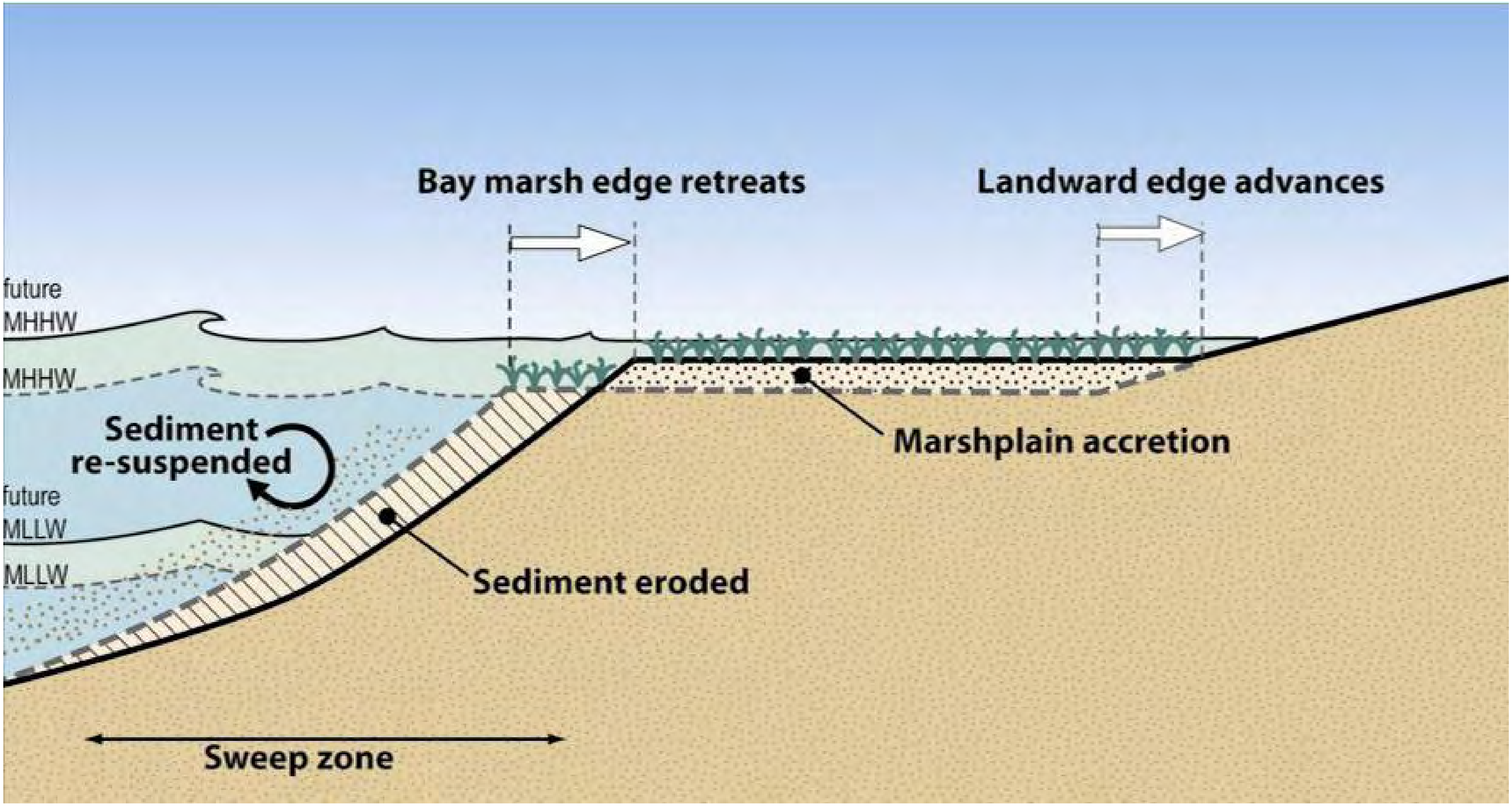

figure ***E.1***
Lower Sonoma Creek Project

Natural Shoreline Evolution

ESA PWA Ref# 1844

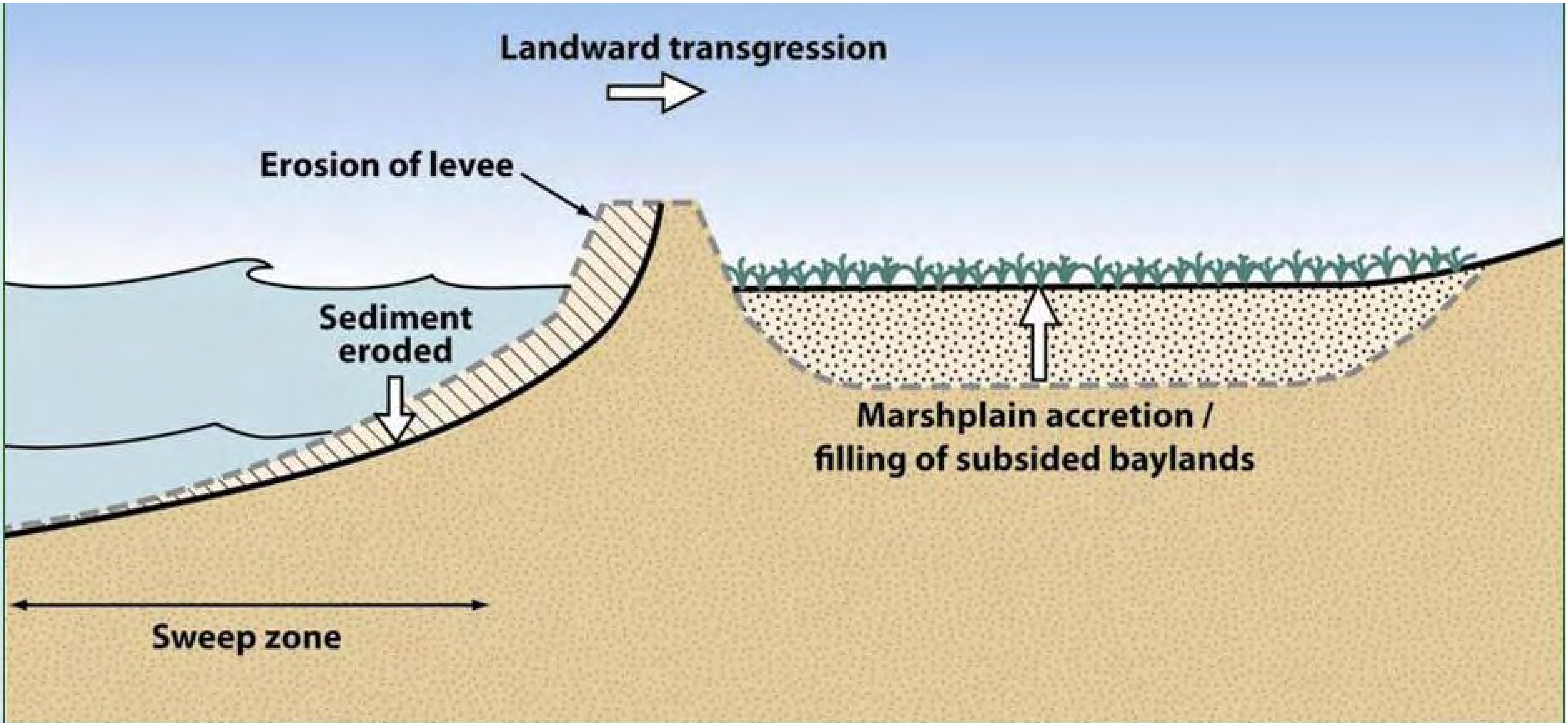

figure ***E.2***

Lower Sonoma Creek Project

Erosion of Bay shore levees

ESA PWA Ref# 1844

APPENDIX F

SEDIMENT TRANSPORT AND GEOMORPHIC ANALYSIS MEMORANDUM
December 8, 2010

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Technical memorandum

date December 8, 2010

to Susan Haydon, SSCRCD

from Betty Andrews, Christie Beeman, James Gregory, and Lindsey Sheehan

subject Sonoma Creek - Sediment Transport and Geomorphic Analysis (Ref. No. 1844, Tasks 2.2 & 2.3 deliverable)

Introduction and Background

This memorandum describes a conceptual model for sediment transport processes throughout the study area, and summarizes the sediment transport implications for various project alternatives.

Sonoma Creek has a total watershed area of about 166 square miles, including the 22-mile long Sonoma Valley and surrounding Coast Range foothills. It is among the five largest tributaries to San Pablo Bay, in the San Francisco Bay-Delta Estuary (the Bay). Physiographically, the Sonoma Creek watershed is defined by the high parallel ridges on its eastern and western boundaries and its low lying, narrow valley floor, which widens towards the south, where the ridges end and the San Pablo baylands (Napa-Sonoma Marsh) begin. The western ridge is dominated by Sonoma Mountain, elevation 2463 ft; the Mayacamas Mountains lie to the east. At the southern end of the basin, the Sonoma and Mayacamas Mountains end at the flat baylands that form the Napa-Sonoma Marsh. In the tidal zone, watershed boundaries become less distinct as flows from Sonoma Creek and Napa River watersheds combine with saltwater from the bay.

This study focuses on the area immediately around and to the south of State Highway 121, including the Schell Creek tributary to Sonoma Creek. The drainage areas of Sonoma and Schell Creeks at Highway 121 are 93 and 20 square miles, respectively. Highway 121 marks the approximate upstream extent of tidal influence in Sonoma Creek and represents a transition zone between fluvial- and tidal-dominated sediment transport. Downstream of Highway 121, Schell and Sonoma Creeks enter a complex network of tidal slough channel before draining to San Pablo Bay.

Geomorphic and Sediment Transport Processes

Upstream of Highway 121, sediment transport in Sonoma Creek is controlled by fluvial processes. In the fluvial environment, stream channel morphology develops in response to terrestrial sediment supply and watershed runoff. In general, a channel is stable when sediment and runoff are in balance, and the stream is able to transport the supply of sediment it receives. However, land use changes and channel modifications (such as levees, channelization and bridge crossings) can alter the balance of watershed sediment and hydrology and result in bank erosion or sediment deposition as the channel adjusts to new conditions.

Sediment transport in the lowest reaches of Sonoma Creek, and throughout the adjacent baylands, is dominated by tidal processes. As in all California tidal marshes, water moves in and out of the channels with the diurnal tidal cycle, bringing with it fine sediments from the Bay or ocean. In a natural marsh system, high tides distribute tidal waters and sediment over the marshplain, which then drain through a complex network of slough channels on the ebb tide. As the tide recedes, it leaves behind fine sediments that maintain the marshplain elevation relative to the tide frame. Slough channel morphology develops in response to the volume of water draining from the marsh area over a typical tidal cycle (tidal prism), and the relationship between tidal prism and channel dimensions has been documented for Bay Area wetlands (Williams et al., 2002). Anthropogenic changes in the tidal zone (levees, fill, channelization) tend to result in a loss of tidal prism draining to slough channels, causing sedimentation as tidal flushing is reduced. Conversely, tidal wetland restoration can reverse this process by increasing tidal prism and associated tidal flushing through slough channels.

Fluvial Sediment Transport

Historically, the Sonoma Creek tributaries that drain the foothills on either side of the Sonoma Valley formed alluvial fans where sediments were deposited as channel slopes decreased at the valley floor. Early maps show that many of these tributaries did not directly connect to the main stem of Sonoma Creek, but instead spread out into smaller channels dispersed across the alluvial fans, eventually infiltrating into the subsurface through the porous alluvial sediments. This subsurface flow slowed delivery of runoff downstream and likely contributed to saturated conditions across much of the valley floor during the rainy season (SFEI, 2008). Sonoma Creek itself deposited much of its sediment load as it reached the low-lying baylands, forming an alluvial fan at the mouth of the valley in the transition zone from fluvial to tidal dominance (Watershed Sciences, 2004), resulting in the creek channel being somewhat perched above the surrounding topography in the vicinity of Highway 121. Flood waters that escape Sonoma Creek in this vicinity therefore tend to flow away from the channel and toward the low-lying baylands to the east.

The current Sonoma Creek channel profile reflects a distinct transition at the Highway 121 Bridge (Figure 1). Upstream of Highway 121, the channel slope is typical of a fluvial system in this environment, at approximately 0.18%. Downstream of Highway 121, the slope flattens dramatically to approximately 0.02%, which is more typical of slough channels in the tidal environment. Figure 1 shows hydraulic modeling results (PWA, 2008) that demonstrate the impact of this slope break on the water surface profile in Sonoma Creek under moderate flow conditions (2-year design event). As flood waters approach the Highway 121 Bridge, flow depth increases and velocity decreases. Further downstream, water levels again drop (and velocity rises) in the vicinity of Big Break (River Station 15635) on the southern end of Millerick Road, where breaches and low spots in the levee allow water to flow out of the channel.

Table 1 summarizes model results for average peak velocity and shear stress in the reach of Sonoma Creek immediately upstream (River Station 0 to 12568) and downstream (River Station 12568 to 47534) of the Highway 121 Bridge for a range of flood events. The steeper slope and higher flow velocities in the upstream portion of Sonoma Creek result in higher shear stresses and therefore a greater capacity to transport sediment downstream. When sediment-laden flows reach the flatter channel slope, sediment transport capacity is reduced and sediment is deposited in the channel.

Table 1. Peak velocity and shear stress upstream and downstream of Highway 121

	Recurrence interval event			
	2-year	**10-year**	**25-year**	**100-year**
Average Peak Velocity (ft/s)				
upstream	7	11	12	13
downstream	5	6	7	7
Average Peak Shear Stress (N/m2)				
upstream	48	75	87	108
downstream	13	22	25	28

Beginning with the development of the valley for agricultural uses in the mid-nineteenth century, ditching and channelization have increased hydrologic connectivity in the valley. Land use changes and the development of stormwater drainage systems in subsequent years have further increased the rate and quantity of runoff and sediment delivered to Sonoma Creek. Increased flows and sediment loads in Sonoma Creek, combined with the confinement of the channel by levees and infrastructure, have exacerbated high water levels at the natural channel slope transition in the vicinity of Highway 121 by more efficiently delivering more water and sediment from the upper watershed.

Tidal Sediment Transport

Prior to agricultural development in the region, the Sonoma salt marsh extended from the downstream extent of the fluvial zone (in the current vicinity of Highway 121) to the margin of San Pablo Bay. During fluvial flood events, flood waters spread out across the marshplain and were dissipated with the ebbing tides. However, the daily tidal circulation is the primary driver for sediment transport in the baylands. The following description of tidal sediment transport processes in the salt marsh is provided in Watershed Sciences, 2004:

> Historically, the broad expanse of the Sonoma salt marsh and its intricate and interconnected tidal slough system was maintained by mixed diurnal tides that distributed a large prism of tidal waters and very fine sediment onto the marsh surface. When ebb tides drain the marsh, water is transported back through the tidal slough system at velocities higher than those that occurred during flood tides. Conceptually one can picture that the flood tides are functioning to distribute sediment and water onto the marsh surface and the ebb tides are functioning to maintain the channel geometry.

The Sonoma Creek channel was an integral element of the slough channel network that drained the historic marsh. The morphology of the creek was largely controlled by the amount of tidal prism that drained through the creek from the tidal marshes to the east. Tidal flushing provided by the expanse of marshland maintained a channel large and deep enough to allow boats to navigate within the tidally-influenced zone. As the marshlands were reclaimed for agricultural uses, the tidal prism flushing through Sonoma Creek was progressively reduced until the present day, when it is confined to the channels themselves (as defined by levees).

The reduction in tidal flushing through the channels means that fine sediments brought up the channels from the bay can deposit within the channels and are not flushed out with the ebb tide, resulting in significant “silting in” of the Sonoma Creek channel (and other slough channels) over time. Sedimentation in the tidal portion of Sonoma Creek has reduced the channel conveyance capacity relative to historic conditions. Tidal wetland restoration can reverse this process by increasing tidal prism and associated tidal flushing through slough channels. PWA evaluated the sediment transport implications of tidal wetland restoration in the project area by looking at both marshplain sedimentation and tidal channel scour, as described in the following sections.

Tidal Scour

PWA evaluated the potential for tidal wetland restoration to enlarge the Sonoma Creek channel through the tidal flushing that would be associated with a larger tidal prism. To estimate equilibrium channel dimensions for various restoration scenarios, we applied empirical hydraulic geometry equations, which relate marshplain area or tidal prism with channel depth, width, and cross sectional area to two restoration scenarios and two possible connection locations. The scenarios assumed theoretical restoration acreages of 400 and 1000 acres in the vicinity of Camps 2, 3, and 4, with the connection to existing channels at either the west end or east end of Wingo Slough downstream of Camp 2 (Figure 2).

The following assumptions were made in the hydraulic geometry analysis:

1) Equilibrium channels are approximately parabolic in shape, with the channel banks and marshplain at the elevation of mean higher high water (MHHW), or 6.3 ft NAVD88.
2) Channel scour occurs downstream from the connection between the restored area and the channel; west end connection results in scour of Sonoma Creek, the east end connection results in scour of 3rd Napa Slough.
3) Upstream of the connection location, there will be a transition from existing channel dimensions to equilibrium (scoured) dimensions extending upstream to approximately the location of Railroad Slough.
4) Fluvial inputs have little influence on channel geometry at this location.

The results of the hydraulic geometry analysis are presented in Table 2. Cross Section 1 and Cross Section 2 represent typical existing channel dimensions and capacity for Sonoma Creek and 3rd Napa Slough. Estimated typical future channel dimensions and capacity for each of the restoration scenarios are also shown. Plots of each cross section are shown on Figure 2, as are the assumed tidal wetland connection locations. The estimated potential future channel dimensions resulting from each restoration scenario would apply to either Sonoma Creek or 3rd Napa Slough depending on where the tidal connection is located.

Table 2. Channel geometry and capacity for existing and potential conditions

Cross Section	Channel Width at MHHW (ft)	Channel Depth below MHHW (ft)	Cross Sectional Area below MHHW (ft^2)	Channel Capacity below MHHW (ft^3/s)*
Existing condition				
Cross section 1 – Sonoma Creek	87	12.1	400	840
Cross section 2 – 3rd Napa Slough	176	14.7	1550	5,090
Potential conditions				
Typical cross section with 400 acres of marsh restoration	175	15.3	1,780	6,350
Typical cross section with 1000 acres of marsh restoration	238	25.6	4,060	20,260

*Channel capacity estimated using Manning's equation (n=0.030, S=0.00025).

As seen in Table 2 and Figure 2, a 400-acre restoration element connected on the west side of Wingo is estimated to increase channel capacity downstream of the connection by approximately 8 times for a typical cross section. For the eastern connection, channel capacity in the (larger) 3^{rd} Napa Slough is increased by approximately 1.25 times. The 1000-acre restoration option is estimated to increase Sonoma Creek capacity by approximately 24 times if connected on the west side of Wingo, and Third Napa Slough by approximately 4 times for the connection on the east side of Wingo. It should be noted that much of the expanded channel cross section lies below the mean tide level, reducing its effectiveness for conveying fluvial flood flows.

Marshplain Sedimentation

A range of habitat types exist in the intertidal zone between the open water of San Pablo Bay and the surrounding uplands, depending on elevation within the tide range. Tidal wetlands occur between approximately Mean Tide Level and Mean Higher High Water. Following methods developed for PRBO (http://data.prbo.org/ apps/sfbslr/), PWA evaluated the potential for restoring and maintaining tidal wetlands in the project area by estimating marshplain accretion in response to ranges of initial ground elevation, suspended sediment concentration, and sea level rise scenarios. These predictions were made for 50 and 100 years in the future using the Marsh98 model.

The quality of the topographic dataset used for initial conditions in the Marsh98 model is improved over the dataset used in the PRBO study, which contained unrealistic abrupt changes in elevation along a rectangular swath in this region. PWA combined topographic data using LiDAR from the National Center for Airborne Laser Mapping (NCALM, 2007), “bare-earth” IFSAR (Interferometric Synthetic Aperture Radar) from Intermap Technologies (circa 2003), and a digital terrain model prepared by Towill (2007) from a combination of photogrammetry and cross section surveys. Areas not covered by these data sources were filled in with a digital elevation model retrieved from the USGS (seamless.usgs.gov).

The Marsh98 model has been used widely to examine tidal marsh sustainability in the face of sea level rise in San Francisco Bay (e.g., Orr et al., 2003). This model assumes that the elevation of a marshplain rises at rates that depend on the (1) availability of suspended sediment and (2) depth and periods of inundation by high tides. When the level of an evolving marsh surface is low with respect to the tidal range, sedimentation rates may be high if the suspended sediment supply is ample. However, as the marsh surface aggrades through the tidal range, the frequency and duration of flooding by high tides is diminished so that the rate of sediment accumulation declines. Marsh98 simulates these physical processes by calculating the amount of suspended sediment that deposits on the marshplain during each period of tidal inundation and then summing that amount of deposition over the simulation period. This analysis can be used to evaluate the likely impact of sea level rise on habitat evolution in the tidal environment.

The Marsh98 model was used to estimate future ground elevations and associated habitat types for the 50- and 100-year time horizons based on different suspended sediment concentration (SSC) and sea level rise assumptions. SSC varies spatially and temporally throughout San Francisco Bay due to variations in wave conditions, proximity to mudflats, hydraulic connectivity, residual circulation, and river inputs. In Marsh98, a SSC index is used as a proxy for actual suspended sediment concentration to integrate these various factors over long simulation periods. Based on previous sediment accretion modeling at other sites around San Pablo Bay, we estimated the range of SSC indices to be approximately 100-300 (mg/L), with a typical value of 150-200 (mg/L). We simulated the effects of both ends of this typical range, 150 and 200 mg/L, in our modeling. For sea level rise, we used two nonlinear sea level rise scenarios based on the guidance provided by the US Army Corps of Engineers (2009), which rely on curves proposed by the National Research Council to extrapolate intermediate and high sea level rise scenarios (“NRC-I” and “NRC-III”, respectively). Depending on the starting year of a project, these scenarios predict approximately 0.5 m and 1.5 m of sea level rise over the next century. The high rate is similar to draft

State of California planning guidance, which recommends planning for 16 inches of rise in the next 50 years and 55 inches in the next 100 years.

Figures 3 and 4 depict the model results spatially by showing the distribution of habitat types for existing conditions, Year 50 and Year 100, assuming a project implementation date of 2010. The existing conditions map shows the habitat types that would currently exist if the study area were exposed to tidal inundation. Based on existing ground elevations, the majority of the study area would support open water and mudflats if it were not separated from the tidal slough channels by levees. Figure 3 shows how these habitat types would evolve after 50 years of tidal inundation under two different suspended sediment concentration assumptions under the higher rate of sea level rise (NRC-III) scenario. In both the 150 ppm and 200 ppm suspended sediment concentration scenarios, the vast majority of the study area would evolve to mid marsh levels in the 50 year time frame. Figure 4 shows the Year 100 results for the same suspended sediment concentration and sea level rise scenarios, with low marsh predominating in the 150 ppm scenario and a mix of low and mid marsh in the 200 ppm scenario.

Our analysis provides a first order estimate of marsh accretion rates for lands adjacent to lower Sonoma Creek under a range of input conditions. It should be recognized that significant uncertainties remain with respect to future sea level rise as well as the physical and biological processes which affect marsh accretion. Still, these simulations provide guidance on the effects of key variables at play in the evolution of these systems under anticipated sea level rise conditions.

In general, the results suggest that marshplain sedimentation could maintain some type of tidal wetland habitat over the planning horizon (50 – 100 years) if projects are initiated in the near term, sediment concentrations are at simulated levels or higher, and sea level rise is within the range predicted. However, during that time frame mid marsh may transition to low marsh as a result of sea level rise combined with inadequate accretion rates. Marsh accretion rates are predicted to fall below sea level rise rates in at least parts of the restored marsh if either of the following conditions occur: a “high” sea level rise scenario, or greater, or project implementation is sufficiently delayed. These conditions will cause lands that would be classified as mid marsh if inundated under current sea level conditions to transition to low marsh within the next 50-100 years. Additionally, even at intermediate sea level rise levels, the presence of sediment concentrations less than 200 ppm will likely cause some mid marsh to transition to low marsh.

The sensitivity of these results to sediment concentrations, starting elevations, and the timing of project initiation underscores the uncertainty associated with restoring and sustaining these tidal marsh systems over time, given sea level rise. While sea level rise uncertainty is likely to continue to be significant and starting elevations and project initiation timing can be controlled, knowledge of sediment concentrations in this region could be improved to enhance our ability to plan for sustainable tidal marsh systems.

Discussion

In the vicinity of Highway 121, Sonoma Creek transitions from fluvial- to tidally-dominated sediment transport processes. This transition is reflected in the channel profile, which flattens dramatically at this location. Project elements evaluated for flood management potential have focused on increasing the conveyance capacity of Sonoma Creek in the vicinity of Highway 121 and/or providing an alternate flow path or “bypass channel’ through the adjacent low lands. Hydrodynamic modeling results showed that increasing flow capacity had little influence on the extent of flooding in most events, due to the low-lying topography, flat channel slope, and influence of Bay tide levels. Attempts to increase conveyance may not be sustainable because of the tendency for fluvial sediments to be deposited in this critical reach of channel due to the decrease in channel slope and transition to tidal influence.

Tidal processes dominate sediment transport processes and channel geomorphology downstream of Highway 121. Historically, large areas of tidal wetland drained through the tidal reaches of Sonoma Creek, flushing sediment from the channel and maintaining a cross-section large enough to support boat traffic. Land use changes have dramatically reduced the amount of tidal prism draining to the channel, causing sedimentation and reducing the size and capacity of the channel. Evaluation of marshplain accretion and channel scour processes confirm that tidal wetland restoration in the project area would be feasible and sustainable from a geomorphic point of view and could increase conveyance capacity in tidal channels.

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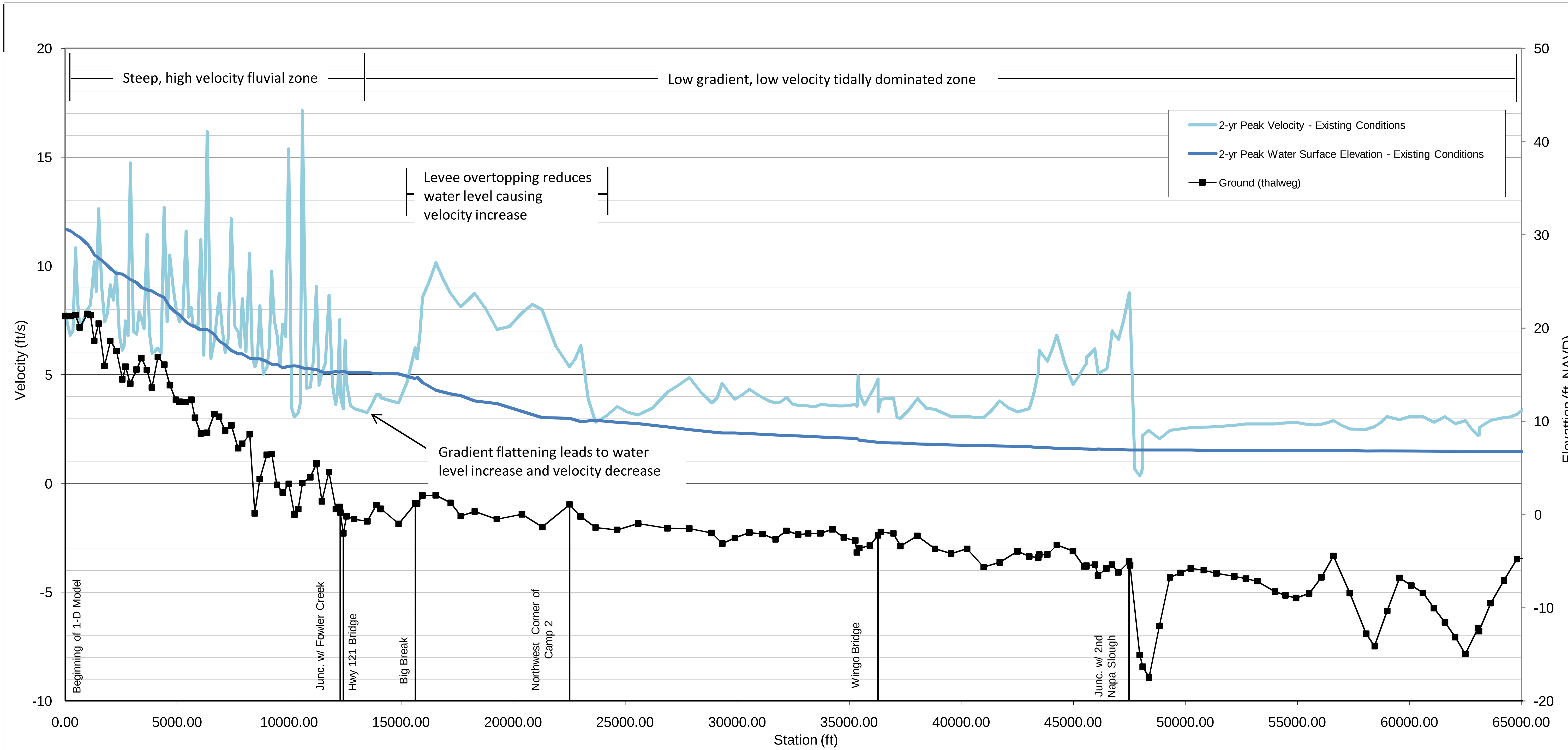

Source: MIKE Flood model (PWA, 2008)
Notes: Model results for Existing Conditions

figure 1

Sonoma Creek Sediment Transport and Geomorphic Analysis

2-yr Sonoma Creek Flood Model Results - Peak Velocity and Water Surface for Existing Conditions

PWA Ref# 1844.00

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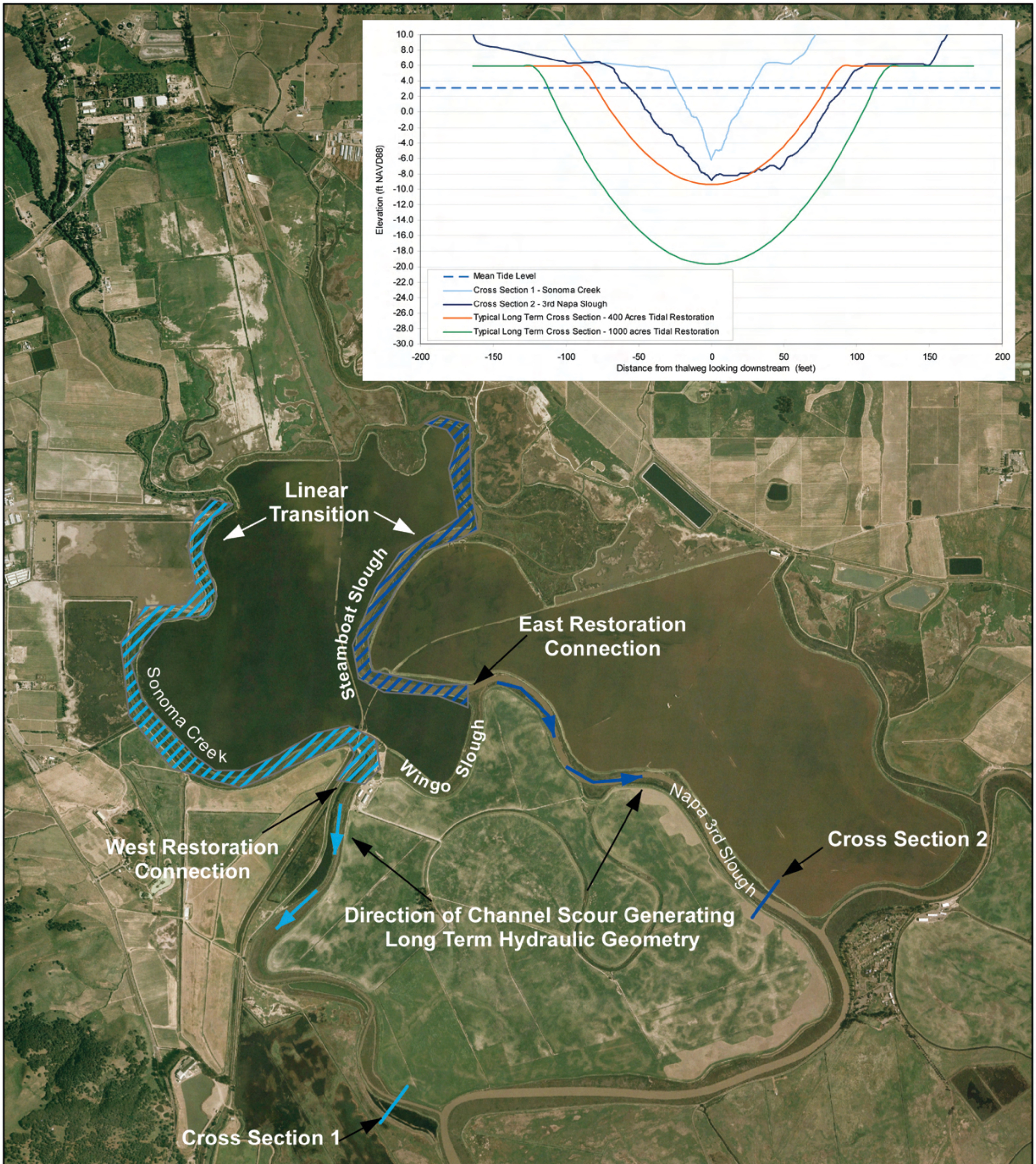

Channel Geometry Impacts for Restoration Connected on West End of Wingo Slough

Channel Geometry Impacts for Restoration Connected on East End of Wingo Slough

N

Feet
0 625 1,250 2,500 3,750 5,000

figure 2

Sonoma Creek Sediment Transport and Geomorphic Analysis
Tidal Restoration Element Schematic

PWA Ref.# 1844.00

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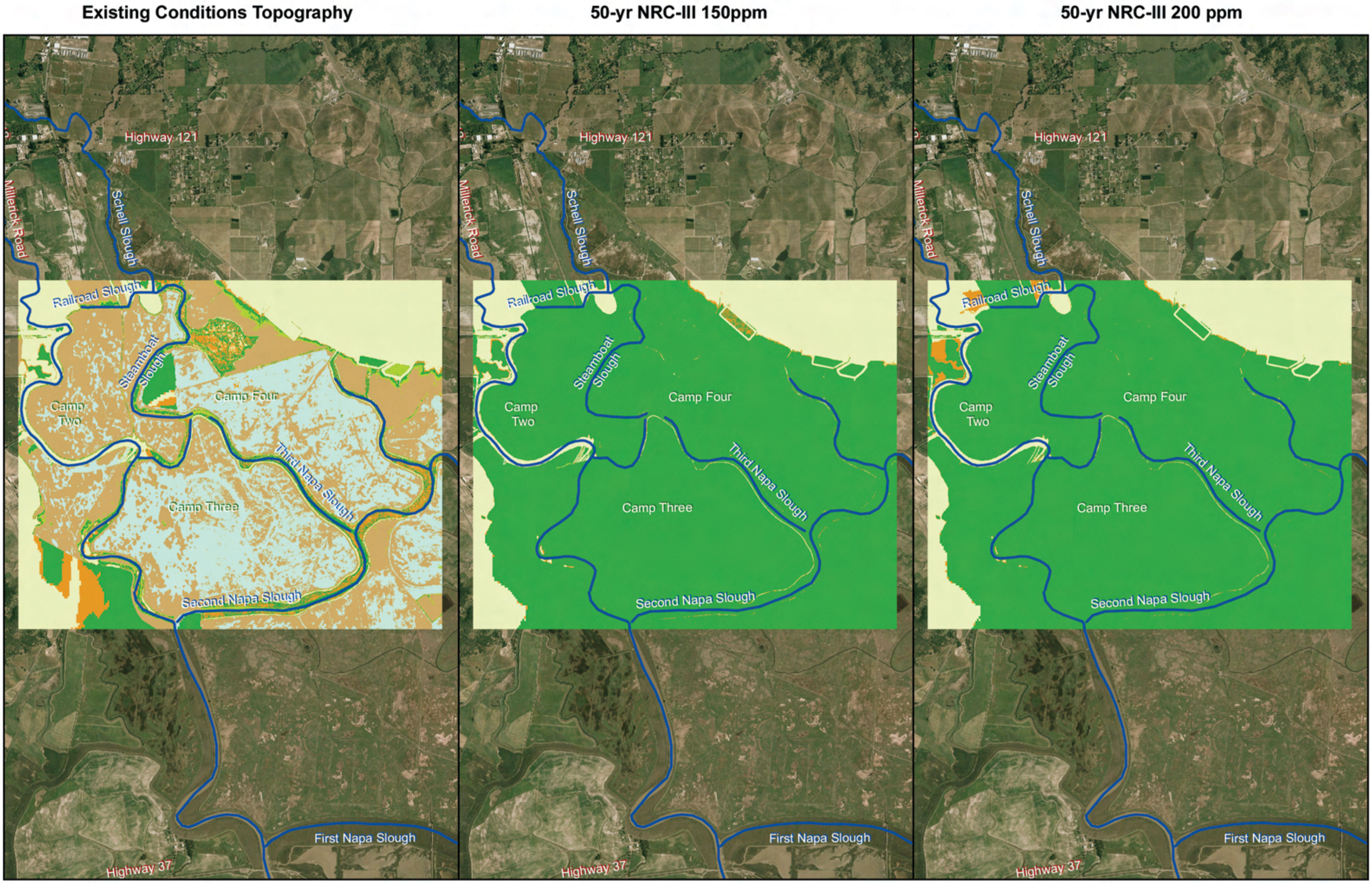

Source: IFSAR, NCALM, Towill, and USGS topography (Existing); Marsh98 model results (50-yr Scenarios); USACE Sea Level Rise Guidance (NRC-III "High" SLR curve)

Note: Scenarios shown for sediment concentrations of 150ppm and 200ppm with high SLR conditions
Elevations are relative to MHHW

N

0 1,875 3,750 7,500 11,250 15,000 Feet

Habitat Type

- Upland (above +1.0ft)
- High Marsh (+0.33ft to +1.0ft)
- Mid Marsh (-1.0ft to +0.33ft)
- Low Marsh (-2.0ft to -1.0ft)
- Mudflat (-5.9ft to -2.0ft)
- Subtidal (below -5.9ft)
- Bay Water Level

figure 3

Sonoma Creek Sediment Transport and Geomorphic Analysis

Marsh98 Habitat Evolution Results 50-yr NRC-III

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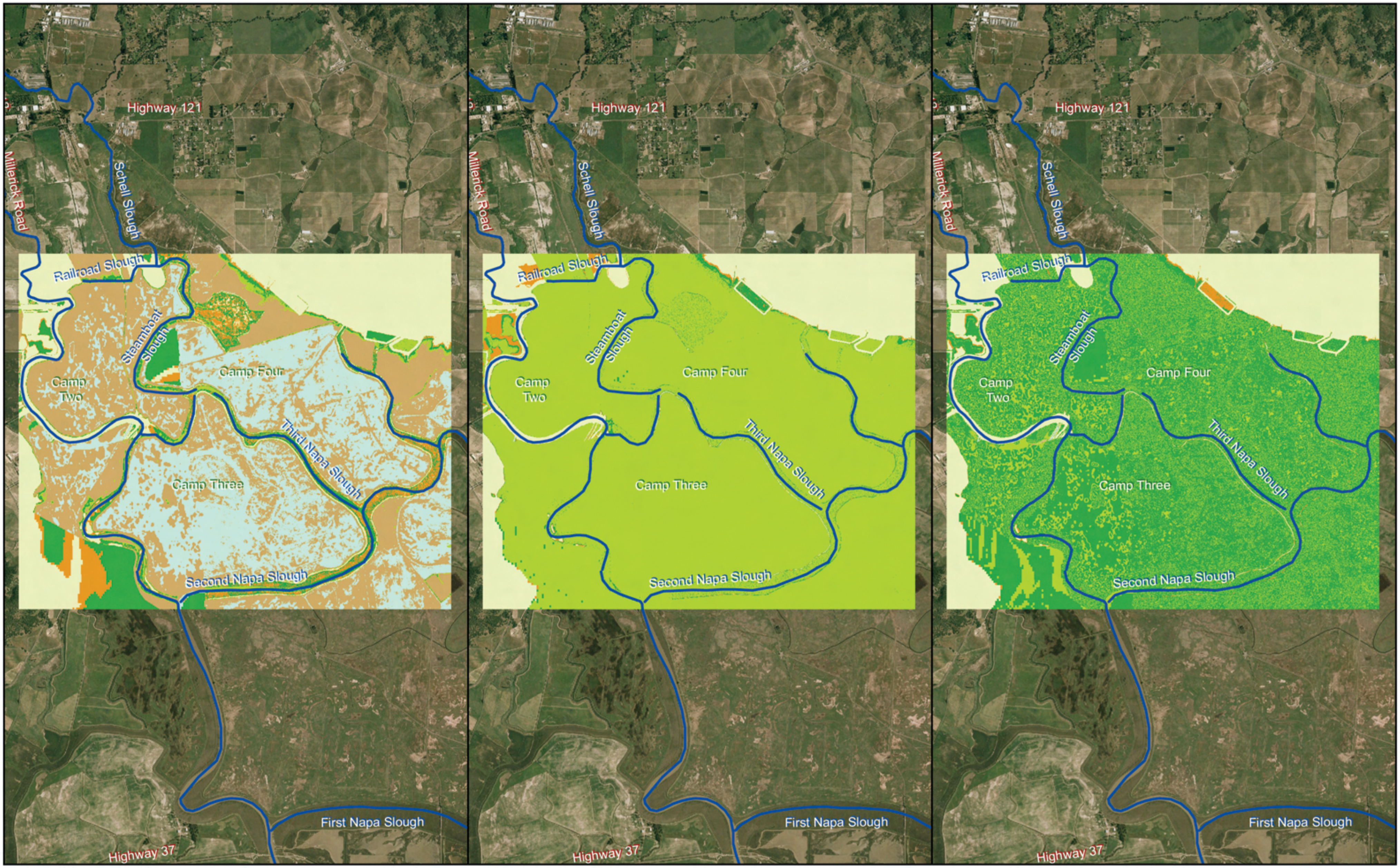
Existing Conditions Topography | **100-yr NRC-III 150ppm** | **100-yr NRC-III 200 ppm**



Source: IFSAR, NCALM, Towill, and USGS topography (Existing); Marsh98 model results (50-yr Scenarios); USACE Sea Level Rise Guidance (NRC-III "High" SLR curve)

Note: Scenarios shown for sediment concentrations of 150ppm and 200ppm with high SLR conditions Elevations are relative to MHHW

N

0 1,875 3,750 7,500 11,250 15,000 Feet

Habitat Type

- Upland (above +1.0ft)
- High Marsh (+0.33ft to +1.0ft)
- Mid Marsh (-1.0ft to +0.33ft)
- Low Marsh (-2.0ft to -1.0ft)
- Mudflat (-5.9ft to -2.0ft)
- Subtidal (below -5.9ft)
- Bay Water Level

figure 4

Sonoma Creek Sediment Transport and Geomorphic Analysis

Marsh98 Habitat Evolution Results 100-yr NR-CIII

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APPENDIX G

BRIEF INTRODUCTION TO
TIDAL MARSH RESTORATION IN THE SAN FRANCISCO BAY AREA

Brief Overview of Tidal Marsh Restoration in the San Francisco Bay Area

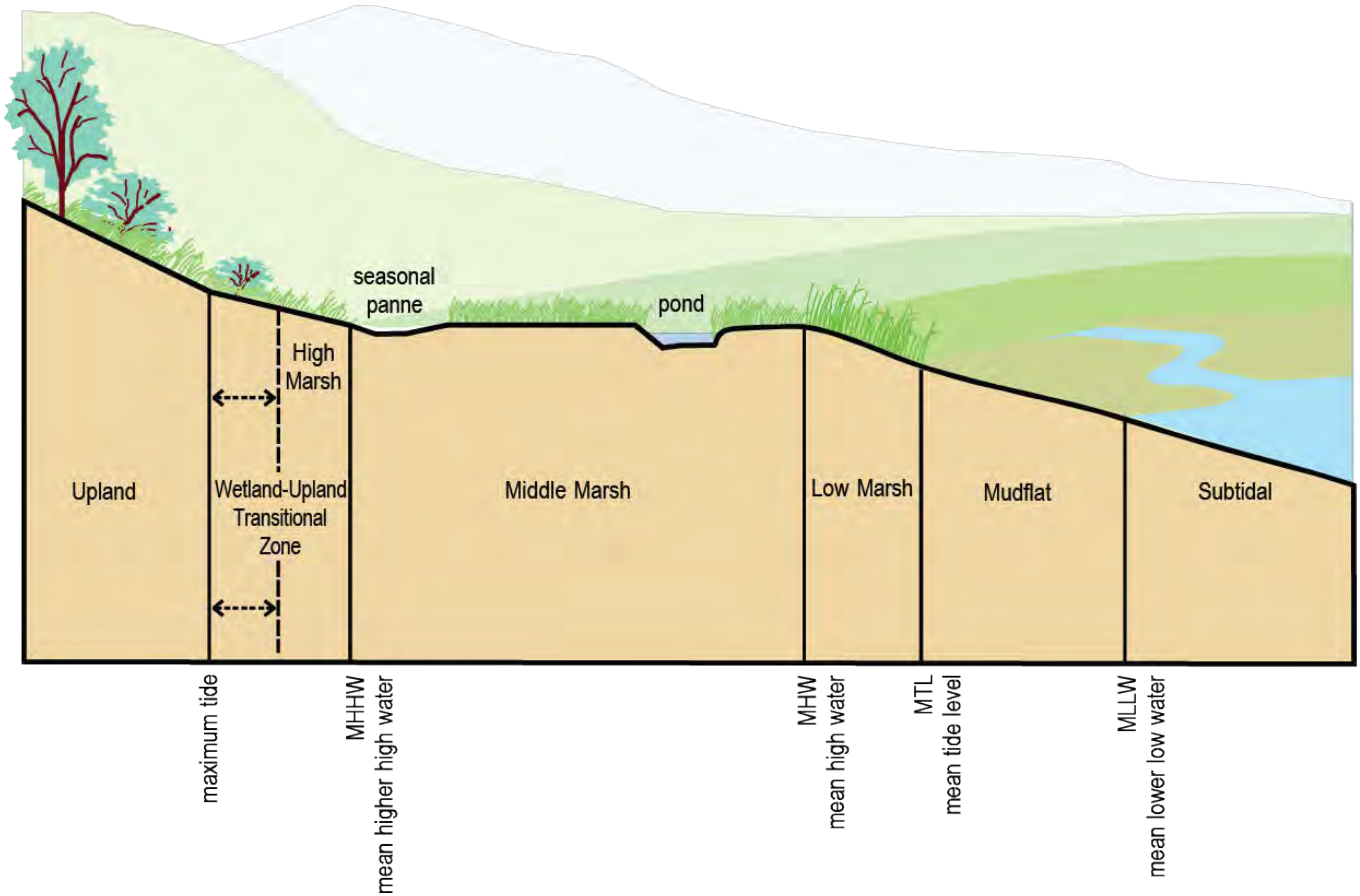
(Based on: PWA (Philip Williams & Associates, Ltd.) and P. M. Faber. 2004. *Design Guidelines for Tidal Wetland Restoration in San Francisco Bay*. The Bay Institute and California State Coastal Conservancy, Oakland, CA. 83 pp. http://www.wrmp.org/design/Guidelines_Report-Final.pdf)

Tidal wetlands are lands on the margin of the estuary that are periodically inundated by tides, including intertidal mudflats, tidal marsh plain, tidal channels within the marsh, and wetland-upland transition areas. A typical mature San Francisco Bay tidal salt marsh has a distinctive vertical profile relative to the tide range, with intertidal mudflats typically occurring between mean lower low water (MLLW) and the mean tide level (MTL), low marsh between MTL and mean higher high water (MHHW), the middle marsh plain at MHHW, and the wetland-upland transition between MHHW and the maximum tide level (Figure 1). A goal of most tidal wetland restoration projects has been to create vegetated tidal marsh habitat (MTL to MHHW), incorporating higher wetland-upland transition zones where possible.

Beginning over 140 years ago, marsh plains around San Francisco Bay have been diked and drained for agricultural use. Over this period, diked lands have typically subsided two to six feet relative to the former marshplain elevation. Sea level has risen by approximately 0.5 feet over the last 100 years, leaving these lands even lower in the tidal frame. In order to restore subsided agricultural lands to tidal marsh habitat, the ground elevation must be raised either through importation of fill or through natural sedimentation. Most San Francisco Bay tidal wetland restoration projects have relied on natural sedimentation processes that are set in motion when a site is exposed to tidal action. In a restoring marsh, suspended sediments from Bay waters are carried in on flood tides and deposited on the flooded site during slack water. Ebb tidal currents are not sufficient to resuspend deposited sediments, except where tidal channels form in the developing marsh. As sediment accumulates, the ground elevation rises through the wetland profile from open water to mudflat and eventually to mature marshplain (Figure 2). At the same time, ebbing tides scour drainage channels to carry water back to the Bay. The rate of sedimentation depends on the sediment concentration in flood tide waters, depth and duration of high water slack, the rate of sea level rise relative to land subsidence, the amount of wind and wave action disturbing deposited sediments, and the rate of accumulation of organic material. The dimensions of drainage channels depend on the volume of water that drains from the site on a typical tidal cycle.

The most successful tidal marsh restorations create conditions that allow the natural physical processes of sedimentation and tidal flushing to support the evolution of sustainable tidal marsh habitat. Once it has been determined that suitable elevations can be achieved through natural sedimentation processes, basic design elements are used to introduce and promote tidal circulation. Typical design elements include strategically placed levee breaches sized to accommodate the full tidal range; excavated “starter” channels within the site; blocking or filling of existing ditches to encourage development of natural drainage channels; and modifications to existing levees to create upland transition or meet other project requirements. Constraints that must be considered in tidal wetland restoration design include the following:

1. Potential impact on offsite flood hazards, stormwater drainage, and groundwater;
2. Presence of existing infrastructure and easements;
3. Public access requirements;
4. Invasive species and vector control considerations; and
5. Impacts to existing habitats.



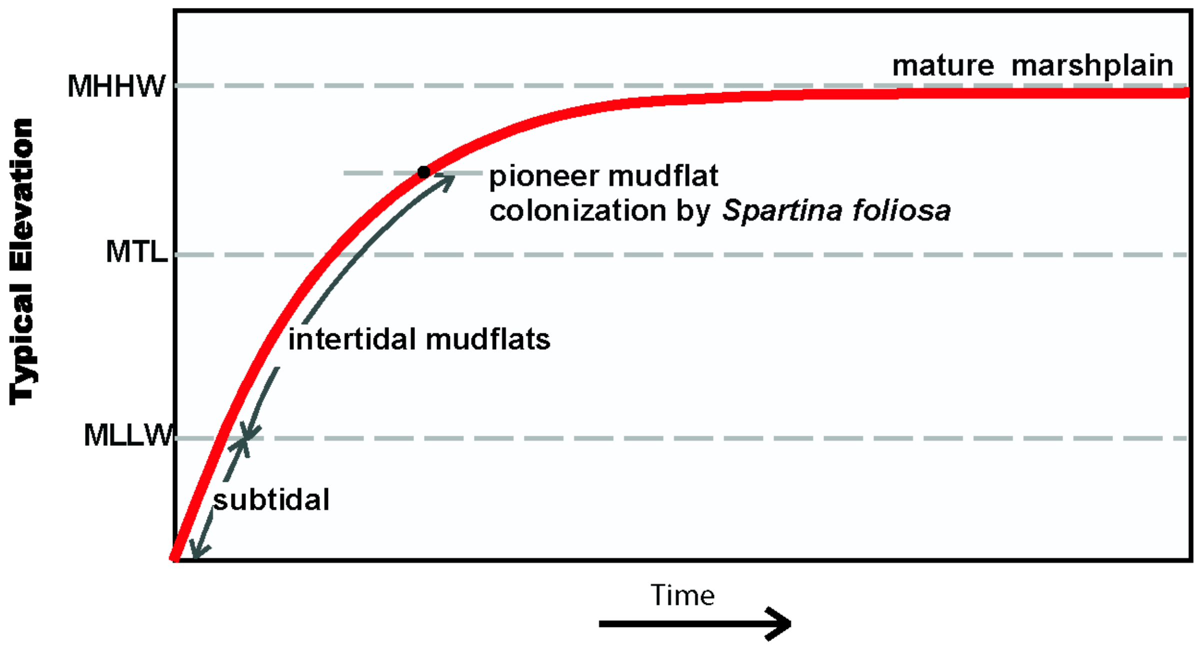
Source: Philip Williams & Associates, Ltd., and P. M. Faber (2004). *Design Guidelines for Tidal Wetland Restoration in San Francisco Bay*. The Bay Institute and California State Coastal Conservancy, Oakland, CA. 83 pp. Figure 2.

figure 1

Brief Overview of Tidal Marsh Restoration in the San Francisco Bay Area

Vertical Profile of Tidal Marsh

PWA



Source: Philip Williams & Associates, Ltd., and P. M. Faber (2004). *Design Guidelines for Tidal Wetland Restoration in San Francisco Bay*. The Bay Institute and California State Coastal Conservancy, Oakland, CA. 83 pp. Figure 7.

figure **2**

Brief Overview of Tidal Marsh Restoration in the San Francisco Bay Area

Evolutionary Trajectory of Restoring Marsh

PWA