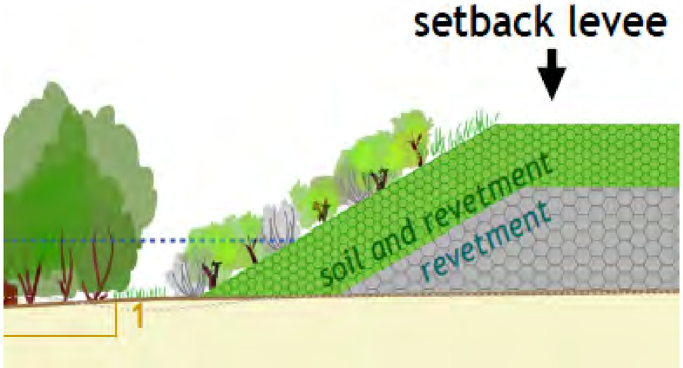

Santa Clara River Parkway

Levee Setback Assessment of the Lower Santa Clara River, Ventura County, California - Implications for Flood Risk Management and Ecological Benefit

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APPENDICES

Appendix A. Levee Setback Modeling Technical Memorandum (cbec Inc. 2011)

1 INTRODUCTION

1.1 Background and Study Context

The Santa Clara River flows from the San Gabriel Mountains in Los Angeles County, through Ventura County, and eventually into the Pacific Ocean near the City of Ventura (Figure 1-1). Since the onset of Eurpoean American settlement over 150 years ago, the contributing watershed and mainstem floodplain have experienced sustained impacts from both development and agricultural influences. Over the past several decades, the lower 64 km (40 miles) of the Santa Clara River and its floodplain have been significantly altered due to flood protection infrastructure (including reinforced levees), water diversions and flow regulation, roads, agriculture, aggregate mining, and urbanization. The flood protection structures have constrained or disrupted natural geomorphic and hydrologic processes, often causing riparian and aquatic habitat loss or degradation. Despite the historical alterations to the riparian system, the lower Santa Clara River (LSCR, reach downstream of the Los Angeles County Line) presents a unique opportunity to conserve and restore riparian functions and ecosystems compared with other coastal southern California rivers, most of which are highly degraded. As the watershed is one of the least altered rivers in southern California, it continues to support a variety of natural aquatic and terrestrial communities and native species. It also provides a regionally important north-south corridor between protected terrestrial wildlife areas in the southern California coastal ecoregion, and the river itself provides an important aquatic habitat linkage from the coast and estuary to upstream habitats in the mainstem channel and tributaries.

The Santa Clara River Parkway project, which is lead by the California State Coastal Conservancy (Coastal Conservancy) and The Nature Conservancy (TNC), seeks to ameliorate historical ecological impacts in the LSCR and conserve existing riparian habitats. The primary goal of the Parkway project is to create, protect and restore 64 km (40 miles) of continuous river and floodplain corridor from the Los Angeles County Line downstream to the Santa Clara River mouth. Other goals of the Parkway project are to: 1) conserve and restore aquatic and riparian habitat for native species, 2) provide enhanced flood protection, and 3) provide public access and environmental education within the Parkway. The Parkway is being created through the acquisition of river channel, floodplain, and agricultural lands that are vulnerable to flooding under current or restored conditions (i.e., without levees) and that do not contain vital infrastructure, and conversion of those lands back to riparian and upland habitats. Land acquisition is being conducted on a willing seller basis and is focused on the lower river, where a number of parcels have already been acquired (Figure 1-2).

Figure 1-1. The Santa Clara River watershed.

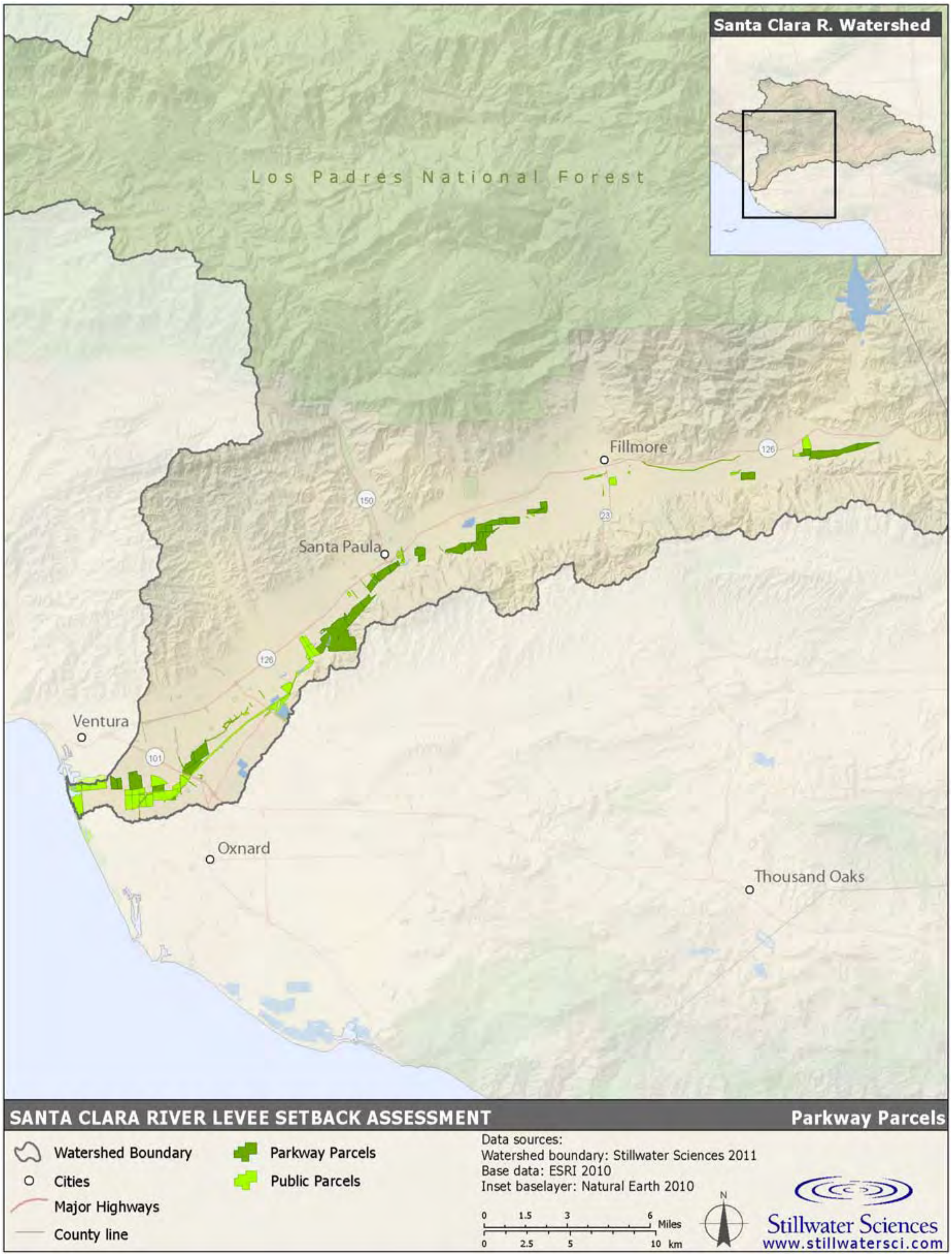

Figure 1-2. Santa Clara River Parkway parcels.

The Santa Clara River Parkway Floodplain Restoration Feasibility Study (Stillwater Sciences 2008) was undertaken to assist with the acquisition, management, and eventual restoration of lands within the Parkway. Through a thorough investigation of historical and contemporary geomorphic and ecological functioning of the Santa Clara River and floodplain, the Feasibility Study identified levee removal and setback as one of the primary restoration strategies that should be considered for the Parkway in order to improve riparian habitat conditions and geomorphic processes affected by channel-confining levees. However, the Feasibility Study also recognized a number of important uncertainties associated with levee setback and removal that would need to be resolved before pursuing the restoration strategy further. One of the primary uncertainties identified was the local change in channel hydraulics and sedimentation resulting from a parcel-based strategy of levee removal or setback. To resolve this uncertainty, the Feasibility Study recommended modeling several flood flows and resultant water depths and velcities as a guide to erosion and deposition trends to ascertain any potentially negative upstream or downstream effects. In addition, a regional-level evaluation using hydraulic models was recommended for the Parkway area to assess the overall potential flood management benefit of this restoration strategy. The attached levee setback modeling (Appendix A) and this levee setback assessment were undertaken in direct response to the recommendations in the Feasibility Study.

1.2 Goals and Objectives

The overall goal of the levee setback modeling and assessment study presented here is to elucidate key hydraulic, geomorphic, flood risk, and ecosystem benefits and uncertainties associated with levee setback and removal along the LSCR. More specifically, the main goal is to characterize the effects of a range of levee setback scenarios on: (1) flood control/risk management; (2) local, upstream, and downstream hydrogeomorphic conditions; (3) riparian vegetation and habitat conditions; and (4) Parkway acquisition efforts.

The objectives of this modeling and assessment study are as follows:

- Development of a hydraulic model of the LSCR capable of gaming the impacts of levee set-back on flow hydraulics at a resolution necessary to assess potential flood-control, geomorphic, and ecological benefits.
- Modeling flood flow water depths and velocities along the LSCR with existing levees and for a suite of levee setback scenarios under current and hypothetical future hydrologic conditions (as impacted by climate change)
- Assessing potential flood-control, geomorphic, and ecologic benefits associated with each levee setback scenario through analysis of modeling results.

For this study, we investigated the potential benefits associated with levee setbacks during an extreme flood event (100-year flood, used to calibrate against the existing FEMA hydraulic modeling of the LSCR) and a more frequently occuring flood event (25-year flood, similar to the peak flow during the January 2005 storm). We also used the most up-to-date knowledge regarding climate change impacts on sea level and flood flows to assess the impact levee removal could have on flood flow water depth and velocity several decades into the future.

1.3 Study Area

The Santa Clara River Parkway Floodplain Restoration Feasibility Study and this levee setback modeling and assessment study focus on the lower 64 km (40 miles) of the mainstem Santa Clara River downstream of the Los Angeles/Ventura County Line (see Figure 1-1). The Santa Clara River originates on the northern slopes of the San Gabriel Mountains in Los Angeles County (approximately 2,700 m [9,000 ft] above mean sea level) and flows through the Santa Clara River Valley and the Oxnard Plain in Ventura County, finally emptying into the Pacific Ocean near the City of Ventura (Figure 1-1). The river has one of the largest watersheds on the southern California coast, draining an area of approximately 4,140 km^2 (1,600 mi^2).

Consistent with other rivers in the region, the Santa Clara River watershed experiences highly variable annual rainfall and peak river flows. Generally, flows in the river are relatively low: 75% of the time flows are less than 4.2 m^3s^{-1} (150 cfs) at the Montalvo gage (approximately 7.2 km [4.5 miles] upstream of the mouth) and 50% of the time flows are less than 0.3 m^3s^{-1} (10 cfs) (URS 2005). However, large peak flows associated with winter storm events exceed 2,800 m^3s^{-1} (100,000 cfs) once every 10 years on average (URS 2005), generally during years with a strong positive El Niño - Southern Oscillation (ENSO) signal (or, ENSO years). In general, ENSO years are characterized by relatively high rainfall intensities and higher annual peak flow magnitudes than in non-ENSO years (Cayan *et al*. 1999, Andrews *et al*. 2004). Flows in the mainstem Santa Clara River can increase, peak, and subside rapidly in response to high intensity rainfall, with the potential for severe flooding under saturated or near-saturated watershed conditions. Between winter rainfall events in wet years, the river may exhibit continuous baseflow to the ocean from residual watershed discharge; in dry years, flow may be intermittent in the mainstem channel. During the dry summer season, flows in the mainstem and tributaries are intermittent or non-existent, depending primarily on areas of rising groundwater or inflows from dam releases or other anthropogenic sources, such as irrigation runoff and treated wastewater effluent.

The Santa Clara River watershed is located within the San Andreas Fault system, a geologically active region that forms the dynamic boundary between the Pacific and North America tectonic plates. Rapid tectonic uplift rates and relatively erodible bedrock lead, combined with frequent high-intensity storm events, lead to extremely high rates of hillslope sediment production. As would be expected, sediment transport processes in the Santa Clara River are dominated by extreme events associated with the river's highest flows. For instance, an estimated 55% of the roughly 57.6 million tonnes (63.5 million tons) of sediment that passed the USGS gage at Montalvo near Highway 101 between 1968 and 1975 was transported during high flows in just two days during two separate floods of record in January and February 1969 (Williams 1979).

In planform, the LSCR is characterized by a wide, relatively straight floodway with one or more low-flow channels that are reconfigured after each flood event. The full mainstem channel bed is occupied only during higher magnitude floods, typically a 5-year event or larger. Erosion of alternate outer banks of the active floodway in some reaches following the large floods in January and February 2005 suggests that the entire floodway of the contemporary lower river behaves in a manner similar to a broad, single thread meandering channel at very high flows. As floods recede, the river becomes more braided in character, with multiple flow courses. There is insufficient perennial flow to retain multiple flowing channels in a majority of the LSCR and, in general, a single dominant channel defines the channel thalweg.

Since the 1950s, a total of 53 levees have been constructed along over 40 km (25 miles) of the LSCR (URS 2005), amounting to approximately 33% of the total river bank length in Ventura County (Figure 1-3). The levees include both public levees (approximately 32 km [20 miles] total length) and private levees (approximately 12 km [7.5 miles] total length) along both left and right banks, and were designed to protect agricultural lands, urban development, and floodplain mining pits. Many of the private levees are composed of riverbed materials and are designed to protect agricultural land from flooding; these levees typically have to be repaired or re-constructed after large floods. Several of these levees are themselves protected by earthen or stone groins projecting perpendicular to river flow and designed reduce the velocity of near-bank flood flows that might otherwise undermine the levee. Notable public levee construction began in 1961 with the completion of a U.S. Army Corps of Engineers levee designed to protect agricultural land along the south side (left bank) of the LSCR between South Mountain and Highway 101. The levee is approximately 7.4 km (4.6 miles) long and was built to prevent floodplain inundation for flows of up to the defined standard project flood (6,370 m^3s^{-1}, 225,000 cfs), or an approximate 100-year flood event (according to watershed-wide hydrologic modeling, see AQUA TERRA Consultants 2009). The Ventura County Watershed Protection District (VCWPD) now manages this stone-revetted levee, along with an adjoining reinforeced levee structure from Highway 101 to Victoria Avenue. Stone-protected or soil cement-cored levees have been constructed for flood and erosion protection of urban developments, including some that project into the historical river course.

Over the past several decades, major flood events have caused damage to the levees along the LSCR. In 1969, for example, a 610 m (2,000 ft) reach of the South Mountain–Highway 101 levee failed due the combined effect of the January and February flood events. Further flood damage to the downstream levee and to the Saticoy “dike” (which protects Cabrillo village) occurred during the 1978 events (Simons, Li & Associates 1983). The damage was attributed primarily to undercutting brought about by channel incision associated with the effects of aggregate mining.

Data sources:
Watershed boundary: Stillwater Sciences 2011
Levees: Stillwater Sciences 2011
Base data: ESRI 2010
Inset baselayer: Natural Earth 2010

Figure 1-3. Existing levees on the lower Santa Clara River.

2 LEVEE IMPACTS AND POTENTIAL BENEFITS OF LEVEE SETBACK

2.1 Levee Impacts on Fluvial and Floodplain Processes

Channel confinement by privately and publicly maintained levees is one of the most severe impacts limiting geomorphic and hydrologic functioning of the LSCR, especially below the confluence of Santa Paula Creek (Simons, Li & Associates 1983, Stillwater Sciences 2007a). Flood flows from the LSCR historically spilled onto the Oxnard Plain and flowed towards the Pacific Ocean. By design, the levees constructed along the Santa Clara River have confined high flows to the active channel width and have significantly reduced the riparian area historically inundated by large floods. The levees have also reduced the effective flow width during floods and stabilized the river's planform, resulting in an alteration of channel morphologic development and sediment transport. Furthermore, the levees have effectively reduced the flood water storage capacity of the river, thus forcing the majority of high flows to be conveyed solely within the active channel rather than being allowed to spread out upon the floodplain (Stillwater Sciences 2007a).

During high flows, the narrowing of the active flow width combined with the increase in flood water volume moving through the river channel due to levee confinement has increased flood stages, velocities, and shear stresses. Thus, there has been greater potential for sustained and systemic bed and bank scour. Since the levees were first constructed in 1961, a pattern of channel bed lowering, or incision, has developed particularly in the reach downstream Freeman Diversion, which is confined by the majority of the river's levees (see Stillwater Sciences 2007a). Channel incision has likely led to the lowering of adjacent floodplain water table elevations and decreased groundwater storage in some reaches compared to historical conditions.

Where levees are used in conjunction with bank protection to "train" the channel to a particular planform there is the risk that, if the imposed channel planform does not align with the natural planform tendency during flood events (or if the channel is simply too narrow), the flood thalweg will flow directly towards the levee in certain locations. This can lead to high near-bank flow velocities and the potential for levee erosion. This effect is accentuated in incising channels wherein the levee toe can be prone to failure and lead to levee breaches. The 1969 flood apparently produced just such an effect, with flow spilling out through a left bank breach downstream of Victoria Avenue in the direction of historical flood overflows (see Simons, Li & Associates 1983 for more details). Many levees have been reinforced with exterior stone revetments and soil-cement cores that can help defend against such erosion and earthen and stone groins projecting into the flow are used to deflect high velocity flows before they attack the banks. However, notable erosion of some levees and other protected banks still occurred in the 2005 floods (Stillwater Sciences 2007a). An additional impact of protected levees is that flood flows can be reflected towards an opposing, unprotected bank that would not otherwise be prone to substantial erosion.

Although the levee system is an integral part of the flood control efforts along the river, its integrity is regularly threatened by winter high flow events, which, in conjunction with alterations to the channel morphology, has led to significant levee failures requiring costly repairs (Simons, Li & Associates 1983, URS 2005).

2.2 Levee Impacts on Aquatic and Riparian Ecology

In addition to altering the river's morphology, the levees have reduced floodplain habitat use opportunities for a variety of species within the lower watershed. For example, Bozkurt *et al*. (2000) outlined levee impacts on ecological systems whereby a decrease in floodplain inundation and channel migration generally leads to reductions in habitat formation and maintenance, and ultimately to loss of biodiversity with a potential decline of many species populations. In recent years, the ecological and societal benefits (e.g. ecosystem services) provided by intact or restored (reconnected) floodplains have received increased attention in river corridor conservation planning and management (Brauman *et al*. 2007, Stillwater Sciences 2007b, Opperman *et al*. 2009 and 2010).

The presence of multiple flood-control structures and reinforced levees has interrupted lateral habitat connectivity, decreasing the degree of linkage between instream aquatic habitat and riparian vegetation and/or freshwater wetlands in the floodplain. The construction of levees in the lower reaches of the river and estuary, together with development on the floodplain, has dramatically reduced the area available for floods to inundate and, thus, for riparian forests to recruit and grow. Simons, Li & Associates (1983) report that the Santa Clara River floodplain was historically as much as 3.2 km (2 miles) wide in the lowermost reaches. Regular flood inundation over a wide floodplain supported the recruitment of riparian trees over a vast area, while groundwater sustained plants through the summer, allowing mature forests to develop in many reaches. The riparian area likely supported dense, multi-storied stands of broadleaf trees, including cottonwood, sycamore, and various willows, that extended from a few to several miles wide in gaining reaches with rising groundwater (Schwartzberg and Moore 1995, Briggs 1996, Boughton *et al*. 2006, Stillwater Sciences 2007c, Beller *et al*. 2011, Orr *et al*. 2011), while drier conditions in losing reaches supported alluvial scrub vegetation (Stillwater Sciences 2007c, Beller *et al*. 2011, Orr *et al*. 2011). In addition, levee construction and land development within and adjacent to the historical Santa Clara River Estuary footprint have decreased the quality and quantity of aquatic habitat (e.g., rearing habitat for native steelhead, see Stillwater Sciences 2011 for a more detailed discussion).

Currently, the riparian corridor of the LSCR is much narrower compared to historical accounts. The 2005 flood (3,850 m^3s^{-1} [136,000 cfs], approximate 17-year recurrence interval based on a flood frequency analysis at Montalvo gage [USGS 11114000]) inundated just over 2,800 hectares (7,000 acres) along 55 km (34 miles) of the lower river. For comparison, the 1938 flood (3,400 m^3s^{-1} [120,000 cfs], 14-year recurrence interval) inundated over 4,900 hectares (12,000 acres) in this same longitudinal area (Figure 2-1). This difference represents a nearly 40% loss in the extent of the riparian corridor since 1938 (Stillwater Sciences 2007c). This loss is most acute in the lowest reaches of the river where nearly 70% of the 1938 riparian corridor has been lost. The loss of is riparian and floodplain habitats int the LSCR is even greater, closer to 60% overall, when current conditions are compared to pre-1850 historical conditions (Beller *et al*. 2011, Orr *et al*. 2011).

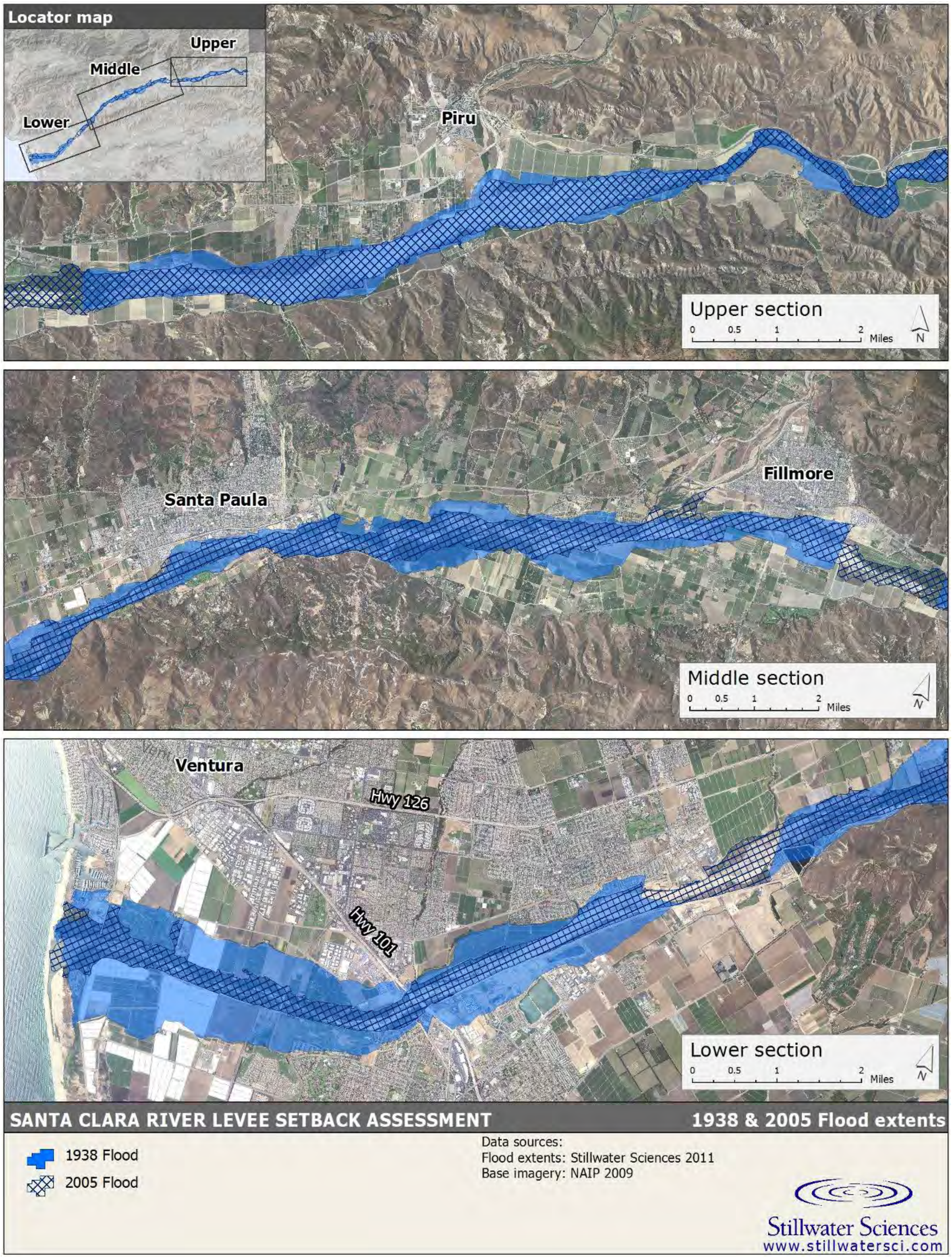

Figure 2-1. Extent of the 1938 and 2005 floods.

2.3 Levee Setback as a Restoration Tool

Levee setback or removal involves some combination of the following actions either singularly or in combination: the active or passive removal of existing channel-confining levees, construction of setback levees away from the river channel, re-contouring of the restored floodplain area to bring the floodplain elevation closer to the channel elevation, and removal or modification of infrastructure.

On properties acquired for conservation uses, floodplain restoration can be accomplished by either passive or active levee removal. Passive removal would be appropriate primarily for privately maintained agricultural levees that are not highly engineered, as are common along the LSCR, particularly in the upper reaches. Passive removal implies allowing failure or breaching to occur naturally during large flood events but without subsequent repair. Active removal requires heavy equipment to dismantle the levee. In locations where levees are allowed to fail or breach, consideration should be given to whether restoration would benefit from the subsequent removal of the remaining levee structure.

In areas that require continued flood protection of development or agriculture on the floodplain, bank-edge levees could be replaced by setback levees constructed to provide the same level or better flood protection while still providing lateral connection between the river and its floodplain, thus encouraging natural fluvial processes and habitat development. A setback levee is placed landward some distance away from the active channel margin, which allows the restored floodplain area between the setback levee and the river's edge to be occasionally inundated during seasonal high flow events (Mount 1995, USACE 2002) (Figure 2-2). In some instances, setback levees are not necessary when there are existing natural or man-made topographic features that will contain flood water within the targeted floodplain parcel.

Along the LSCR, levee setback strategies should be focused downstream of the Vern Freeman Diversion Dam, where existing levees severely constrain the floodplain width and opportunities for setback exist. Some opportunities also exist in the reaches upstream of the Diversion Dam, however the reaches downstream should be the priority becuase they have the greatest extent of channel confinement and have shown a trend of channel incision over the past several decades (see Stillwater Sciences 2007a). The recent FEMA floodplain mapping of the Santa Clara River presents a strategic opportunity for setting back levees: when levees are reconstructed to meet FEMA certification standards, they can be simultaneously setback. Because they increase the floodway width and so inherently increase the river's flood conveyance capacity, setback levees need not be as high as bank-edge levees and are much less disruptive to high-flow processes.

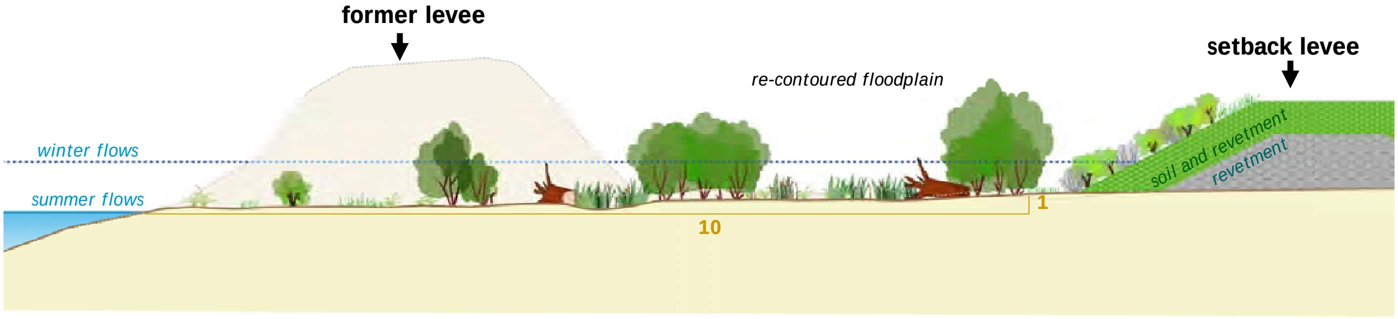

Figure 2-2. Conceptual diagram of levee setback strategy.

Following removal of existing levees or construction of setback levees, some areas may require re-grading of the floodplain surface that is now part of the active floodway. This procedure, also called floodplain re-contouring, may involve filling in any abandoned gravel-mining pits, or other man-made depressions that could present stranding issues for salmonids and other native fishes, and increased risk of predation by avian or fish species. Lowering or sloping of the floodplain towards the river channel may also be required to increase the potential for seasonal inundation, especially along incised reaches where the elevation of the floodplain in relation to the channel bed has dramatically changed from pre-development conditions. Similar to other restoration projects involving floodplain re-contouring, the restored riparian corridor could be passively or actively revegetated with native plant species to provide habitat for wildlife. Floodplain re-contouring may also be necessary in the few areas where levee removal or setback would connect former mining or industrial areas with the floodplain.

Another activity associated with levee removal and/or setback is the modification or removal of infrastructure in the floodway. As the floodplain is widened and the channel is allowed to migrate, existing infrastructure may have an increased risk of damage by bank erosion or flood flows. In most cases, infrastructure is modest, consisting primarily of fencing, concrete debris, power lines, and pumping facilities. In other cases, such as McGrath State Beach, it would be prudent to relocate camping and day use facilities farther away from the river mouth to allow the river to move away from the Ventura Water Reclamation Facility and reduce maintenance costs following high flows. In more extreme cases, modifying bridges or relocating wastewater treatment facilities would be necessary to improve fluvial processes and reduce flood risk to these structures.

2.4 Potential Benefits Associated with Levee Setback

Implementation of levee setback or removal has the potential to provide numerous benefits to riparian habitat conditions and geomorphic processes that have been substantially altered due to the presence of the existing channel-confining levees. The primary potential ecological benefit of this restoration strategy is the re-establishment of a seasonally inundated floodplain. The river's re-connection to its floodplain would allow for an exchange of water, sediment, and nutrients between the river and its floodplain, and an increase in riparian habitat patch size and quality.

Constructing setback levees would, where necessary, maintain flood protection for the surrounding developments outside of the Parkway area. An enlarged river corridor would enhance landscape linkages, providing movement corridors for wildlife between protected lands. Additionally, a wider floodway should increase the residence time of flood waters on the floodplain and so increase groundwater recharge (Poole *et al*. 2002, Kazama *et al*. 2007). It should be noted that while levee setback and removal may need to be implemented in a parcel-by-parcel fashion due to land acquisition and funding constraints, the larger benefits of this restoration strategy, particularly flood control and landscape linkages, as well as cost efficiencies, will not be fully realized until larger extents of levees are setback or removed.

Re-initiation of fluvial processes, such as bank erosion, bar growth, channel migration and width increases to the active channel bed, would be an expected outcome following implementation of this restoration strategy. During flood events in a braided-meandering river such as the Santa Clara River, bank erosion naturally occurs at the outer banks of a river bend where velocities are greatest, or near perturbations on the channel bed, such as midchannel bars, that can topographically steer the flow against the adjacent bed or banks causing higher shear stresses to scour the channel boundaries (Leopold *et al*. 1964). Deposition of sediment occurs in slower portions of the channel and contributes to the formation of point bars, mid-channel bars, and natural sedimentation processes. The re-initiation of this process would not only restore a dynamic physical characteristic of the Santa Clara River but also would benefit in-channel and riparian habitat diversity (Bozkurt *et al*. 2000, Stillwater Sciences 2007b, Opperman *et al*. 2010).

A long-term trend of channel incision downstream of the Highway 118 bridge (as illustrated in Stillwater Sciences 2007a) could potentially slow or cease following implementation of this restoration strategy, because the flood waters would be allowed to spread out upon the reconnected floodplain, thus increasing the river's flood capacity and effective flood width. Also, because floodplain discharge has low velocities due to frictional resistance from vegetation and other roughness features on the floodplain, sufficiently broad floodways can attenuate flood flows, thus diffusing the potential for deep, high velocity flows to scour the channel bed.

An additional benefit from the seasonal inundation of the restored floodplain is recharge of groundwater into the basin's aquifers, which are a major source of fresh water for the many land use activities in the valley, especially agriculture. The amount of groundwater recharge by inundated floodplains depends on several factors, the most critical of which are the residence time of the water on the floodplain, the permeability of the floodplain substrates, and depth to the water table. For these reasons, arid-region rivers dominated by sporadic high flow events such as the LSCR, have greater potential for groundwater recharge because their floodplains are often composed of coarse sediments with high permeability, and the groundwater table is usually well below the channel (G. Wallace, Pacific Groundwater Group, pers. comm., 2008). Short residence time, low porosity, and a shallow groundwater table inhibit groundwater recharge. For example, the Oxnard Plain groundwater basin has several clay strata that inhibit effective infiltration of floodwater. However, the majority of the groundwater basins underlying the LSCR occur in recent and relatively deep alluvial deposits that are very porous and allow easy infiltration of floodwater.

A final benefit from this action is the potential for improved flood protection for the various developments located throughout the LSCR valley. Hydraulic modeling of levee setback scenarios suggests that water surface elevations and velocities for high-magnitude flow events can be greatly reduced. Flood protection can be further enhanced by new setback levees by building them according to the latest engineering and FEMA certification standards. Setback and properly constructed levees should also reduce levee maintenance and other public works and private property costs associated with flood damage.

3 ASSESSMENT OF LEVEE SETBACK MODELING

3.1 Modeling Approach

To assess the potential flood risk management, geomorphic, and ecologic benefits associated with levee setback, and to assist with restoration project design, a sophisticated numerical model of the LSCR was developed. Previous hydraulic models of the LSCR were 1-dimensional (1D) HEC-RAS models capable of simulating flood velocity and stage. These models provide a snapshot of flood hydraulics (i.e., river stage and velocity) at individual cross sections for one discrete flow and do not adequately simulate the complex nature of flow movement between the river and adjacent floodplains over an entire flood hydrograph necessary for examining the impacts of levee setback. A-MIKE FLOOD model (coupled 1D/2D hydraulic model) of the LSCR was therefore developed to assess impacts of levee setback on both in-channel and floodplain flow hydraulics throughout an individual flood. The model topography is based on the 2005 LiDAR data and its domain extends from the Los Angeles County Line downstream to the Santa Clara River mouth. A key benefit of this model is the ability to visualize a flood moving through the LSCR by tracking changes in in-channel and floodplain flow depth, velocity, and inundation extent as the flood pulse moves downstream. For this project, the model output of interest for assessing the impact of levee setback for each scenario included a time series of flood stage/water depth and average velocity values within the main river channel and adjacent floodplain. Appendix A provides a complete and detailed description of the MIKE FLOOD modeling approach.

Prior to modeling the impacts of levee setback, the MIKE FLOOD model was calibrated for existing conditions using a combination of results from a pre-existing hydraulic model and floodplain inundation observations. The flood stage and floodplain inundation extent derived from the recent FEMA 100-year floodplain 1D hydraulic modeling effort along the LSCR was used to calibrate the model and help guide refinement of model inputs. It should be noted that the modeled 100-year flood event is very large (i.e., peak discharge at Montalvo of over 5,700 m^3s^{-1} [200,000 cfs]) and has not been experienced in the LSCR since European American settlement in the watershed over 150 years ago. The model was calibrated further for a 25-year flood event with information regarding spatial patterns of floodplain inundation during the January 2005 flood event, which had a recorded peak discharge in the mainstem LSCR that was somewhat higher than that for a modeled "watershed-wide" 25-year flood event used in this analysis. In this instance, the watershed-wide 25-year flood event is defined as the flood event where all tributaries to the LSCR are experiencing a 25-year flood (with values derived from watershed-wide hydrologic modeling, see AQUA TERRA Consultants 2009). The floodplain inundation information was therefore used as a check to identify areas where levee elevations needed to be incrased to better reflect actual condtions (i.e., where modeling showed floodplain inundation but no inundation was observed).

Following calibration, the MIKE FLOOD model was set-up to simulate the hydraulic effects of levee setback at several locations for a range of hydrologic conditions. The levee setback areas consisted of four floodplain parcels (Vulcan, Camp, Lower North Bank [NB], and Lower South Bank [SB]) that the Coastal Conservancy and TNC are interested in including in the Santa Clara River Parkway (see Figure 3-1). Several other floodplain parcels were initially considered for inclusion within the levee setback assessment (e.g., south bank floodplain area across from the Sespe Creek confluence with the LSCR), however the relatively high restoration potential of these four parcels made them the current assessment priorities. The model was modified to reflect a suite of levee setback scenarios: levee setback at individual floodplain parcels and levee setback at all four floodplain parcels combined. These scenarios were then run for the 25-year and 100-year flood events to allow for comparison with the calibration (or, existing conditions) model runs. In an effort to determine the levee setback impacts under hypothesized future hydrologic conditions as compared to current conditions, the model scenarios were run with an increased 25-year flood hydrograph and downstream sea level elevation derived from climate change projections for 2050 (see Carollo 2011 and references therein).

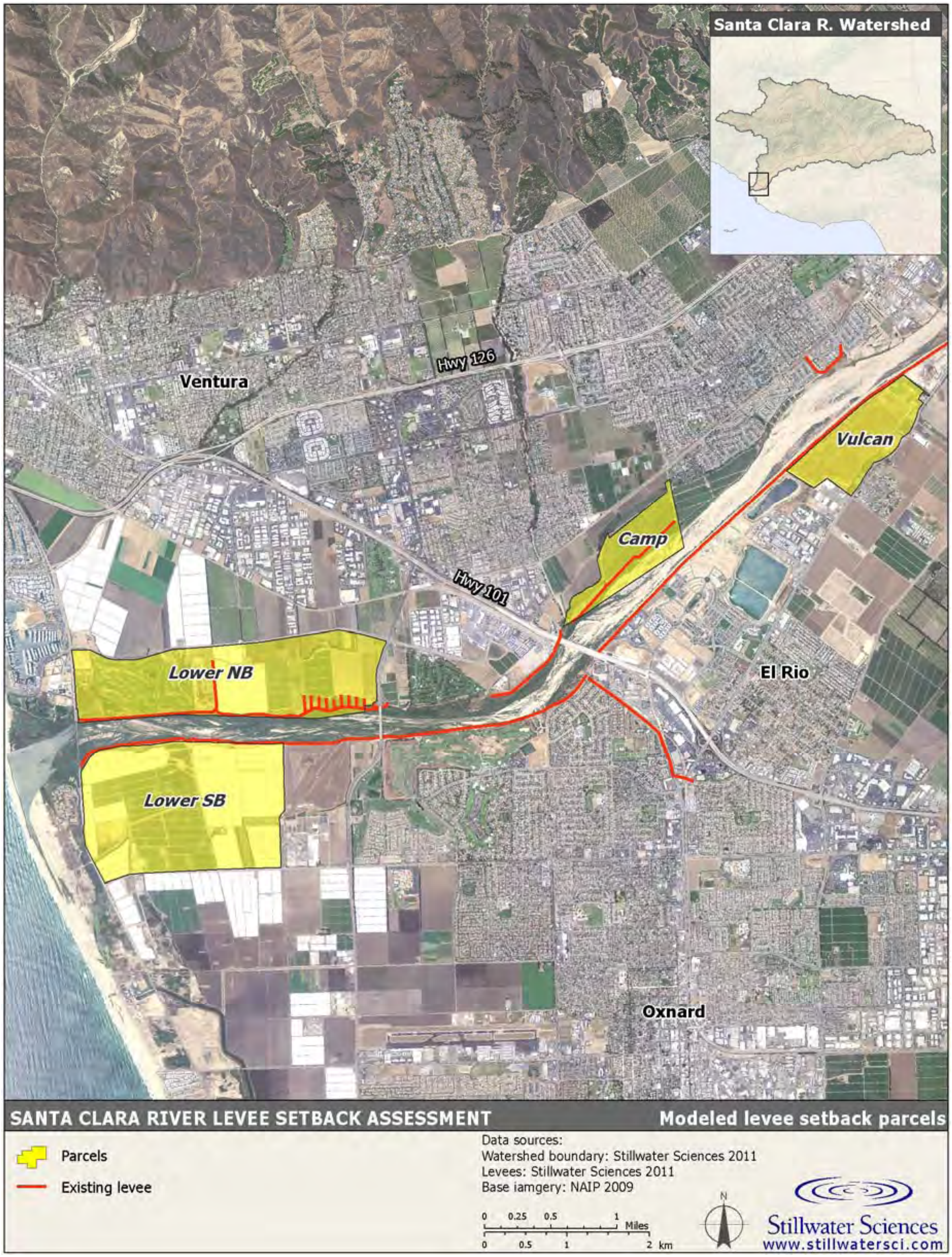

Figure 3-1. Modeled levee setack parcels along the lower Santa Clara River

3.2 Key Findings of the Levee Setback Modeling

The most salient results asscociated with the levee setback modeling effort are described in brief below. We concentrate the discussion on the results from the current and hypothesized future 25-year flood event model runs for the suite of levee setback scenarios as they are most applicable to understanding potential benefits associated with lower flood flows (i.e., the flows at the beginning and end of the flood hydrogrpah) and the largest peak flood flow of recent record (i.e., the peak discharge for the January 2005 flood event). A comprehensive discussion of the modeling results for all the model runs can be found in Appendix A.

Modeling the levee setback scenarios for current hydrologic conditions illustrated both the flows that initiate floodplain inundation and the likely flood risk management benefits associated with individual and combined levee setback approaches at present. The modeling effort showed that floodplain "activation," or the initation of floodplain inundation, occurs at the setback levee locations between 480 and 710 m^3s^{-1} (17,000 and 25,000 cfs, approximate 2.5- to 3-year flood events) and that floodplain areas become inundated (i.e., the entire floodplain area shows some degree of saturation) between 1,400 to 2,000 m^3s^{-1} (50,000 to 70,000 cfs, approximate 5- to 7-year flood events). The floodplain activation flow is lower for the Vulcan and Lower SB parcels (480 m^3s^{-1} [17,000 cfs] and 570 m^3s^{-1} [20,000 cfs] respectively) and higher for the Camp and Lower NB parcels (710 m^3s^{-1} [25,000 cfs] for both). With regard to effects on flood hydraulics, levee setback at the Vulcan and Camp parcels had similar limited benefits due to relatively small floodplain areas (0.2 m [0.7 ft] maximum river stage decrease and 0.2 to 0.5 m s^{-1} [0.7 to 1.6 ft s^{-1}] average river velocity decrease). Levee setack at the Lower NB parcel showed increased benefits (0.6 m [2.0 ft] maximum stage decrease and 0.5 m s^{-1} [1.6 ft s^{-1}] maximum velocity decrease), while levee setback at the Lower SB parcel had the greatest benefits (1.3 m [4.3 ft] maximum stage decrease and 0.8 m s^{-1} [2.6 ft s^{-1}] maximum velocity decrease). The impact is greatest at Lower SB in part because of the relatively low floodplain elevation and the southern model domain extent allowing for flooding of both Harbor Boulevard and McGrath Lake. There was no apparent difference in benefits at each levee location when comparing individual levee setback with the comprehensive levee setback scenario because the decrease in stage and velocity associated with levee setback were localized around each levee setback area. This localized nature of levee setack effects is due to three primary factors: 1) limited overall flood water storage and rapid floodplain 'filling' during the first half of the modeled storm; 2) increase in flood stage due to floodwater impoundment behind bridges downstream of levee setback parcels; and 3) increase in flood stage at the downstream extent of the model due to a static water surface elevation (set at mean higher high water [MHHW] in the model). The first two factors controlled the impacts at the Vulcan and Camp pacels while the third factor was the primary control on the impacts at the Lower NB and Lower SB parcels.

For hypothesized future hydrologic conditions, levee setback at the selected parcels has a somewhat greater beneficial effect compared to current conditions. Assuming that the LSCR river bed elevation remains static, the localized flood stage decrease associated with the future 25-year flood event and MHHW elevation is slightly higher than for current conditions (0.3 m [1 ft] maximum stage decrease at the Vulcan and Camp parcels and 1.6 m [5.2 ft] maximum stage decrease at the Lower NB and Lower SB parcels). Although there are data suggesting a trend of modest bed aggradation adjacent to the Vulcan and Camp parcels and modest bed incison adjacent to the Lower NB and Lower SB parcels between 1993 and 2005 (see Figure 5-9e in Stillwater 2007a), a static bed elevation assumption for future conditions seemed appropriate given all other modeling assumptions and caveats. As discussed in Appendix A, the future 25-year flood event was estimated based on the concept that large storm frequency will increase as climate changes (e.g., a future 25-year flood event will be similar to the present-day 38-year flood event).

Following this logic, and assuming a static bed elevation, it can be concluded that the flows required to activate and inundate the selected floodplain parcels will also occur more frequently in the future.

3.3 Model Implications for Lower Santa Clara River and Floodplain Management

3.3.1 Flood dynamics

The modeling exercise effectively illustrates the anticipated flood risk management benefits associated with the levee setback scenarios. The modeling results show that there can indeed be a considerable reduction in local flood stage and in-channel flow velocity for large storm events, however these effects have been shown to be localized and maximized at the largest parcels (over 1 m [3 ft] decrease in stage and greater than 0.5 m s^{-1} [0.16 ft s^{-1}] decrease in velocity at the Lower NB and Lower SB parcels). In general, the decreases in stage and velocity are maximized at the center of the setback location and extend less than 2 km (1.2 miles) upstream or downstream, or to the next upstream or downstream bridge. The modeling further shows that flood risk management benefits associated with the levee setback scenarios would increase somewhat under future flood flows conditions due to a proportional relationship between floodplain storage potential and maximum flood discharge (i.e., there is more flood risk management benefit associated with levee setback for a 100-year flood than a 25-year flood).

With regard to management implications, the modeling results highlight two factors that should be considered when developing either an integrated or targeted levee setback plan for flood risk management purposes along the LSCR. The spatial extent of the floodplain area intended to store floodwater exerts a primary control on the relative degree of flood risk management benefit and should therefore be considered an initial factor in plan development. Modeling results show that setting back levees at the larger, downstream parcels had a greater effect than setting back levees at the smaller, upstream parcels. Although this control may be apparent, it emphasizes the need to seek opportunites for restoring the largest floodplain areas where ever possible, and suggests that obtaining adjacent floodplain properties and setting back contiguous levees could be an effective means of maximizing flood risk management benefit. The modeling results also highlight the impacts of bridge structures on flood hydraulics and associated flood risk management benefits. Bridges along the LSCR appear to have a strong control on the upstream and downstream propogation of flood risk management benefit (as shown by the effects of the Union Pacific Railroad, Highway 101, and Victoria Avenue bridges on flood stage). Because of this, any plan developed to setback levees for flood risk management purposes should either seek to avoid levees in the vicinity of bridges or seek opportunities to include modification of the nearby bridge structures as part of the flood risk management plan.

3.3.2 Geomorphic and ecological functioning

The changes to flood hydraulics associated with the levee setback scenarios translate to changes in geomorphic and ecological functioning of the channel and adjacent floodplain. These changes are a result of alterations to flood flow velocity, floodplain inundation frequency, and floodplain inundation depth and extent. From a management perspective, it is important to understand the relative effect on geomorphic and ecologic functioning associated with each scenario as a means of helping to develop levee setback priorities for the LSCR.

Levee setback allows for increased floodplain inundation frequency and decreased average in-channel flow velocity for flood events. In general, increased floodplain inundation leads to increased fine sediment deposition and the creation of suitable habitat for riparian vegetation species. The more frequent and deeper the inundation flow, the more frequent the fine sediment deposition and habitat creation and resetting of vegetation successional processes, which can create and maintain or more diverse mosaic of natural riparian habitat. Decreased in-channel flow velocity during flood flows results in decreased channel and bank scour, which can cause increased in-channel sediment deposition, channel stabilization, and subsequent in-channel habitat maintenance. In-channel sediment depositon downstream of Victoria Avenue is of particular importance as it could help offset the recent trend of incision. As climate change continues and sea level and flood frequency increase, levee setback essentially allows for more frequent floodplain inundation, thereby increasing the potential for improved channel and floodplain functioning into the future.

In considering management approaches for the LSCR, modeling results suggest that setting back levees at all four parcels considered provides the greatest benefit to geomorphic and ecological functioning, under both current and predicted future hydrologic conditions. Setting back levees at all four parcels has the greatest total effect on decreasing in-channel velocity and increasing floodplain inundation, albeit from a combination of localized changes at individual levee setback locations. With regard to which specific parcels have the greatest potential benefits associated with levee setback, Lower NB and Lower SB should be considered the highest priorities due to their relatively large floodplain area and relatively high floodplain inundation frequency. As with the flood risk management benefit, seeking opportunities to increase levee setback areas by combining adjacent floodplain properties would be an effective means of increasing the potential geomorphic and ecological benefits.

3.4 Recommendations

Overall, the approach to levee setback along the LSCR should be developed with consideration of improved flood risk management and geomorphic/ecologic benefits for both current and future conditions. The modeling exercise described in brief above (and presented in detail in Appendix A) has provided some answers on how best to accomplish this goal and has also highlighted some data and analysis gaps that would need to be addressed when developing an approach. The primary recommendations drawn from this modeling excercise for moving forward with developing a robust levee setback approach that addresses all pertinent considerations are as follows:

- The modeling effort clearly illustrates potential flood risk management and ecologic/geomorphic benefits associated with levee setback at all four floodplain parcels. In consideration of all modeling results, we suggest that acquisition and restoration priorities should be focused on the Lower NB and Lower SB parcels. Combined, these parcels provide the greatest flood risk management benefit and the largest floodplain extent available for restoration of natural geomorphic and ecologic processes. Setting back levees along the Lower SB parcel would, however, need to be combined with flood protection or other flood risk management considerations along Habor Blvd. and McGrath Lake.
- Prior to implementation of any levee setback approach, improving the modeling framework, to the extent possible, should be done to help improve the prediction of the magnitude and extent of flood risk management and geomorphic/ecologic benefits. Improvements can be gained through such action as additional calibration data collection (e.g., collection of water surface data in the LSCR for known flow discharge values), better defining the extent of floodplain restoration (e.g., adding levees to protect infrastructure at the Lower SB parcel southern extent), and modeling additional parameters (e.g., sediment transport and bed scour). Including sediment transport and bed scour is of particular importance and could help better define the maximum in-channel flood stage and associated floodplain inundation extent associated with storm events.

- Assessing the impact of both levee setback and bridge modification on flood stage and velocity should be included in future modeling efforts to determine the potential flood risk management and ecologic/geomorphic benefits given less hydraulic constraint. The current modeling suggests that the Highway 101 bridge, the Union Pacific Rail Road bridge, and the Victoria Avenue bridge have the greatest impact on flood hydraulics. The openings beneath these bridges could be modified in the model and a sensitivity analysis could be conducted to determine the opening characteristics that provide the optimal amount of flood water passage.
- Moving forward, levee setback efforts along the LSCR should be focused on parcels with willing sellers that have a relatively large potential inundation area (i.e., large floodwater storage and floodplain inundation area), have a relatively low average ground surface elevation compared to the adjacent river bed (i.e., high inundation frequency), and have levees that can be setback without adversely affecting adjacent, protected properties or the upstream and downstream river channel stability. Combining an assessment of these factors with an analysis of restoration-related costs would be an effective means of prioritizing and targeting LSCR levee setback opportunities.

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Appendix A

Levee Setback Modeling Technical Memorandum

(cbec, Inc. 2011)

MEMORANDUM

Date:	August 24, 2011
To:	Scott Dusterhoff, Zooey Diggory (Stillwater Sciences)
From:	Chris Campbell, April Sawyer
Project:	09-1005 – Santa Clara River Levee Setbacks
Subject:	Appendix of Model Results

1 INTRODUCTION

A 2D hydrodynamic model was developed for the lower Santa Clara River (SCR), from the Ventura-Los Angeles County line to the Ocean in Ventura County, to assess the potential flood benefits afforded to the SCR system as a result of specific levee setback scenarios. The 2D model was used as a tool to specifically assess how the setbacks, in part and in combination, changed water levels and inundation extents within the lower SCR. Previous hydraulic studies have modeled this reach of the lower SCR, but those studies have been limited to 1D model platforms (i.e., HEC-RAS). However, these existing 1D models provided several model input parameters (e.g., bridge details), which made for efficient 2D model development.

This study was undertaken in collaboration with the California State Coastal Conservancy (SCC) and Stillwater Sciences.

2 EXISTING CONDITIONS MODEL DEVELOPMENT

2.1 MODEL DOMAIN

The 2D hydrodynamic modeling platform MIKE FLOOD (DHI, 2009) was used to simulate the potential flood benefits of specific levee setback scenarios. MIKE FLOOD is a dynamically coupled 1D/2D (MIKE 11/MIKE 21) model that can simulate the complex interplay between and amongst the river and adjacent floodplains. This model includes robust methods to accommodate wetting and drying of the floodplain and can readily accommodate hydraulic structures in both the 1D and 2D components of the model. Furthermore, due to the dynamic nature of the model, it can be used to effectively characterize the transient storage effects of the levee setback scenarios by accounting for the volume of water moving through the system and the effect they have on inundation levels and infrastructure.

A MIKE FLOOD model was constructed for a 40-mile long reach of the SCR from the Los Angeles County Line to the Ocean (see Figure **1**). The entire river and floodplain were represented in 2D, with only the hydraulic structures (i.e., bridge crossings) represented in 1D (see Section 2.4 for details). An unstructured 2D mesh consisting of triangular and quadrilateral elements was created for the channel and floodplain areas (see Figure **2** for example). Areas within the FEMA designated 100-year floodway were defined with triangular elements of finer resolution (15 m to 30 m element faces). Areas outside the floodway on the floodplains, upper floodplain terraces, and adjacent valley hillslopes were defined with triangular elements of coarser resolution (up to 100 m element faces). The model was registered to UTM 11N WGS84 meters (horizontal datum) and NAVD88 meters (vertical datum).

2.2 TOPOGRAPHY AND BATHYMETRY

Channel bathymetry and floodplain topography was derived from a 2005 LiDAR dataset developed for the FEMA restudy sponsored by the Ventura County Watershed Protection District (VCWPD) and registered to CASP V NAD83 feet and NAVD88 feet. LiDAR for the lower watershed was flown in mid February 2005 with river flows in the 10 – 18 cms range following a major flood event with a peak occurring on January 9, but before a second major flood event in February of 2005 with a peak occurring on February 22 (see Figure **3** for details). LiDAR for the upper part of the SCR above Vern Freeman Diversion Dam was flown after the February 2005 event in early March 2005 when the river flows were in the 40 – 55 cms range. At the seam between the two flights, the channel is slightly misaligned due to changes as a result of the February 2005 flood as well as differences in flow due to LiDAR returns off of the water surface. Overall, the flows in the SCR varied during these multi-week LiDAR flights, and as such, variability was introduced into the topography and bathymetry used for this modeling effort, which then introduces some uncertainty in the model results, as discussed in Section 4.1.2.

Project levees (i.e., FEMA certified), non-project levees (i.e., not FEMA certified), agricultural berms, and road embankments within the SCR model domain were identified using levee alignments provided by Stillwater Sciences and by thoroughly examining the LiDAR contours to identify streamwise and lateral topographic features that would impede flow onto floodplain surfaces. Quadrilateral elements were defined at these locations to ensure that the topographic maxima were represented within the model domain along the entire length of the features.

2.3 BOUNDARY CONDITIONS

2.3.1 Existing Conditions Hydrology

Design hydrographs for the 25-year (Q25) and 100-year (Q100) recurrence interval flood events were derived from the calibrated and validated HSPF (Hydrologic Simulation Program Fortran) model, a US Environmental Protection Agency (EPA) watershed hydrology model, developed for the VCWPD and the Los Angeles County Department of Public Works (LACDPW) by AQUA TERRA Consultants (2009). Thirty four Q100 design hydrographs were extracted from the HSPF model (see Table 1 for a list of inputs). To obtain the Q25 design hydrographs, the Q100 design hydrographs were individually scaled based on published scaling factors (AQUA TERRA, 2009) provided in Table 1. Q100 hydrographs from this HSPF model were also used as inputs to the FEMA (2009) restudy HEC-RAS (RAS) model used as a tool for model parameterization and validation throughout this analysis.

Note: the 50-year (Q50) design hydrographs were originally going to be analyzed in this study; however, after review of preliminary model results, cbec and Stillwater staff decided to analyze the Q25 flood event because a) the January 2005 flood event was a flood event of recent memory (with anecdotal evidence) with a peak discharge similar to the Q25 flood event, and b) the modeled Q50 flood event overwhelmed more than half of the levees chosen for setback analysis under existing conditions, resulting in little to no flood benefits under setback conditions.

Table 1. Hydrologic summary table

Stream Name	Reach Node Name	Q100 Peak Discharge (cms)[1,2]	Q25 Peak Discharge (cms)[1]	Q25 Scale Factor [1,3]	Q25 Future Peak Discharge (cms)[1]	Q25 Future Scale Factor[1,4]
Piru Creek	RCH529	1163.8	528.4	0.454	665.7	1.26
Salt Canyon	RCH322	165.9	79.9	0.481	100.6	1.26
Tapo Canyon	RCH401	124.6	56.6	0.454	71.3	1.26
Edward	RCH603	61.2	27.8	0.454	35.0	1.26
Warring Real Canyon	RCH605	83.8	40.5	0.483	51.0	1.26
Hopper Canyon	RCH614	552.2	250.7	0.454	315.9	1.26
Basolo Ditch	RCH631	45.9	22.0	0.479	27.7	1.26
Pole Creek	RCH634	209.3	95.0	0.454	119.7	1.26
Sespe Creek	RCH728	3794.4	2083.1	0.549	2624.8	1.26
Reimer Ditch	RCH806	124.6	60.0	0.482	75.6	1.26
Balcom Canyon	RCH812	130.0	62.6	0.481	78.9	1.26
Orcutt Canyon	RCH821	150.1	72.2	0.481	91.0	1.26
Timber Canyon	RCH822	142.4	68.5	0.481	86.3	1.26
Santa Paula Creek	RCH835	1115.7	490.9	0.440	618.5	1.26
Fagan Canyon	RCH837	128.8	62.0	0.481	78.1	1.26
Peck Drain	RCH838	51.8	34.0	0.656	42.8	1.26
Adams Barranca	RCH842	194.8	94.0	0.483	118.5	1.26
Haines Barranca	RCH844	83.5	40.2	0.481	50.7	1.26

Stream Name	Reach Node Name	Q100 Peak Discharge (cms)[1,2]	Q25 Peak Discharge (cms)[1]	Q25 Scale Factor [1,3]	Q25 Future Peak Discharge (cms)[1]	Q25 Future Scale Factor[1,4]
Todd Barranca	RCH852	188.3	90.6	0.481	114.2	1.26
Briggs Rd Drain	RCH853	34.8	16.7	0.480	21.1	1.26
Cummings Rd Drain	RCH854	51.0	24.6	0.483	31.0	1.26
Ellsworth Barranca	RCH862	269.6	130.0	0.482	163.8	1.26
Franklin Wason	RCH874	111.9	53.8	0.481	67.8	1.26
El Rio Drain	RCH881	29.7	19.5	0.657	24.6	1.26
Brown Barranca	RCH882	77.0	37.1	0.482	46.7	1.26
Sudden Barranca	RCH885	38.8	18.7	0.482	23.5	1.26
Clark Barranca	RCH886	43.6	28.6	0.656	36.0	1.26
Patterson Rd Drain	RCH891	41.1	26.9	0.655	33.9	1.26
Fairview	RCH619	37.7	18.1	0.481	22.8	1.26
Grimes	RCH641	126.6	60.9	0.481	76.7	1.26
Bear	RCH807	85.8	41.3	0.482	52.1	1.26
O'Leary	RCH809	106.5	51.3	0.481	64.6	1.26
Harmon	RCH883	131.1	63.1	0.482	79.6	1.26
Santa Clara River at LA County Line	RCH320	1877.4	852.3	0.454	1073.9	1.26

[1] Q25 = 25-year; Q100 = 100-year; EX = existing conditions; FUT = future conditions
[2] Data extracted directly from VCWPD HSPF model output (AQUA TERRA, 2009).
[3] Scaling factor adopted from AQUA TERRA (2009) Appendix L, Table 5.
[4] Scaling factor was calculated by the method outlined in Section 3.2.1.

2.3.2 Existing Conditions Tidal Boundary

At the ocean, a constant water surface elevation derived from NOAA tidal datums was used as the downstream tidal boundary condition. Since the mouth of the SCR is located between the NOAA tide stations at Santa Barbara and Santa Monica, the average of the mean higher high water (MHHW) values was used in the model (see Table 2). This assumption was considered reasonable considering that a) limited sensitivity testing demonstrated that the effect of lower tidal elevations did not propagate past Harbor Blvd, and b) the FEMA (2009) restudy RAS model assumed critical depth conditions at the downstream boundary, which resulted in WSEs higher than MHW for the 10-year (Q10) flood event and larger.

Table 2. Existing conditions tidal datums

Datum (m, NAVD88)	Santa Barbara (ID 9411340)	Santa Monica (ID 9410840)	Average Value
MHHW	1.615	1.597	1.606
MHW	1.384	1.371	1.378
MTL	0.827	0.798	0.813
MLW	0.271	0.226	0.249
MLLW	-0.029	-0.057	-0.043

2.4 HYDRAULIC STRUCTURES

Nine bridges were included in the simulation throughout the study reach. Head losses through these structures were calculated in 1D in the MIKE 11 component of the MIKE FLOOD software. Hydraulic structure geometry, loss factors, hydraulic roughness, and other coefficients were extracted from the FEMA (2009) restudy RAS model and used as inputs to the MIKE 11 setup. The Vern Freeman Diversion Dam was also included in the model. The 2005 LiDAR dataset included the dam crest elevation, so the structure was represented in the model as a broad crested weir.

2.5 HYDRAULIC ROUGHNESS

Hydraulic roughness or Manning's n for the MIKE FLOOD model was derived from Stillwater's 2005 vegetation mapping (Stillwater Sciences & URS, 2007) by comparing the 2005 vegetation habitat types to Manning's n values from the FEMA (2009) restudy RAS model. The RAS model hydraulic roughness also relied on an independent field verified land use classification derived from aerial imagery. RAS cross section locations were compared to underlying 2005 polygons to associate habitat type to Manning's n based on station along the cross section. Once it was established that certain habitat types correlated well with RAS Manning's n values, the Manning's n values were assigned to the individual vegetation types (see Figure **4** and Table 3).

Table 3. Santa Clara River hydraulic roughness coefficients

Habitat Type	**Manning's n**
Water (channel bed)	0.035
Riverwash	0.035
Beach	0.035
Herbaceous (native and non-native)	0.040
Sand dune	0.040
Freshwater wetland	0.045
Tidal Marsh	0.045
Riparian Shrub (desert and mixed/willow)	0.055

Giant reed (*Arundo donax*)	0.055
Disturbed	0.055
Mixed non-native trees	0.075
Agriculture	0.085
Cottonwood/willow forest	0.115
Mixed riparian forest	0.115
Coastal sage scrub	0.115
Developed	0.130

3 FORMULATION OF SCENARIOS

3.1 SETBACK SCENARIOS

Several locations within the study reach were chosen to assess the potential flood attenuation benefits of levee setbacks (see Figure **5**). These setback locations would also facilitate improved ecological services to the system as a whole by increasing channel to floodplain connectivity. Setback locations were chosen by SCC and Stillwater based on current land ownership and potential opportunities to utilize the parcels as seasonal floodplain habitat with minimal risk to existing infrastructure or nearby development (see Table 4). Levees proposed for removal included non-project levees with the exception of the levee at the Vulcan property. Levees were typically set back to existing road embankments surrounding the parcels of interest. See Figure **5** for modeled setback levee locations relative to existing levee alignments. Also, as shown by Table 4, some of the Q100 setback scenarios were grouped together. The reason for doing so was to demonstrate maximum benefits for adjacent setback areas when existing conditions results for Q100 already showed these areas as fully inundated.

Table 4. Levee setback scenario catalog

Levee Scenario	Description	Hydrology		
		$Q_{25,EX}$	$Q_{100,EX}$	$Q_{25,FUT}$
1	Existing Conditions	X	X	X
2	Camp Prop[1]	X	X	
3	Vulcan Prop[2]	X		
4	Lower NB[3]	X	X	
5	Lower SB[4]	X		
6	No Constraints[5]	X	X	X

[1] Levee on the north bank of the SCR upstream of Highway 101
[2] Levee on the south bank of the SCR upstream of Highway 101
[3] Levee on the north bank of the SCR between Victoria Ave and Harbor Blvd
[4] Levee on the south bank of the SCR between Bailard Landfill and Harbor Blvd
[5] Combination of Scenarios 2 through 5

3.2 BOUNDARY CONDITIONS

3.2.1 Future Conditions Hydrology

To represent increased storm intensity in this system and sea level rise due to predicted climate change, future conditions hydrology was developed assuming 2050 condition using existing conditions (i.e., 2005) as a baseline. A relatively recent analysis of the frequency of extreme precipitation events in the US identified a 50% increase in such events for coastal southern California (Madsen & Figdor, 2007). For simplicity, it was assumed that a 50% increase in extreme precipitation frequency directly translated into a 50% increase in flood recurrence interval. As such, the peak flow for a future Q25 flood event would be equivalent to the peak flow of an existing 37.5-year (Q37.5) flood event. Based on this reasoning, data from four (4) US Geological Survey (USGS) gages on the SCR were analyzed by Stillwater using the Log-Pearson distribution to identify Q25 and Q37.5 peak flows based on historic flow data. Table 5 shows the results of this analysis and suggests that a scaling factor of 1.26 (as also shown in Table 1) should be used to convert the existing Q25 flood hydrographs into future Q25 flood hydrographs.

Table 5. Future conditions hydrology

USGS Gage	Existing Q_{25} (cms)	Existing $Q_{37.5}$ or Future Q_{25} (cms)	$Q_{37.5}/Q_{25}$
SCR @ LA Co Line (11108500/11109000)	967.0	1251.7	1.29
Sespe @ Fillmore (11113000)	2173.6	2617.8	1.20
SPC @ Santa Paula (11113500)	482.8	620.0	1.28
SCR @ Montalvo (11114000)	4852.9	6036.3	1.24

3.2.2 Future Conditions Tidal Boundary

To represent predicted increases in sea level rise, an increase of 0.41 meters was added to the MHHW elevation shown in Table 2. The increase of 0.41 meters (relative to MSL) was derived from a recent study in the SCR (Carollo Engineers, 2011).

4 MODEL RESULTS

4.1 EXISTING CONDITIONS

4.1.1 Steady-State Comparison to FEMA 100-Year Model Results

Following model development, the existing conditions model was run for steady-state Q100 conditions and compared to the FEMA restudy RAS Q100 inundation mapping and peak water surface profile given that both models relied upon the same input data. These 2D model results generally showed good agreement with the spatial inundation patterns (see Figure **6**a and 6b) and maximum water surface profile (see Figure **7**) predicted by the 1D FEMA restudy RAS model. However, the 2D results did differ from the 1D results in a few locations:

1. Near the town of Santa Paula, more extensive flooding was predicted behind the Santa Paula Freeway embankment on the north bank of the SCR because the Santa Paula Creek flood control channel was included in the 2D model.
2. Downstream of the Vern Freeman Diversion Dam, more extensive flooding was predicted with the filling of various aggregate mining pits on the south bank. These areas did not show inundation in the FEMA model due to the presence of a project levee along the south bank. While the 2D model also included this levee, flow entered these areas at much localized low points in the model terrain.
3. Near Wagon Wheel Rd on the south bank of the SCR between Highway 101 and the Union Pacific Rail Road train bridge, flow overtopped the levee in the 2D simulation causing more extensive inundation because these low lying areas were modeled as ineffective areas in the FEMA restudy RAS model.
4. The historic lagoon near McGrath Lake in the southern estuary showed more inundation than in the FEMA model. Slight dips in the topography not captured in the reaches between cross sections of the 1D model likely resulted in these differences.

4.1.2 Validation to the January 2005 Flood

The January 2005 flood event was a flood event of recent memory with a peak discharge similar to the Q25 flood event in the lower river (approximately 3850 cms at USGS gage #11114000 at Montalvo). Anecdotal evidence for this event (e.g., Stillwater (2007); aerial photographs; on-the-ground photographs; and VCWPD post-event damage estimates) was used to verify the extent of inundation under existing conditions.

The first round of modeling showed inundation at the Camp property, Lower North Bank and Lower South Bank setback locations (Figure **5**), yet the anecdotal evidence showed that these areas were not inundated during the January 2005 flood event. To correct these inundation errors, levee heights were adjusted as needed in order to show the proper level of floodplain inundation and to demonstrate the flood attenuation benefits of the proposed setbacks (under Q25 only):

1. At the Camp property, levee elevations were increased up to 2 m to restrict floodwaters from inundating the property.
2. On the lower south bank, levee elevations were increased up to 3 m to restrict floodwaters from inundating the low lying areas.
3. On the north bank between Victoria Ave and Harbor Blvd, an east-west berm that excluded floodwaters from agricultural fields was likely scoured away during the January 2005 flood (Figure **9**). This berm was replaced in the 2D model in its original location with 2 m of relief above the surrounding topography.

Levee height adjustments were used as a means to compensate for key factors, as listed below, that likely contributed to higher than observed flood stages:

1. USGS gage data from the January 2005 storm event was compared to the HSPF model outputs for the Q25 flood event at two locations, (1) the SCR at the LA County Line, and (2) Sespe Creek, a significant tributary to the SCR (Figure **8**). While peak flows were very similar, the HSPF model outputs under-predicted flood volumes at both locations, on the rising limb on the SCR at the LA County Line and on the falling limb at Sespe Creek. Differences in flood volumes influence transient flood storage, and in this instance, under-predicting volumes can lead to under-predicting flood stages when using a design flood as a surrogate for an observed flood.
2. Channel bathymetry at the peak of the flood was likely different from the post-flood condition captured in the LiDAR since the LiDAR was flown after this event. Moving bed conditions during the flood likely scoured the channel bed, resulting in a lower bed profile during the peak of the flood, a phenomenon that was not simulated in the 2D model since sediment transport functionality was not enabled (or scoped). A lower bed profile increases the cross sectional area, and hence, the conveyance capacity of the reach under moving bed conditions. Evidence that moving bed conditions were important during the January 2005 flood was corroborated by the significant amount of riparian vegetation that was removed from the reach between Highway 101 and Harbor Blvd as shown by the scour patterns in this area (Figure **9**). As mentioned in Section 2.2, LiDAR water returns used as bed bathymetry in the shallow braided channels of the lower reach likely had negligible effects on stage due to the relative magnitude of flight-time base flow (in the 10 – 55 cms range) compared to the peak of the Q25 flood event (approximately 3300 cms).

As part of the validation for the January 2005 flood event, limited sensitivity testing was performed to understand how downstream tide levels affect upstream water levels. To assess whether the MHHW tidal boundary was affecting upstream inundation, the Q25 flood hydrograph was modeled with MTL and the actual low water that occurred during the January 2005 flood event. Reductions in the downstream tide level did not affect the hydrodynamics upstream of Harbor Blvd, which suggests that channel geometry downstream of Harbor Blvd buffers inaccuracies in the downstream tide level and perhaps even the effects of sea level rise.

4.2 PROPOSED ALTERNATIVE SCENARIOS

4.2.1 100-year Storm Event

Setback Scenarios 2 and 3 – Camp and Vulcan Property Setbacks Combined

For the Q100 flood event, the Camp and Vulcan properties were combined into a single scenario because Camp was inundated under existing conditions and it was assumed that any additional storage at the Camp property would augment flood attenuation benefits at Vulcan. As shown by Figure **10**, there were localized stage reductions of up to 0.3 m in the centerline water surface profile at the Vulcan property at approximately station 9100 m to 12000 m. Further downstream at the Camp property, stage reductions were less than 0.15 m. This pattern of localized stage reduction was constant for all scenarios, as setback benefits do not propagate significantly far upstream or downstream of the setback extents. As shown by Figure **11**, inundation mapping for the combined Camp/Vulcan setbacks relative to existing conditions resulted in full inundation of the Vulcan setback to E Vineyard Rd with very similar inundation extents elsewhere. Thus, for the Q100 flood event, Vulcan provides the only real flood storage benefit in the reach between Los Angeles Ave and Highway 101.

Setback Scenarios 4 and 5 – Lower North and South Bank Setbacks Combined

Similar to above, the Lower North and Lower South setback areas were combined because portions of these areas already showed inundation under existing conditions. As shown by Figure **12**, there were localized stage reductions between Victoria Ave and Harbor Blvd of up to about 1.3 m. As shown by Figure **13**, inundation mapping for the combined Lower North/South Bank setbacks relative to existing conditions resulted in inundation of the Olivas Links golf course. It was difficult to discern whether the main stage reduction benefits were attributed mostly to the Lower North Bank or Lower South Bank setbacks, but it was likely that removal of the levee around the golf course contributed significantly to the rather large stage reduction midway between Victoria Ave and Harbor Blvd by removal of the pinch point and that removal of the South Bank levee allowed for the relatively unobstructed passage of floodwaters across Harbor Blvd.

Setback Scenario 6 – No Constraints

Under the no constraints alternative, all setbacks were combined to assess the maximum potential benefits of all identified setback areas. As shown by Figure **14**, there were very similar localized stage reductions as previously identified in the combined scenarios. As shown by Figure **14** and Figure **15**, there was no noticeable system-wide increase in benefit as a result of combining all setbacks.

4.2.2 25-year Storm Event

As mentioned in Section 4.1.2, the January 2005 (or Q25) flood event was contained within the levees in the lower reach of the SCR from Los Angeles Ave to the Ocean. The Q25 flood benefits of each scenario listed in Table 4 are described below.

Setback Scenario 2 – Camp Property Setback

As shown by Figure **16**, there were localized stage reductions of up to 0.25 m when the Camp levee was removed. The extent of inundation (as shown by Figure **17**) was limited by natural topography or an elevated terrace on the property. Stage reductions were accompanied by localized reductions in maximum channel velocity up to 0.3 m/s adjacent to the removed levee segment, especially in the lower half approximately 1 km upstream of the Highway 101 bridge.

Setback Scenario 3 – Vulcan Property Setback

As shown by Figure **16**, there were localized stage reductions at the Vulcan property of up to 0.25 m when the Vulcan levee was removed. The extent of inundation (as shown by Figure **18**) on the Vulcan property was limited due to higher ground behind the levee; hence, the entire area of the property was not utilized. Decreases in maximum channel velocity occurred in the lower portion of the levee setback area, ranging from 0.2 – 0.5 m/s with the largest reductions occurring in the lower third of the setback area.

Setback Scenario 4 – Lower North Bank Setback

As shown by Figure **19**, there were localized stage reductions of up to 0.6 m due to removal of The Nature Conservancy (TNC) and Olivas Links golf course levees. The extent of inundation to the north between Victoria Ave and Harbor Blvd (as shown by Figure **20**) was maximized to the limits of the floodplain terrace. Reductions in maximum channel velocity were greatest in the lower third of the levee setback length (up to 0.5 m/s), moderate in the middle third (up to 0.3 m/s) and lowest in the upper third (up to 0.2 m/s).

Setback Scenario 5 – Lower South Bank Setback

As shown by Figure **19**, there were localized stage reductions of up to 1.2 m with removal of the south levee downstream of the landfill. The extent of inundation (as shown by Figure **21**) did not extent as far south as W Gonzales Rd, but did overtop Harbor Blvd, flowing into McGrath Lake behind the sand dunes. Reductions in maximum channel velocity were greatest in the lower half of the setback area, ranging from 0.7-0.8 m/s and decreasing to 0.2-0.3 m/s in the upper portion.

Setback Scenario 6 – No Constraints

As shown by Figure **22**, and in comparison to Figure **16** and Figure **19**, there was no appreciable increase in flood benefit during the Q25 flood event as a result of combining all of the setbacks into a single scenario. Reductions in WSE were still fairly local to each setback area and did not propagate upstream or downstream considerably. One reason for this is that the setback areas were typically filled with floodwaters during the rising limb of the flood hydrograph, thereby allowing the flood peak to travel through the system more-or-less not attenuated. A second reason is that the setbacks were not contiguous, so floodwaters still had to be conveyed through constricted reaches to include the bridges. In addition, the overall extent of inundation (as shown by Figure **23**) for the setback areas in combination did not differ considerably from the individual setback areas. One small exception occurred in the Olivas Links golf course where there was a slight reduction in inundation due to the hydraulic relief afforded by the Lower South Bank levee removal. When all setback areas are implemented in combination, maximum channel velocity reductions are commensurate in magnitude with the reductions reported in the previous sections.

4.2.3 25-year Storm Event – Future Conditions

To understand the effects of climate change on the potential flood benefits afforded by setback areas, a future Q25 flood event coupled with sea level rise was modeled for 1) existing topographic conditions and 2) all four setbacks in combination. As shown by Figure **24**, the future flood hydrology under existing levee conditions resulted in 1) the Camp Property inundating, 2) the Lower North Bank in the vicinity of TNC landholdings inundating, and 3) small isolated breakouts downstream of Highway 101 along the south levee. These areas inundated with the increase in flood flows under future conditions, which generally resulted in WSE increases over the entire study reach by 0.3 m to 0.6 m.

With implementation of all four setbacks, the combined flood benefits of the setbacks under a future Q25 flood event were slightly greater relative to an existing Q25 flood event. As shown by Figure **25**, 1) flood depths within Vulcan increased relative to existing Q25 levels, 2) inundation extents within the Camp Property increased slightly due to levee removal, 3) Olivas Links golf course fully inundated due to levee removal, and 4) flood depths on the Lower South Bank near Harbor Blvd and McGrath Lake increased with the increase in flood relief afforded by the levee removal. As shown by Figure **26**, slightly greater reductions in stage under future conditions resulted in 1) up to 0.3 m of stage reduction near Vulcan, and 2) up to 1.5 m of stage reduction downstream of Victoria Ave, which was 0.3 m more than seen under current Q25 conditions (see Figure **22**).

5 CONCLUSIONS AND RECOMMENDATIONS

Based on the Q25 and Q100 model runs for existing conditions, proposed setback conditions, and proposed setbacks with future climate change and sea level rise, the 2D model results generally showed that each setback area resulted in localized reach scale flood benefits with little to no system wide flood benefits propagating beyond the setback areas and general vicinity. The following are a summary of 2D model findings that lead to this overall conclusion:

- The 2D model results generally showed good agreement with the spatial inundation patterns and maximum water surface profile predicted by the 1D FEMA restudy RAS model for steady state Q100 conditions. Slight differences in extents and profile were likely due to the 2D versus 1D spatial resolution in capturing the hydraulic effects of low lying topography and lateral berms or levees.
- The 2D model required levee height adjustments at various locations under the January 2005 validation, which were an interim fix for other factors that may have contributed to differences in expected inundation patterns. Such factors included differences in flood hydrograph volumes (which could not be corroborated at the downstream end since the USGS Montalvo gage was inactive during January 2005) and use of post-flood bed topography (which was likely lower during the passage of the flood peak due to bed scour).
- Under the existing Q100 setback scenarios, whether in part or combination, there was a consistent pattern of localized stage reduction, which did not propagate significantly far

downstream or upstream of the setback extents. This resulted because most of the setback areas, apart from Vulcan and Olivas Links golf course, were already inundated under existing Q100 conditions. The area with the greatest water level reduction occurred in the Lower North and South Bank areas with floodwaters escaping across the south floodplain, across Harbor Blvd, to McGrath Lake.

- Under the existing Q25 setback scenarios, there was no appreciable increase in flood benefit as a result of combining all of the setbacks into a single scenario. Again, water level reductions were fairly local to each setback area with the greatest reductions occurring in the Lower North and South Bank areas. Possible reasons for this were that 1) the setback areas typically filled with floodwaters during the rising limb of the flood hydrograph, thereby allowing the flood peak to travel through the system more-or-less not attenuated, and 2) the setbacks were not contiguous, so floodwaters still had to be conveyed through constricted reaches to include the bridges.
- Under the existing Q25 setback scenarios, reductions in maximum channel velocities typically occurred to the greatest extent in the lower half of reaches directly adjacent to the setback areas with diminishing deceases moving upstream. For example, decreases up to 0.8 m/s were simulated in the lower reach adjacent to the Lower South Bank with typical decreases in the upper reaches adjacent to individual setbacks up to 0.3 m/s.
- Under the future Q25 setback scenarios, which were done to understand the effects of climate change on the potential change in flood benefits afforded by setback areas, there was an overall increase in water levels across the entire study reach by 0.3 m to 0.6 m. As a result of these water level increases, the Camp Property and TNC landholdings upstream of Olivas Links golf course inundated. Again, water level reductions were fairly local to each setback area with the greatest reductions occurring in the Lower North and South Bank areas whereby there was an increase in the relative flood benefit with 0.3 meters of additional drop when compared to existing Q25 conditions.

If the 2D model will continue to be used in the future to evaluate additional scenarios or enhance system understanding, the following recommendations are put forth to improve model performance (i.e., no interim fixes) and perhaps demonstrate greater flood benefits resulting from the various setback scenarios:

- Update the model calibration for a period in time that includes measured flow and water level data within the area of interest.
- Perform additional sensitivity tests to evaluate other model parameters (e.g., hydraulic roughness, flow inputs).
- Include sediment transport modeling to assist in validating the January 2005 flood condition and to more realistically simulate the effects of bed scour (and bed profile changes) associated with passage of a flood wave.
- Develop concepts to address flooding of Harbor Blvd and the McGrath Lake area since the Lower South Bank setbacks downstream of Victoria Ave could be interpreted to exacerbate flooding in this area.

- Consider performing a cost-benefit-risk analysis for each setback scenario based on land acquisition costs, levee degradation and hauling costs, potential flood benefits and impacts, as well as ecological functions and values resulting from more frequent floodplain inundation.

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Notes: background image courtesy of BingMaps.

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Santa Clara River Levee Setback Assessment

Location map and model domain

Project No. 09-1005	Created By: AMS	**Figure 1**

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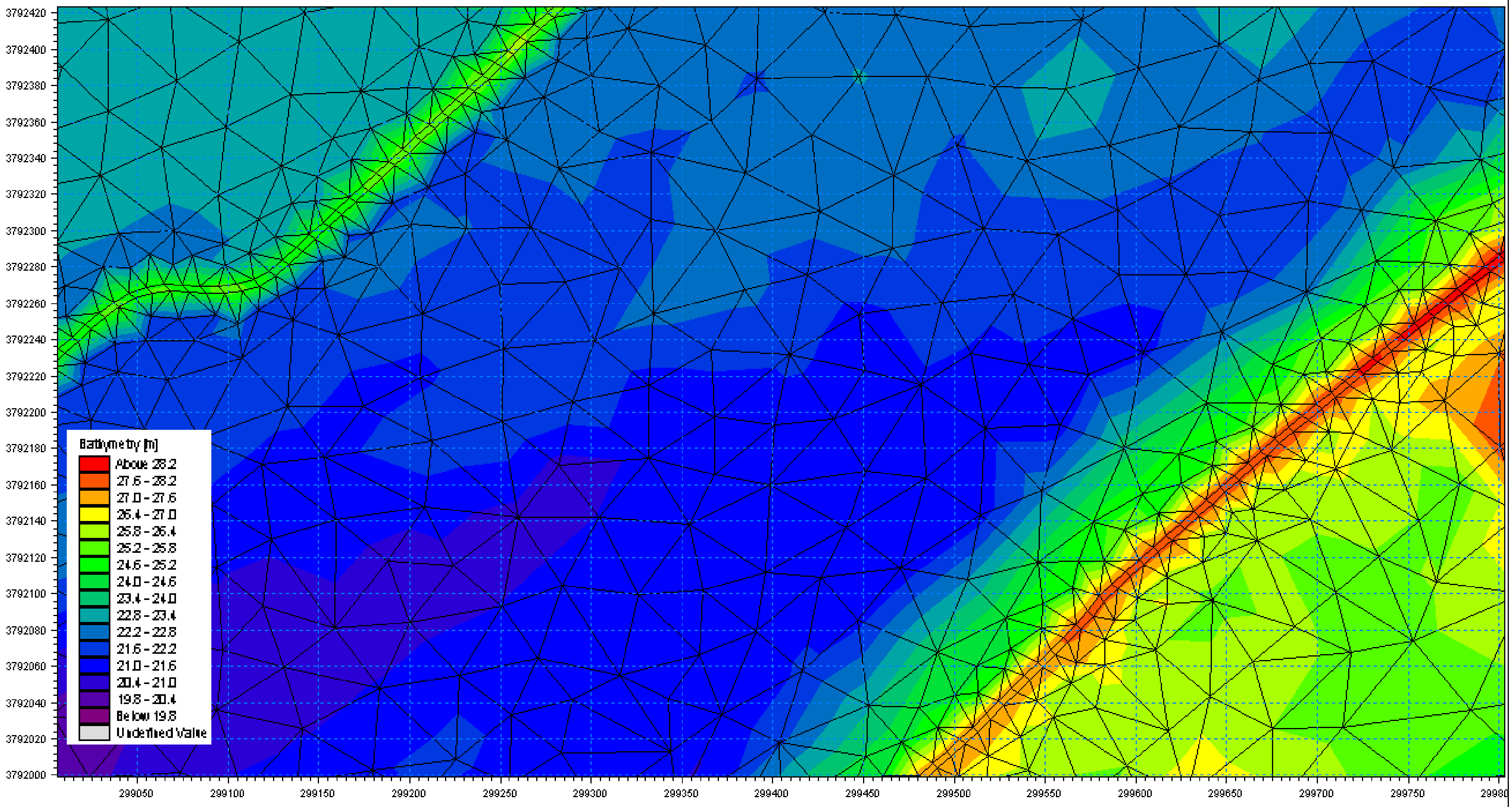

Notes: existing conditions topography; levee at top left is the Camp property levee; projected coordinates in WGS1984 UTM11N.

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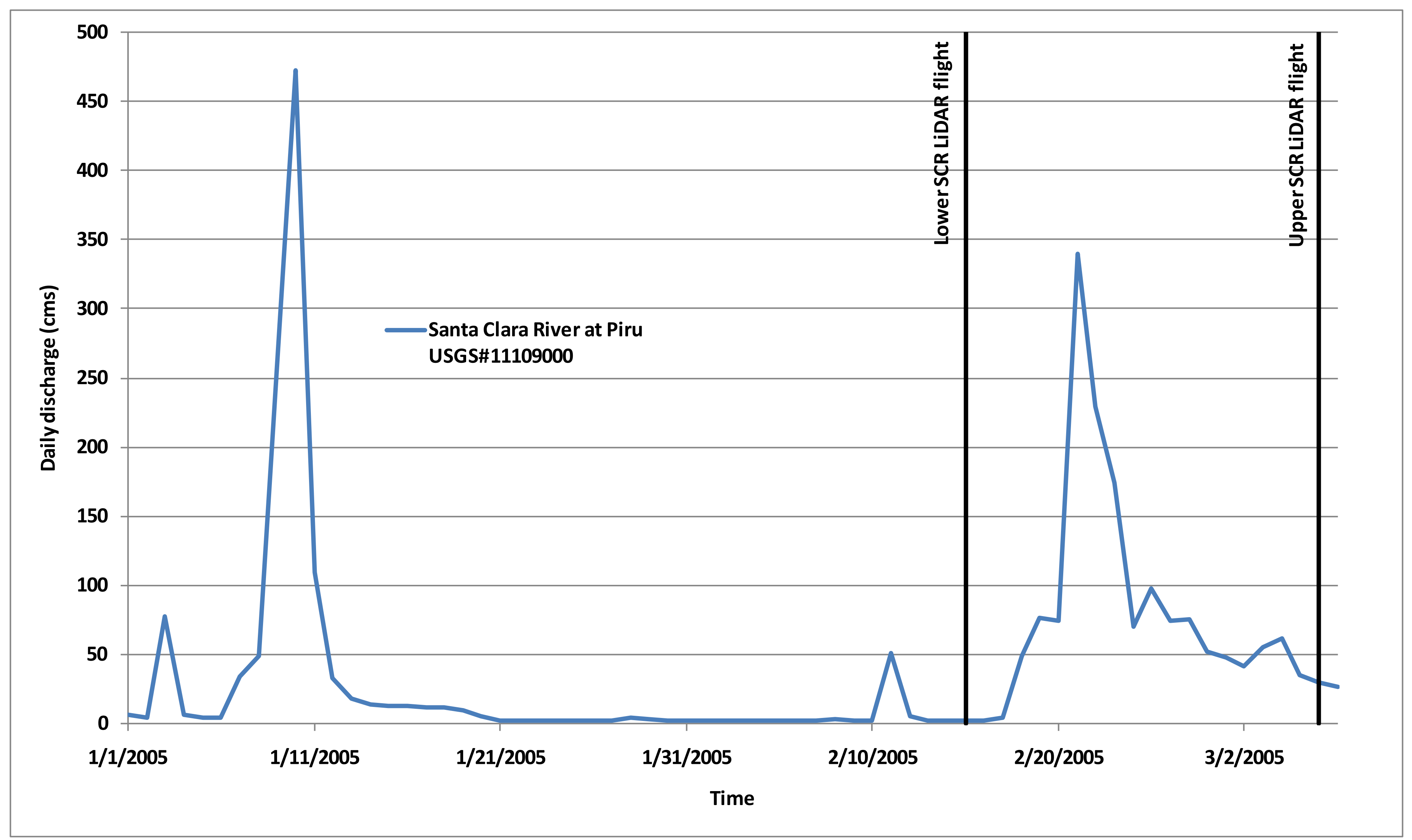
Santa Clara River Levee Setback Assessment

Unstructured mesh and topography

Project No. 09-1005	Created By: AMS	**Figure 2**



Notes: flight dates are approximate.

Santa Clara River Levee Setback Assessment

LiDAR flight timing

Project No. 09-1005 | Created By: AMS | **Figure 3**

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Notes: see Table 3 for habitat types corresponding to Manning's n values. Vegetation mapping from Stillwater Sciences (2007); background image courtesy of BingMaps.

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Santa Clara River Levee Setback Assessment

Hydraulic roughness mapping

Project No. 09-1005	Created By: AMS	**Figure 4**

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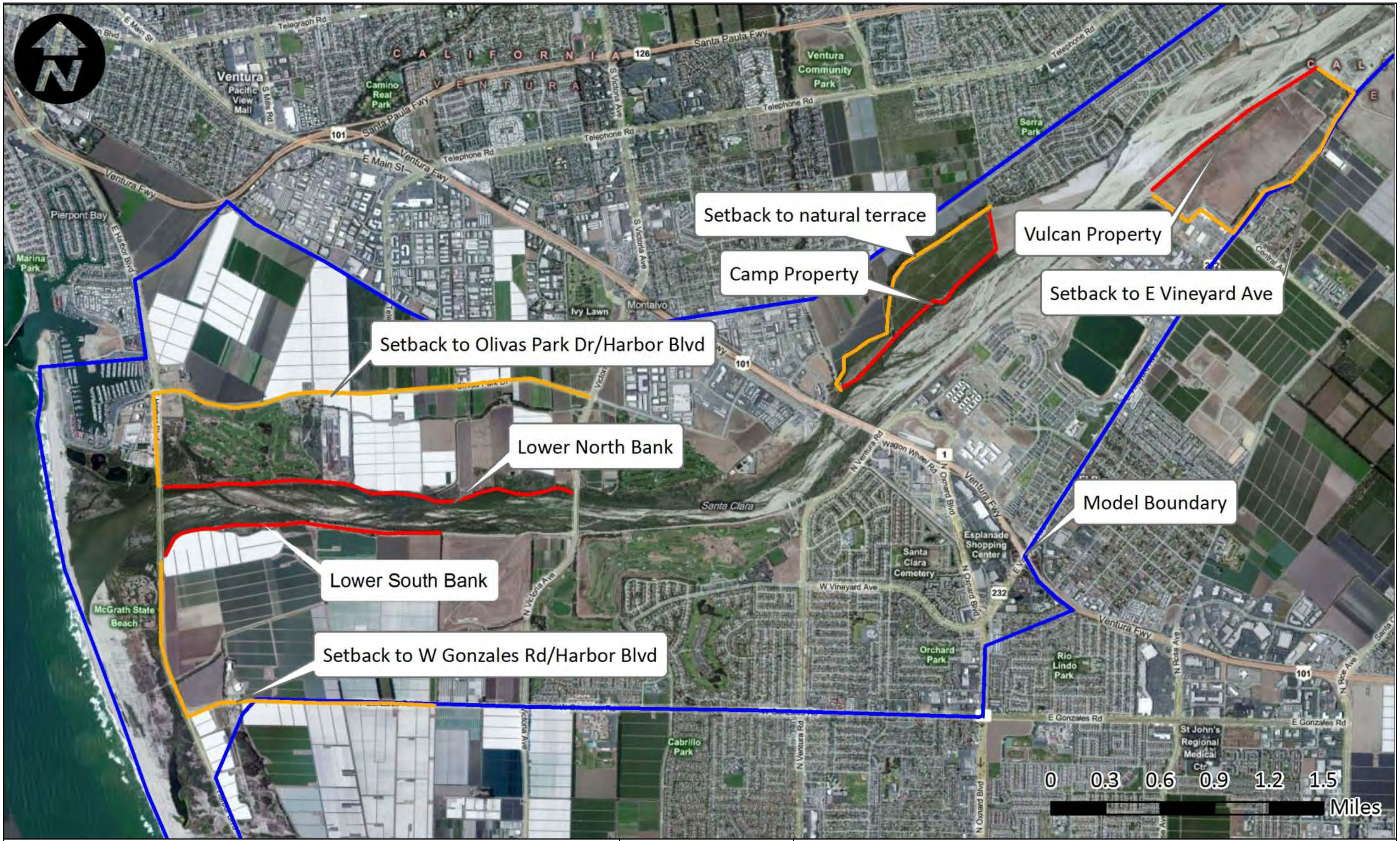

Notes: see Table 4 for run catalog with these levee setback scenarios; red are existing levees to be set back; orange are location of setback levees.

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Santa Clara River Levee Setback Assessment

Levee setback scenarios

Project No. 09-1005	Created By: AMS	**Figure 5**

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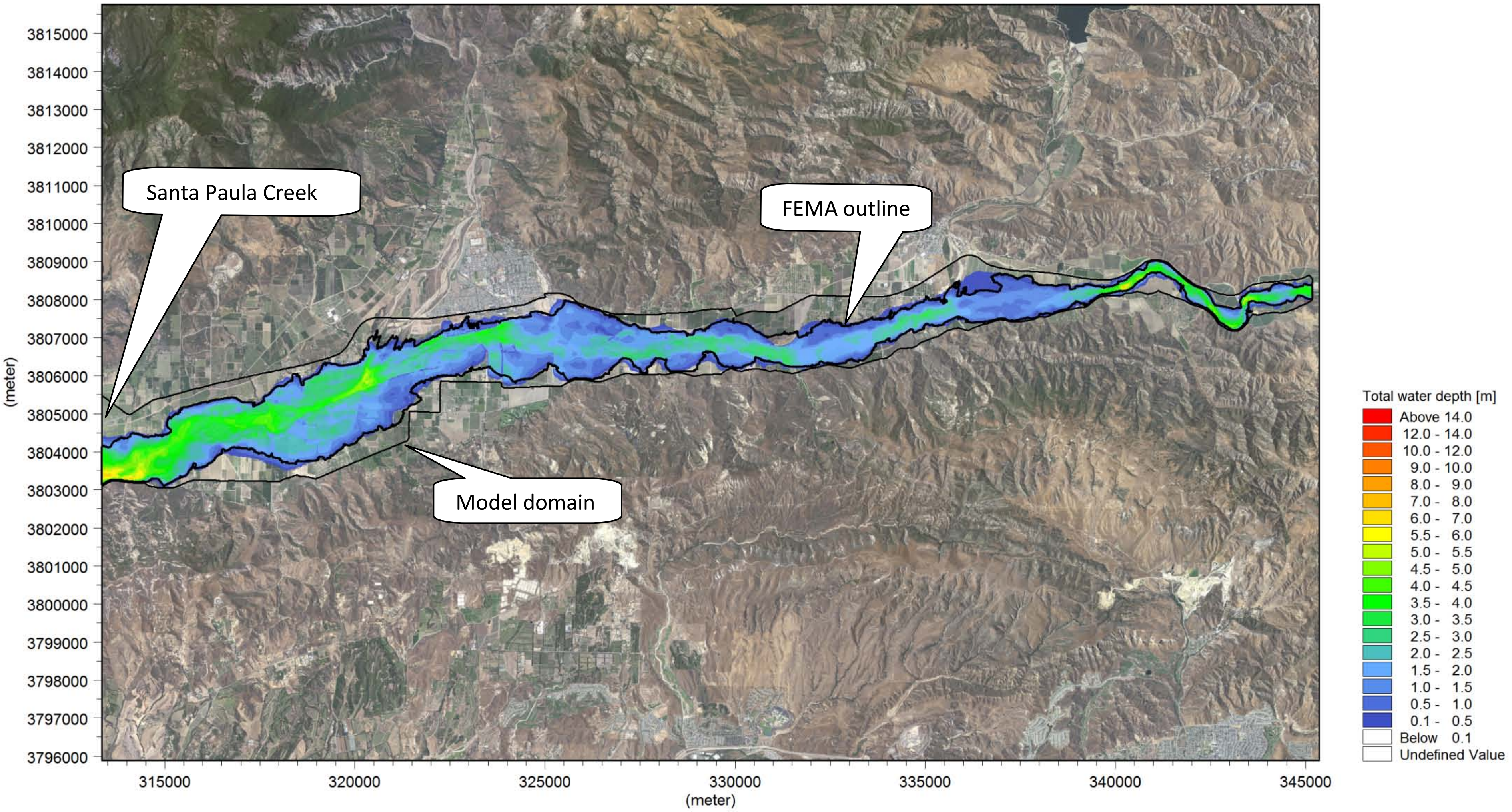

Notes: upper reach; inner black outline denotes the FEMA restudy RAS predicted inundation extents; projected coordinates in WGS1984 UTM11N.

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Santa Clara River Levee Setback Assessment

Existing conditions Q100 comparison to FEMA mapping

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Figure 6a

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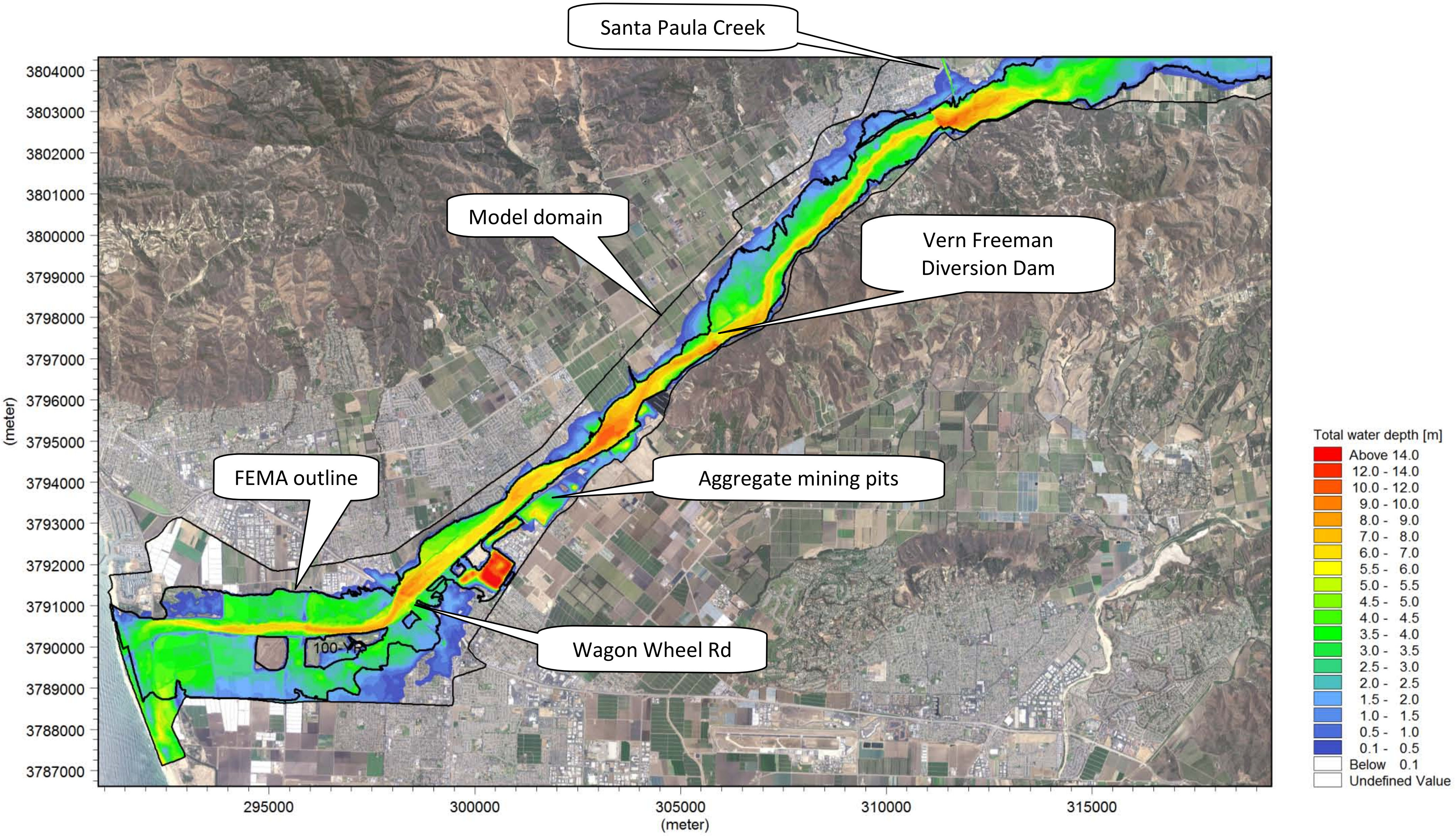

Notes: lower reach; inner black outline denotes the FEMA restudy RAS predicted inundation extents; projected coordinates in WGS1984 UTM11N.

Santa Clara River Levee Setback Assessment

Existing conditions Q100 comparison to FEMA mapping

Project No. 09-1005 | Created By: AMS | **Figure 6b**

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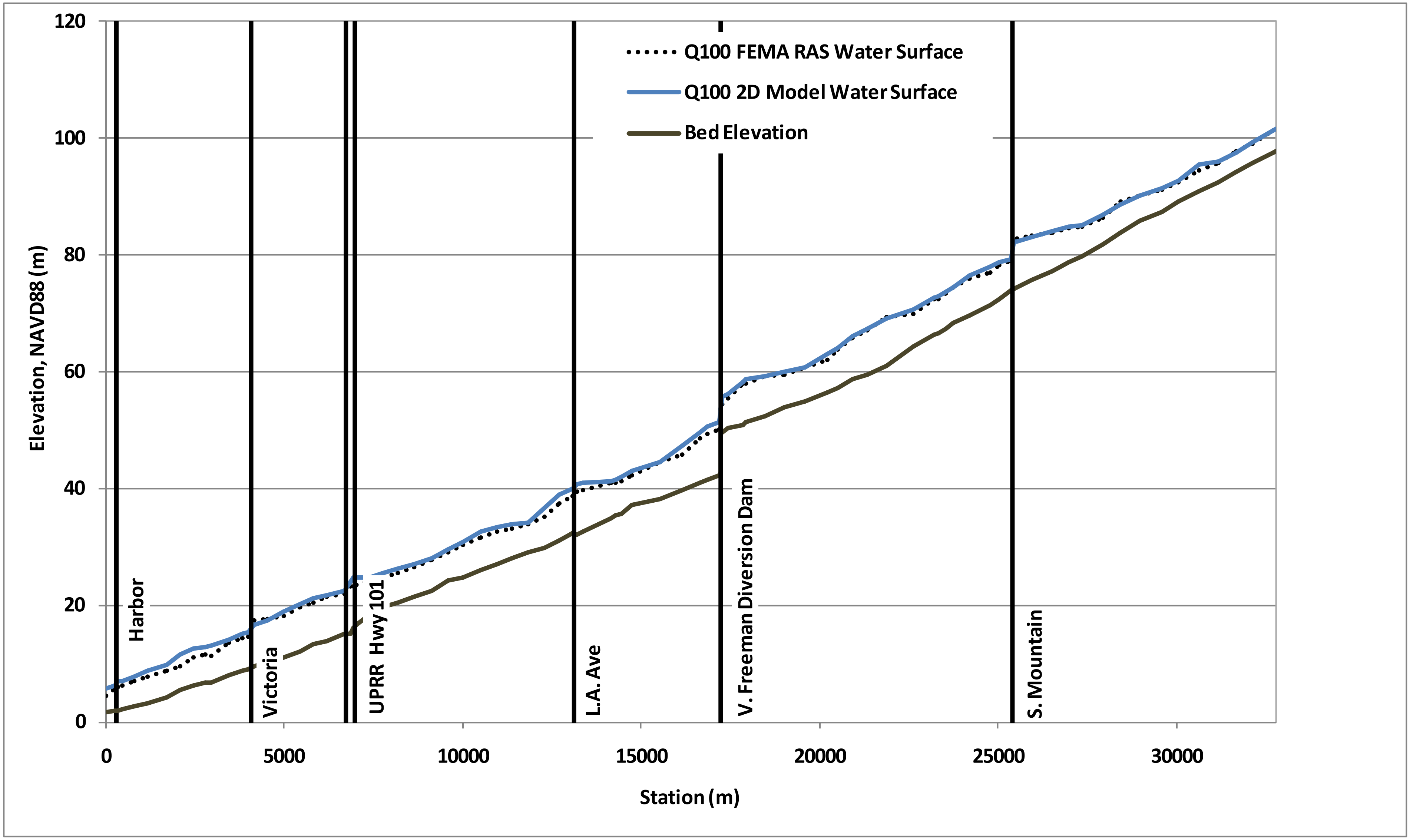
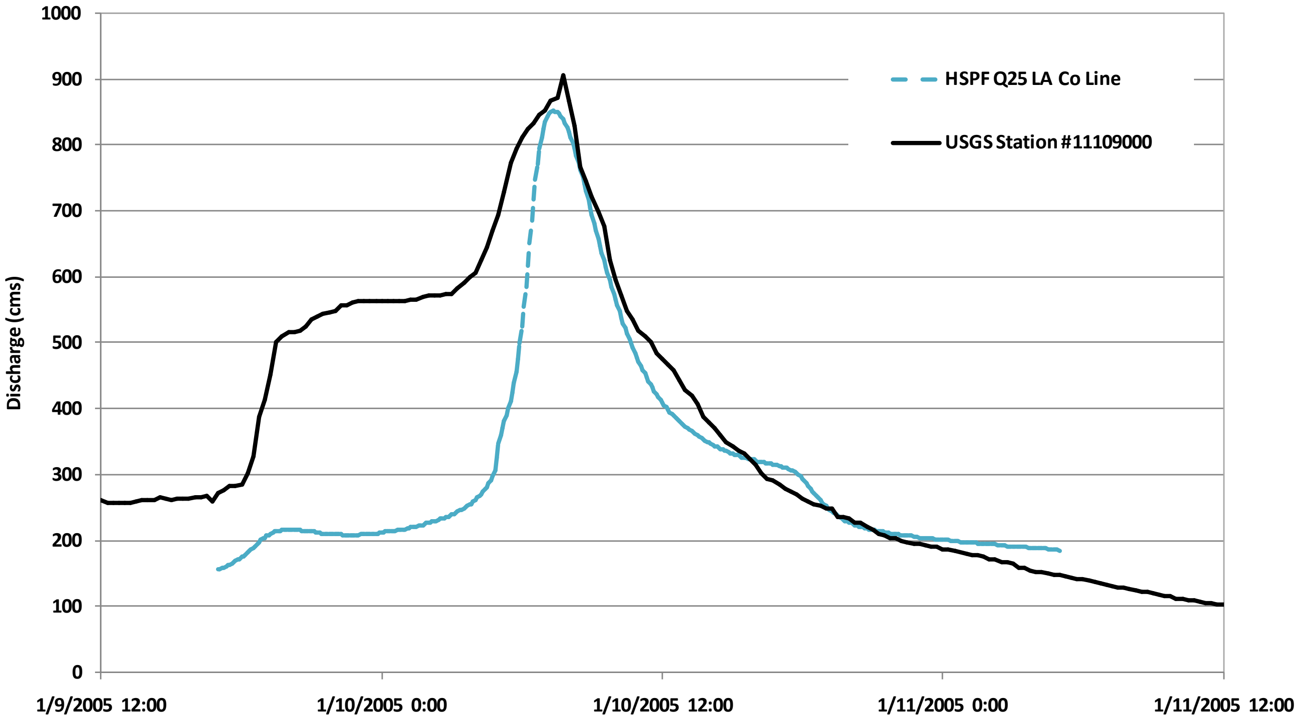
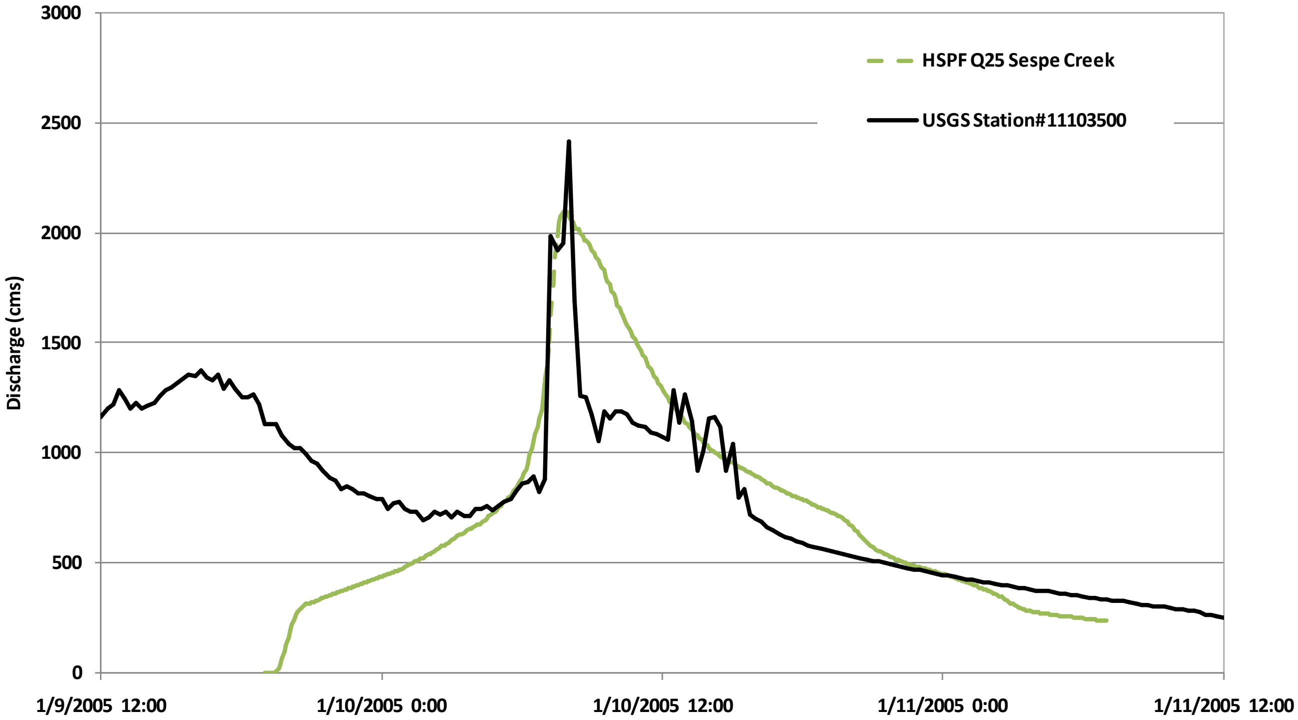


Notes:	cbec eco engineering	*Santa Clara River Levee Setback Assessment* **Existing conditions Q100 comparison to FEMA profile**		
		Project No. 09-1005	Created By: AMS	**Figure 7**





Notes:

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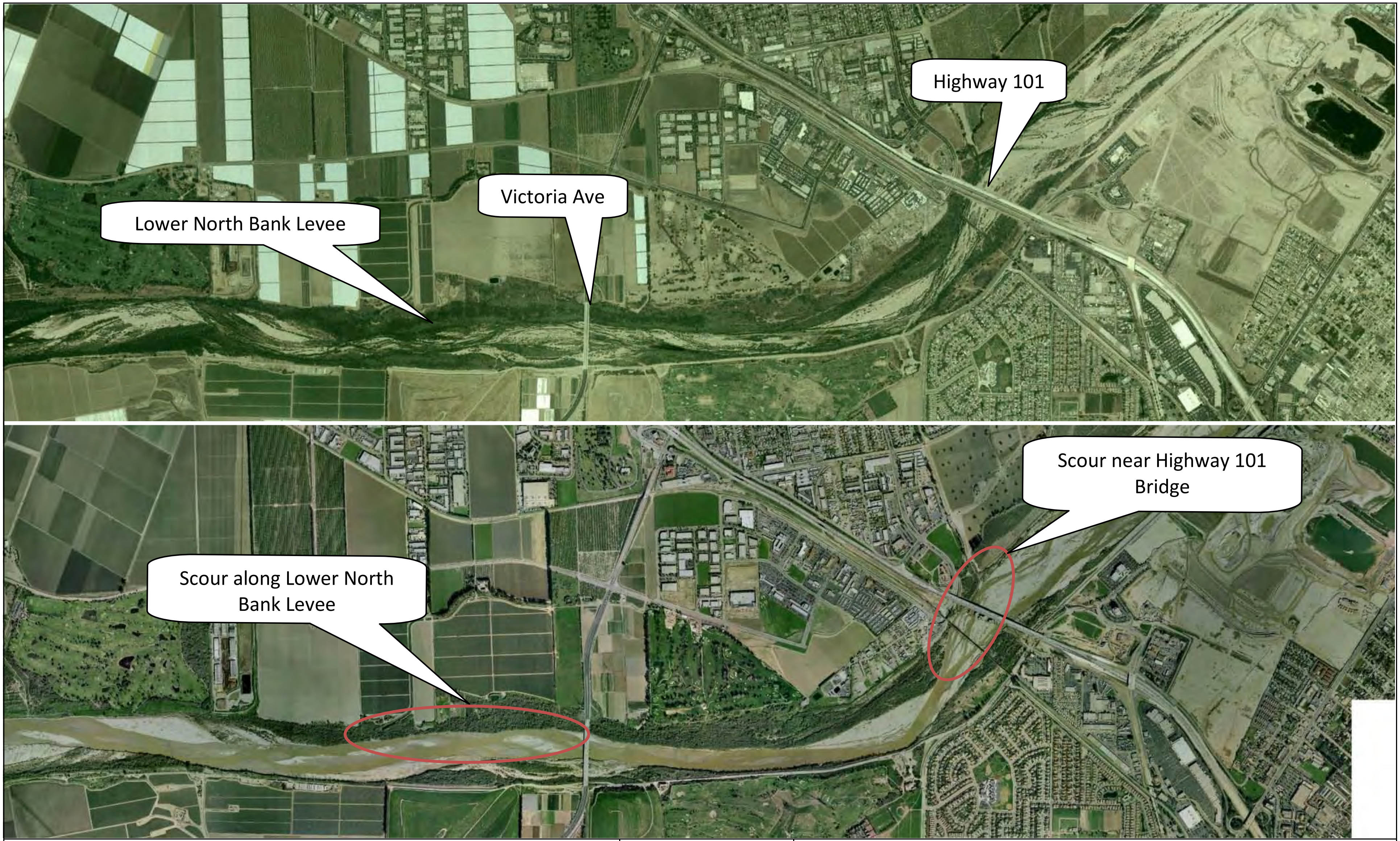
Santa Clara River Levee Setback Assessment

January 2005 event-based hydrology

Project No. 09-1005 | Created By: AMS | **Figure 8**



Notes: 2004 – 2005 NAIP images; significant scour of vegetation and possibly some berms in the reach from Highway 101 to Harbor Blvd.

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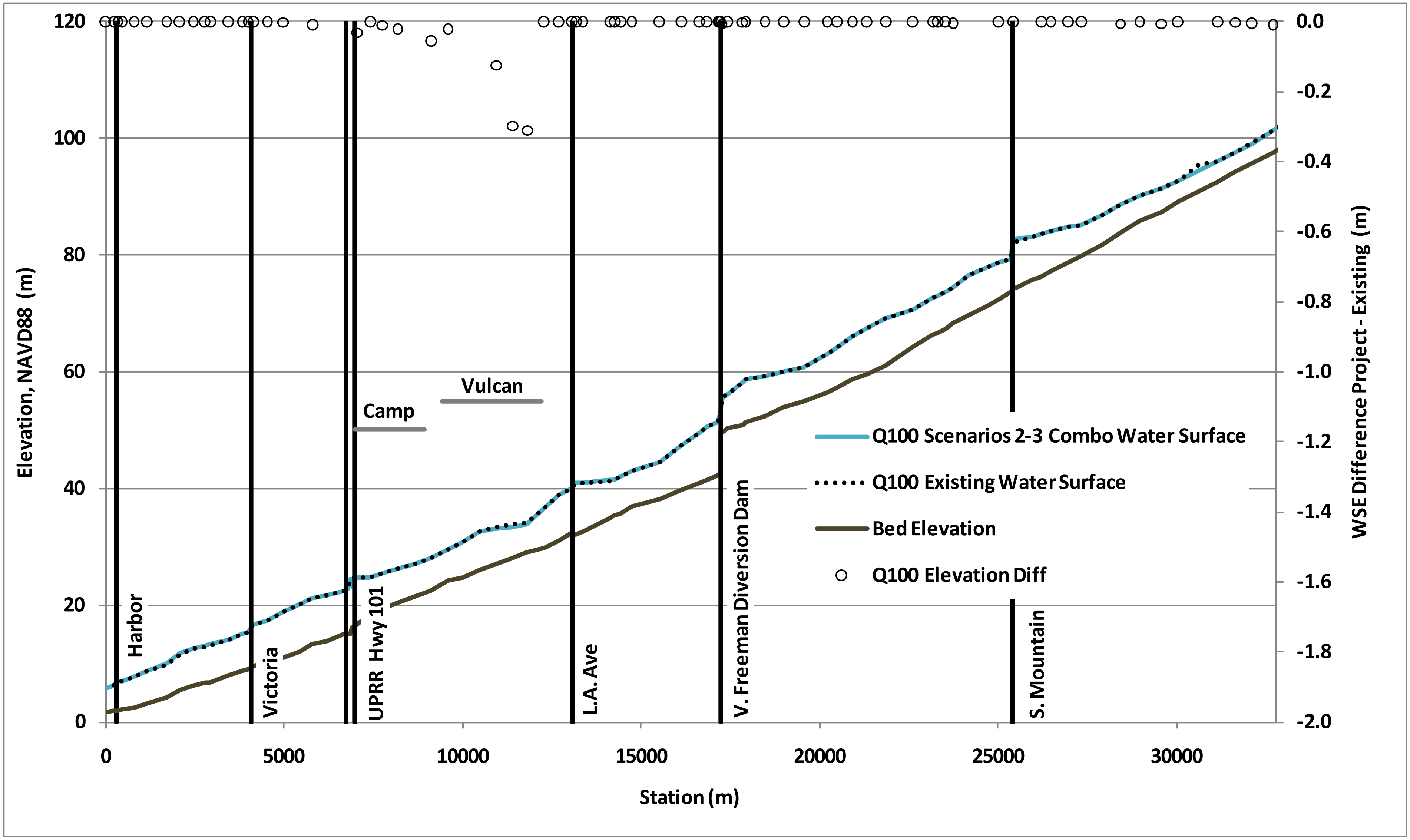
Santa Clara Levee Setback Assessment

2004 to 2005 aerial photo comparison

Project No. 09-1005	Created By: AMS	**Figure 9**



Notes: water surface elevation (WSE).

Santa Clara River Levee Setback Assessment

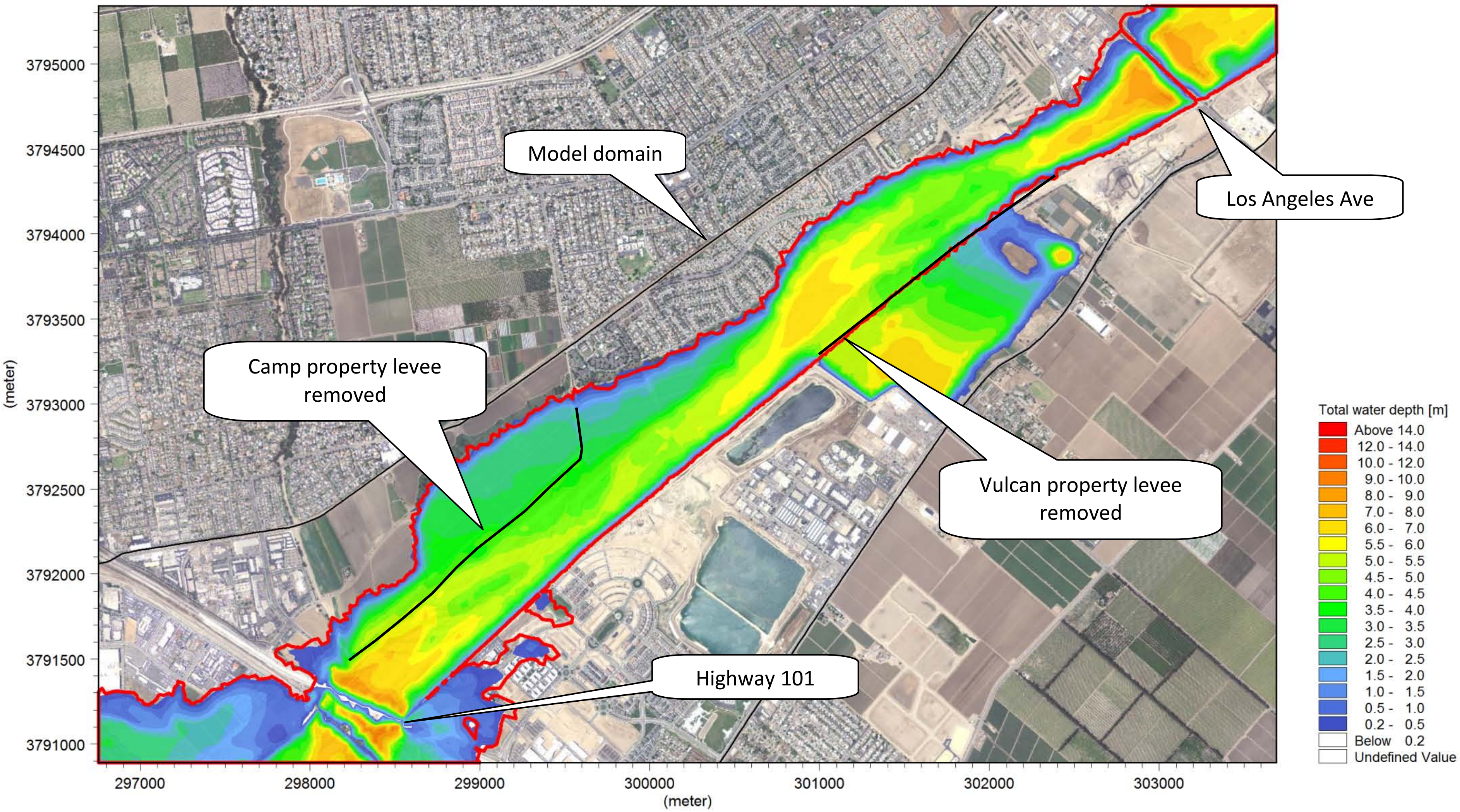
Q100 WSE comparison – Scenarios 2 and 3

Project No. 09-1005

Created By: AMS

Figure 10

R:\Projects\09-1005_Santa_Clara_River\Reporting\Figures\parts\Fig10_Q100_LevScen2-3_WSE.docx
8/24/2011



Notes: red outline denotes the Q100 existing conditions inundation extents; projected coordinates in WGS1984 UTM11N.

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Santa Clara River Levee Setback Assessment

Q100 inundation mapping – Scenarios 2 and 3

Project No. 09-1005

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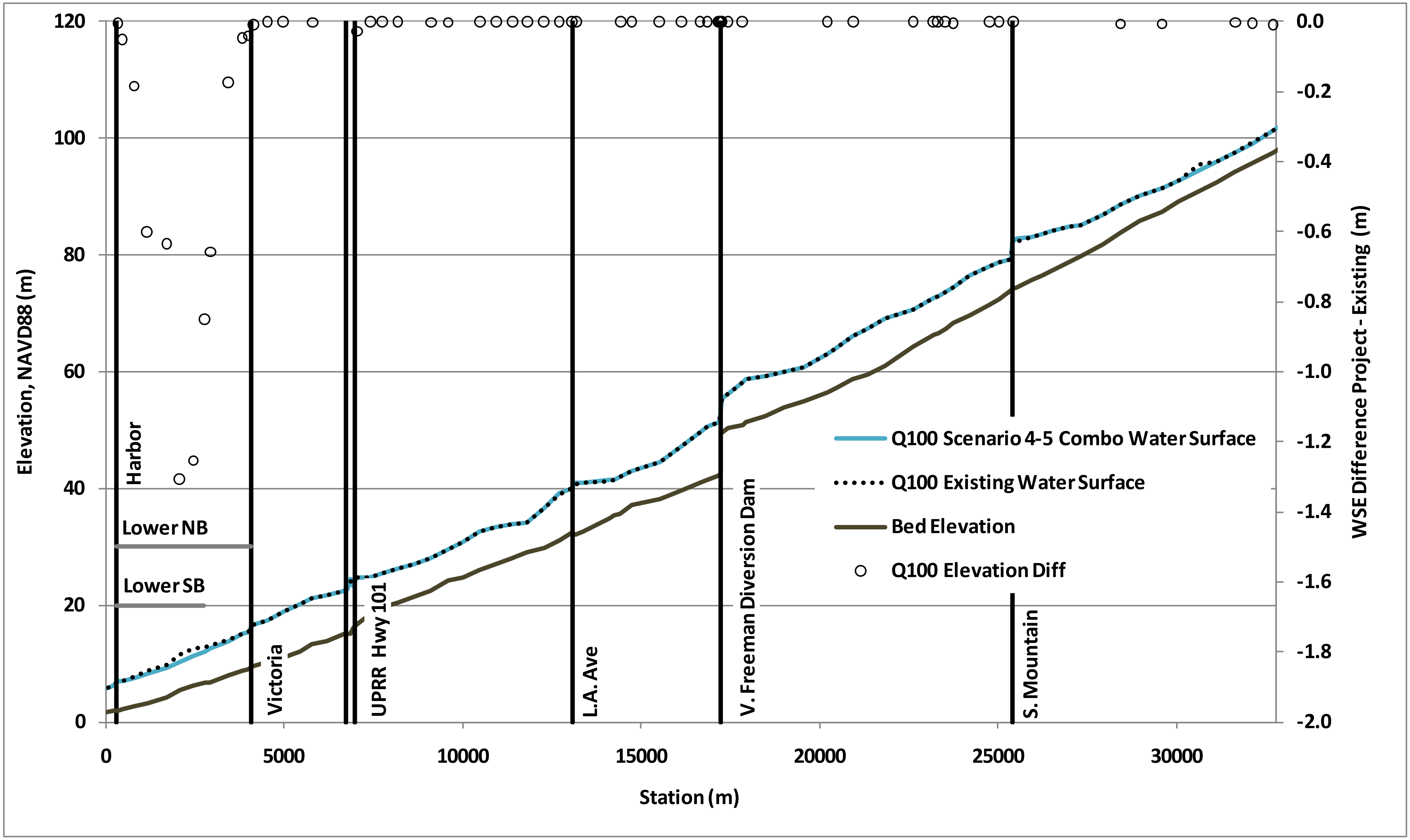
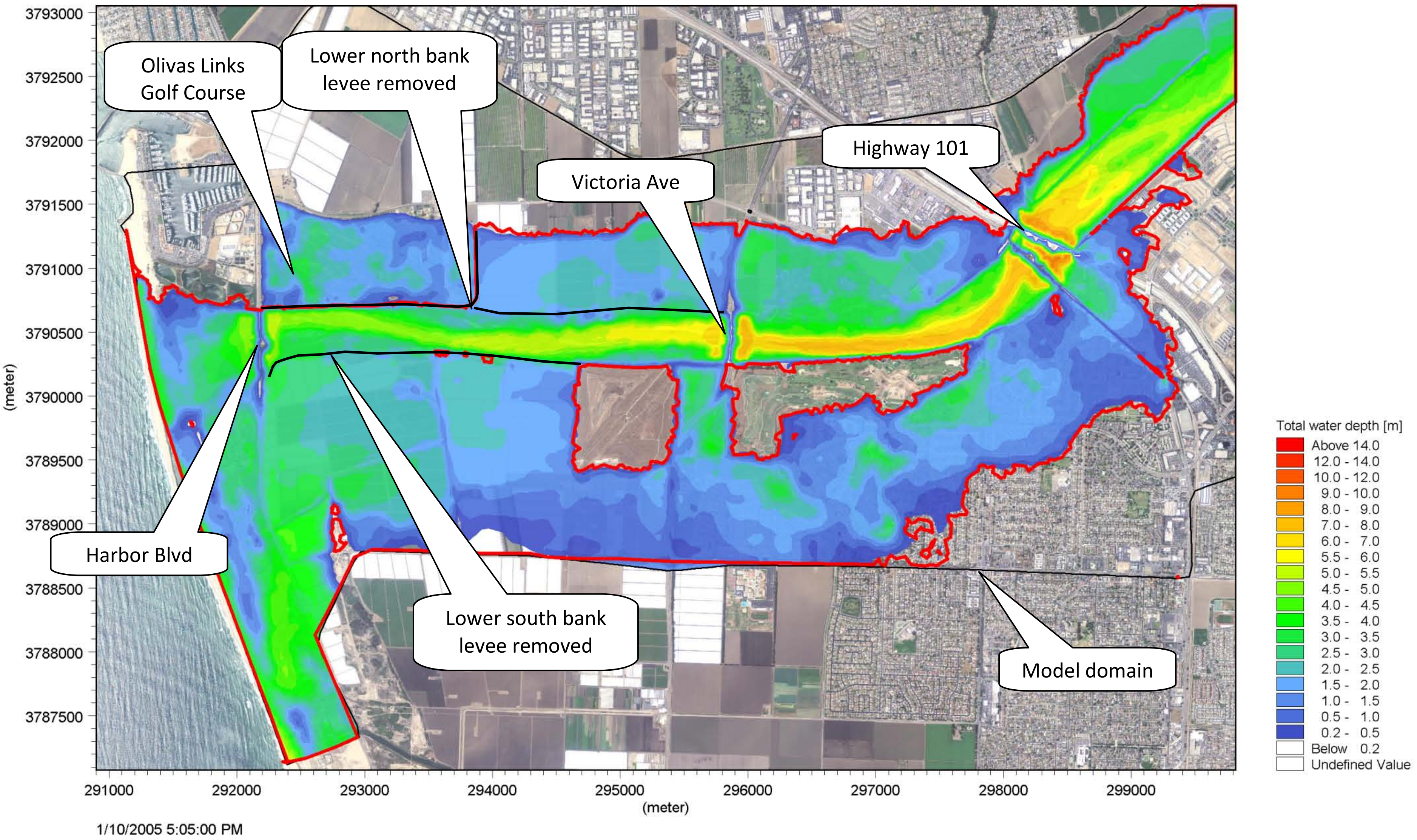
Figure 11



Notes: water surface elevation (WSE).	*Santa Clara River Levee Setback Assessment* **Q100 WSE comparison – Scenarios 4 and 5**		
	Project No. 09-1005	Created By: AMS	**Figure 12**

R:\Projects\09-1005_Santa_Clara_River\Reporting\Figures\parts\Fig12_Q100_LevScen4-5_WSE.docx
8/24/2011



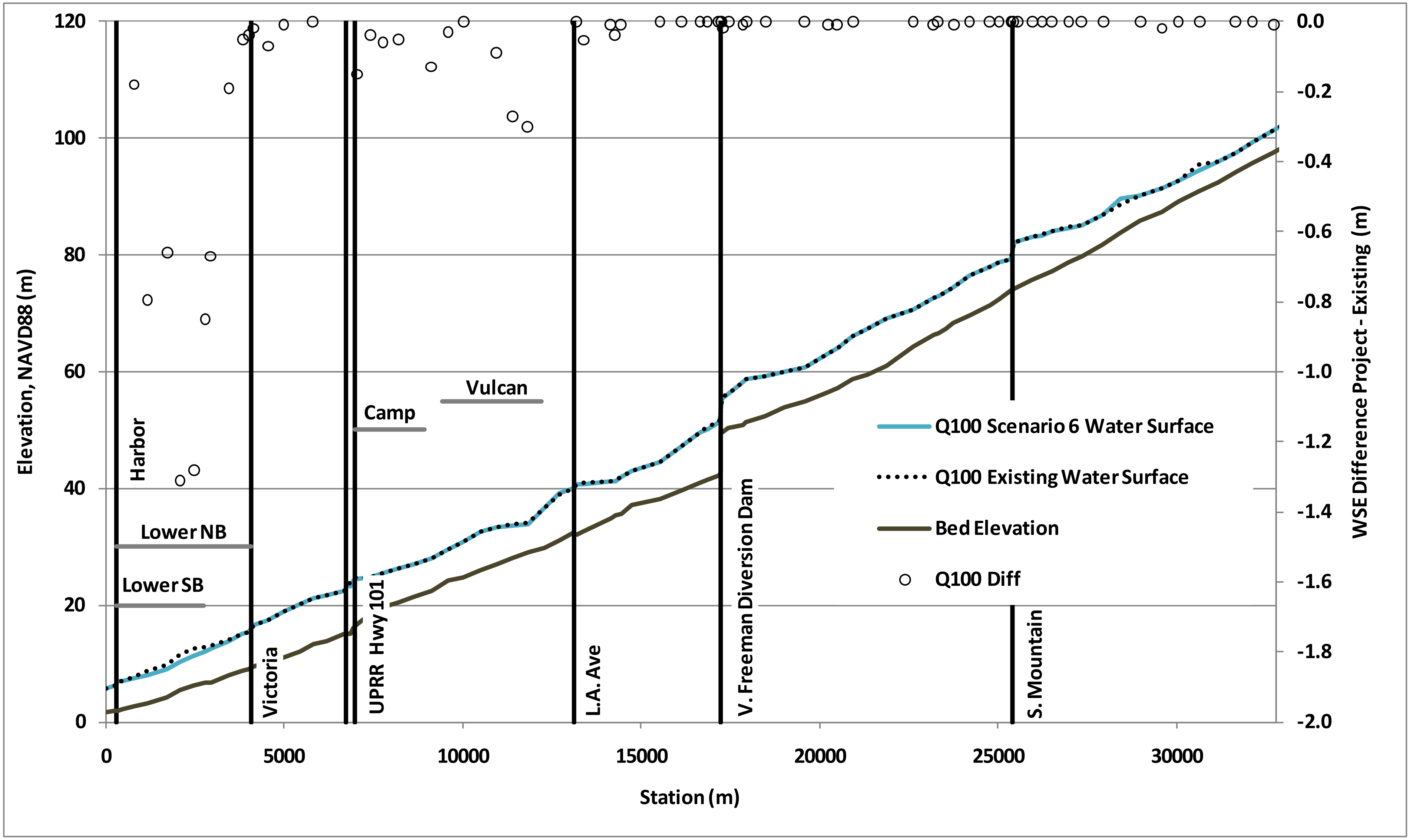
Notes: red outline denotes the Q100 existing conditions inundation extents; projected coordinates in WGS1984 UTM11N.

Santa Clara River Levee Setback Assessment

Q100 inundation mapping – Scenarios 4 and 5

Project No. 09-1005 | Created By: AMS | **Figure 13**

R:\Projects\09-1005_Santa_Clara_River\Reporting\Figures\parts\Fig13_Q100_LevScen4-5_extents.docx
8/24/2011



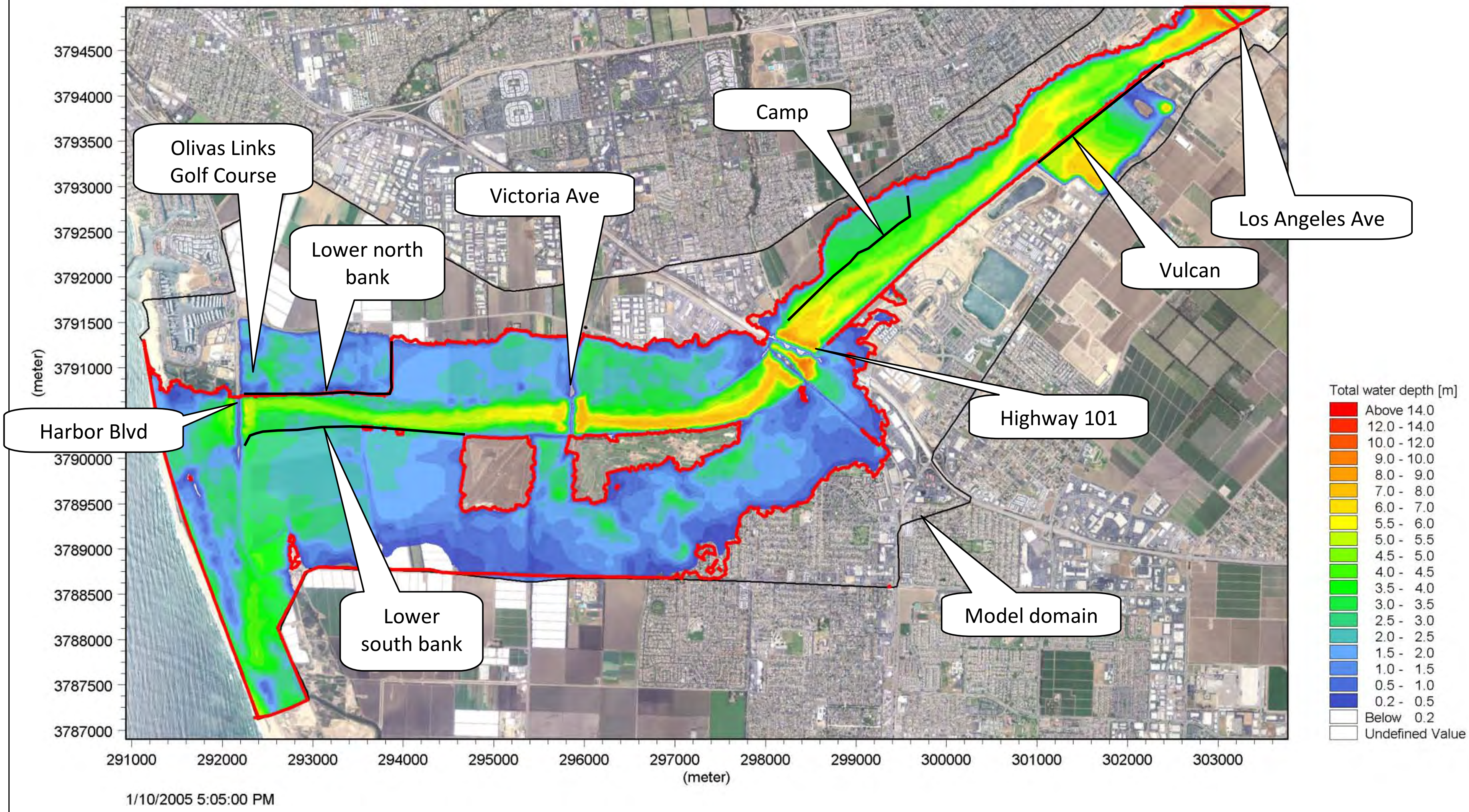
Notes: water surface elevation (WSE).

Santa Clara River Levee Setback Assessment

Q100 WSE comparison – Scenario 6

Project No. 09-1005	Created By: AMS	**Figure 14**

R:\Projects\09-1005_Santa_Clara_River\Reporting\Figures\parts\Fig14_Q100_LevScen6_WSE.docx
8/24/2011



Notes: red outline denotes the Q100 existing conditions inundation extents; projected coordinates in WGS1984 UTM11N.

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Santa Clara River Levee Setback Assessment

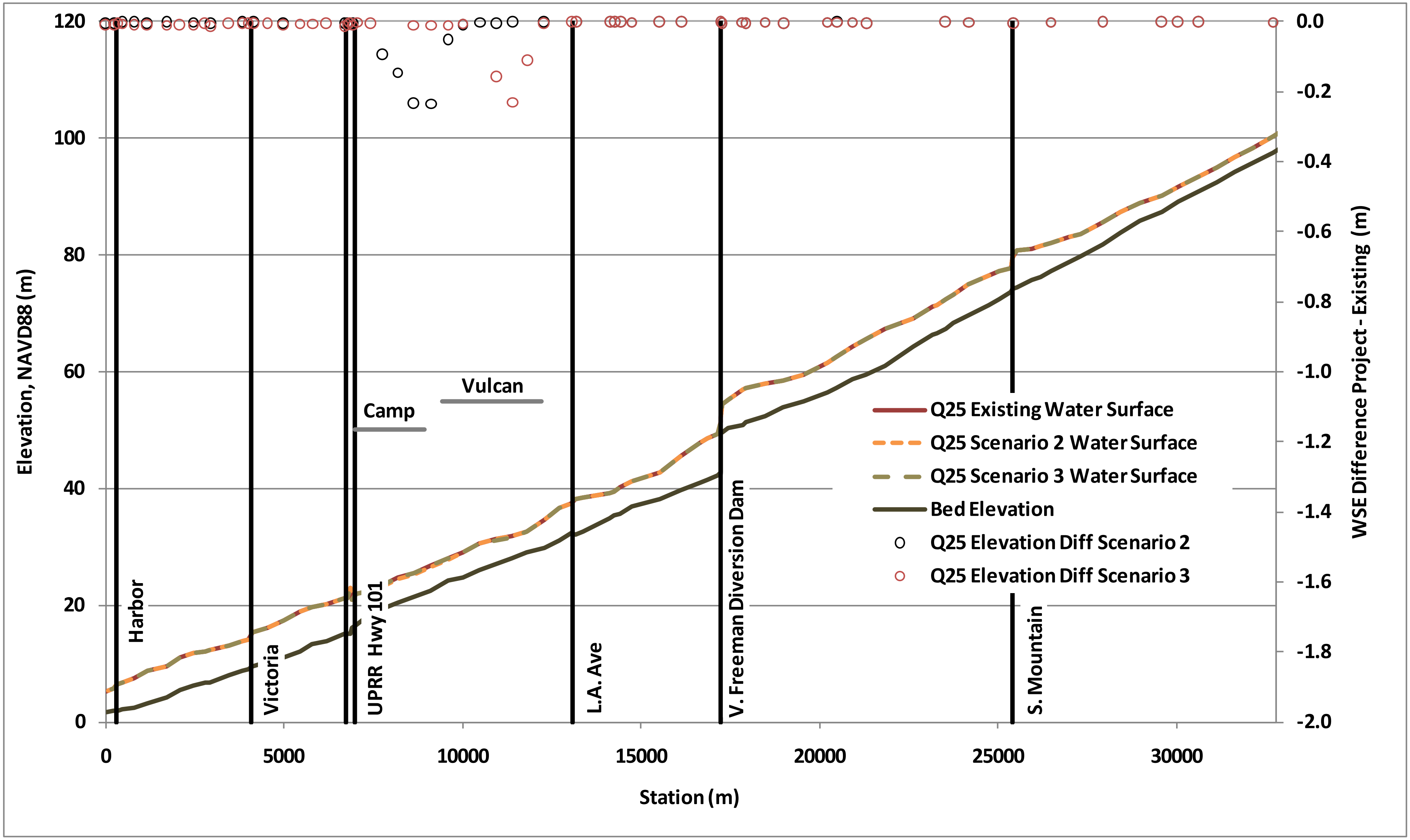
Q100 inundation mapping – Scenario 6

Project No. 09-1005

Created By: AMS

Figure 15

R:\Projects\09-1005_Santa_Clara_River\Reporting\Figures\parts\Fig15_Q100_LevScen6_extents.docx
8/24/2011



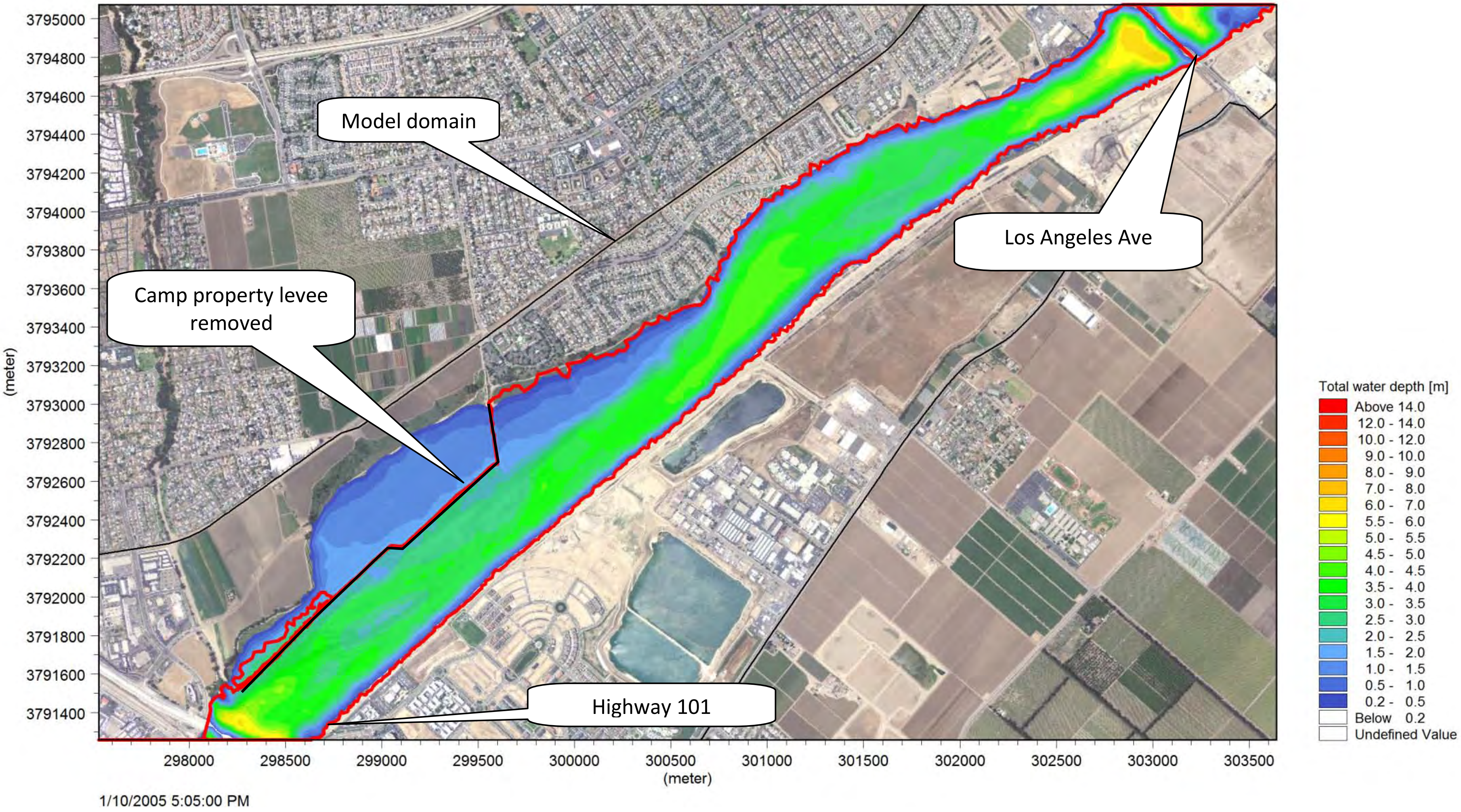
Notes: water surface elevation (WSE).

Santa Clara River Levee Setback Assessment

Q25 WSE comparison – Scenarios 2 and 3

Project No. 09-1005	Created By: AMS	**Figure 16**

R:\Projects\09-1005_Santa_Clara_River\Reporting\Figures\parts\Fig16_Q25_LevScen2-3_WSE.docx
8/24/2011

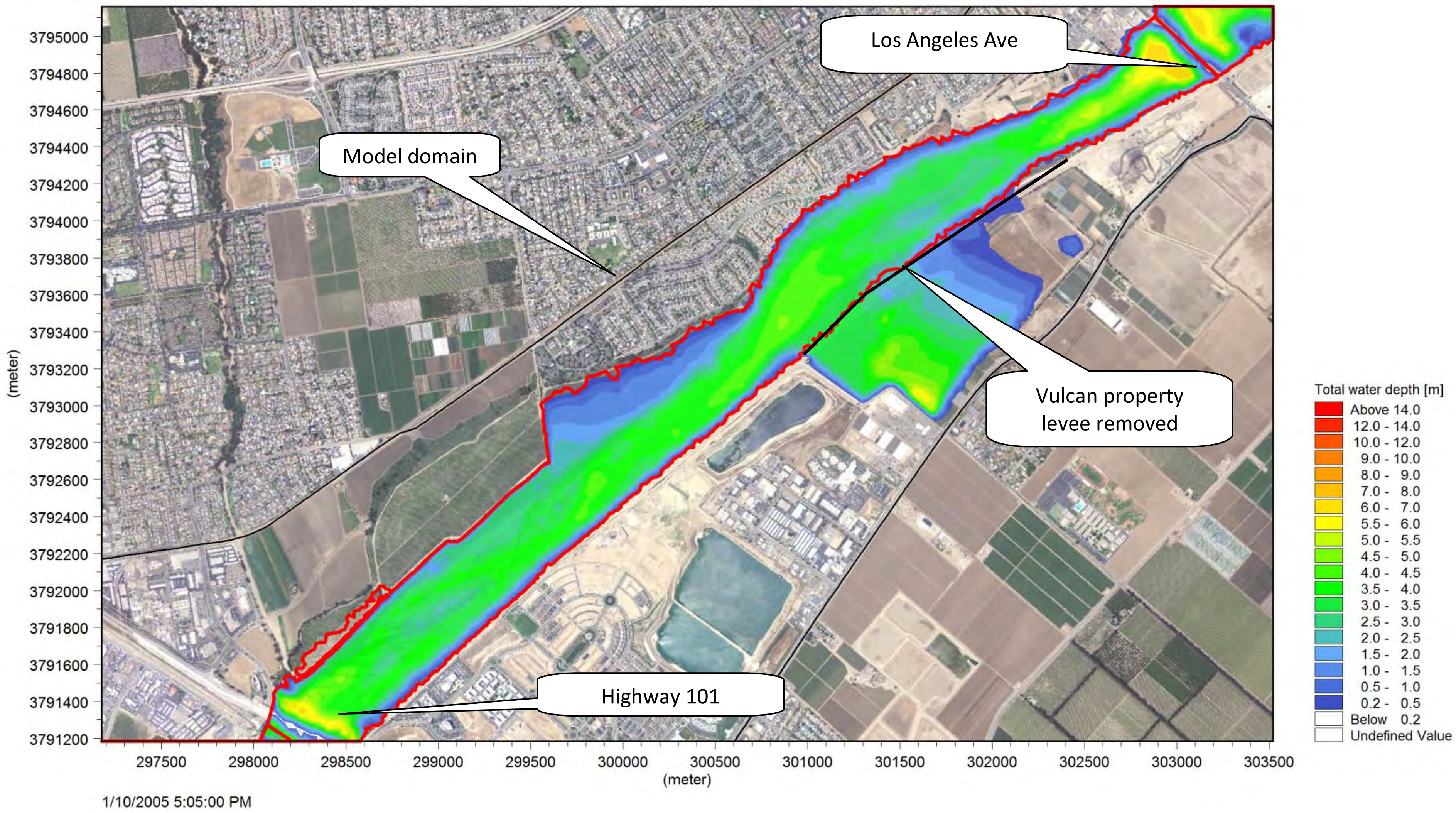


Notes: red outline denotes the Q25 existing conditions inundation extents; projected coordinates in WGS1984 UTM11N.

Santa Clara River Levee Setback Assessment

Q25 inundation mapping – Scenario 2

Project No. 09-1005	Created By: AMS	**Figure 17**



Notes: red outline denotes the Q25 existing conditions inundation extents; projected coordinates in WGS1984 UTM11N.

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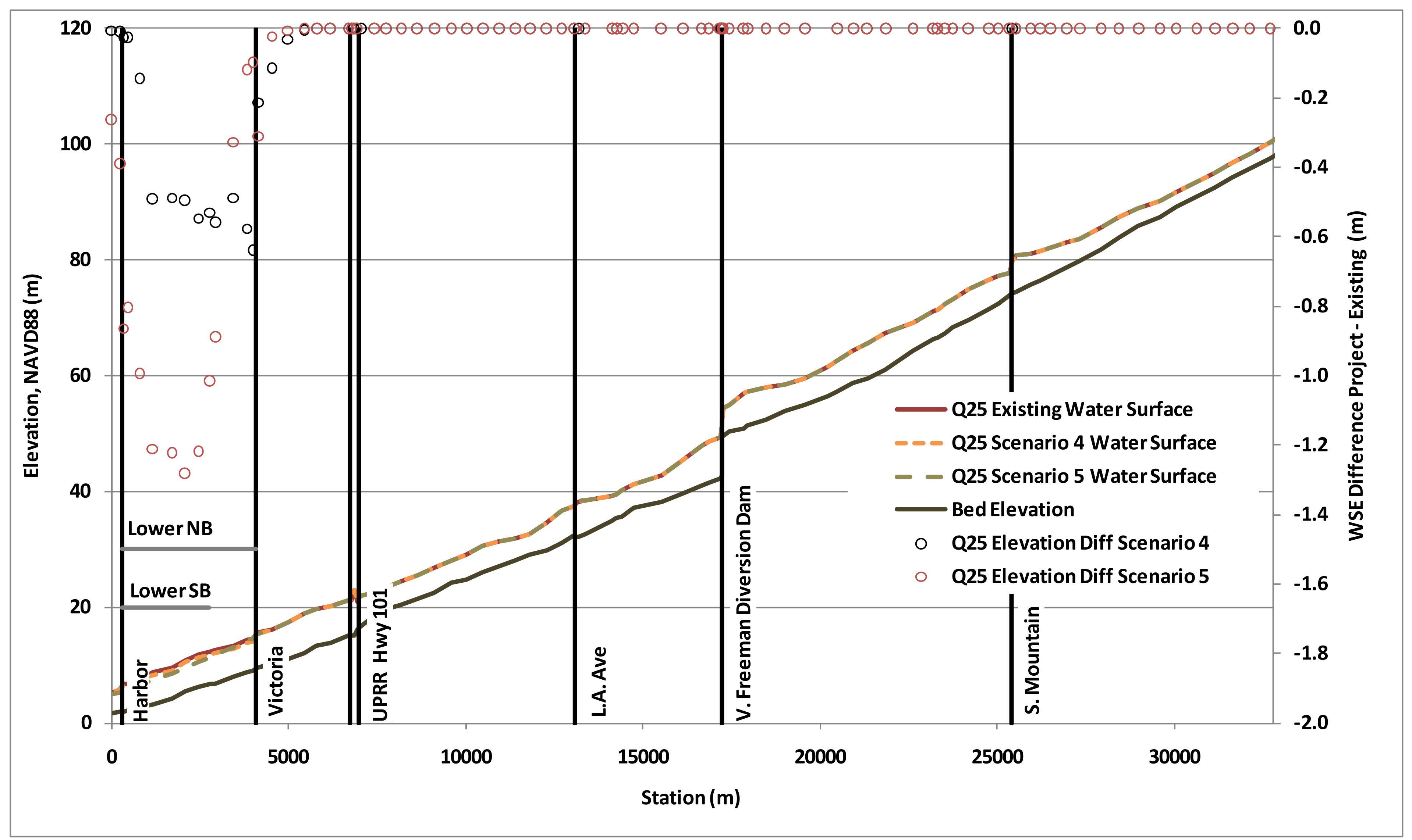
Santa Clara River Levee Setback Assessment

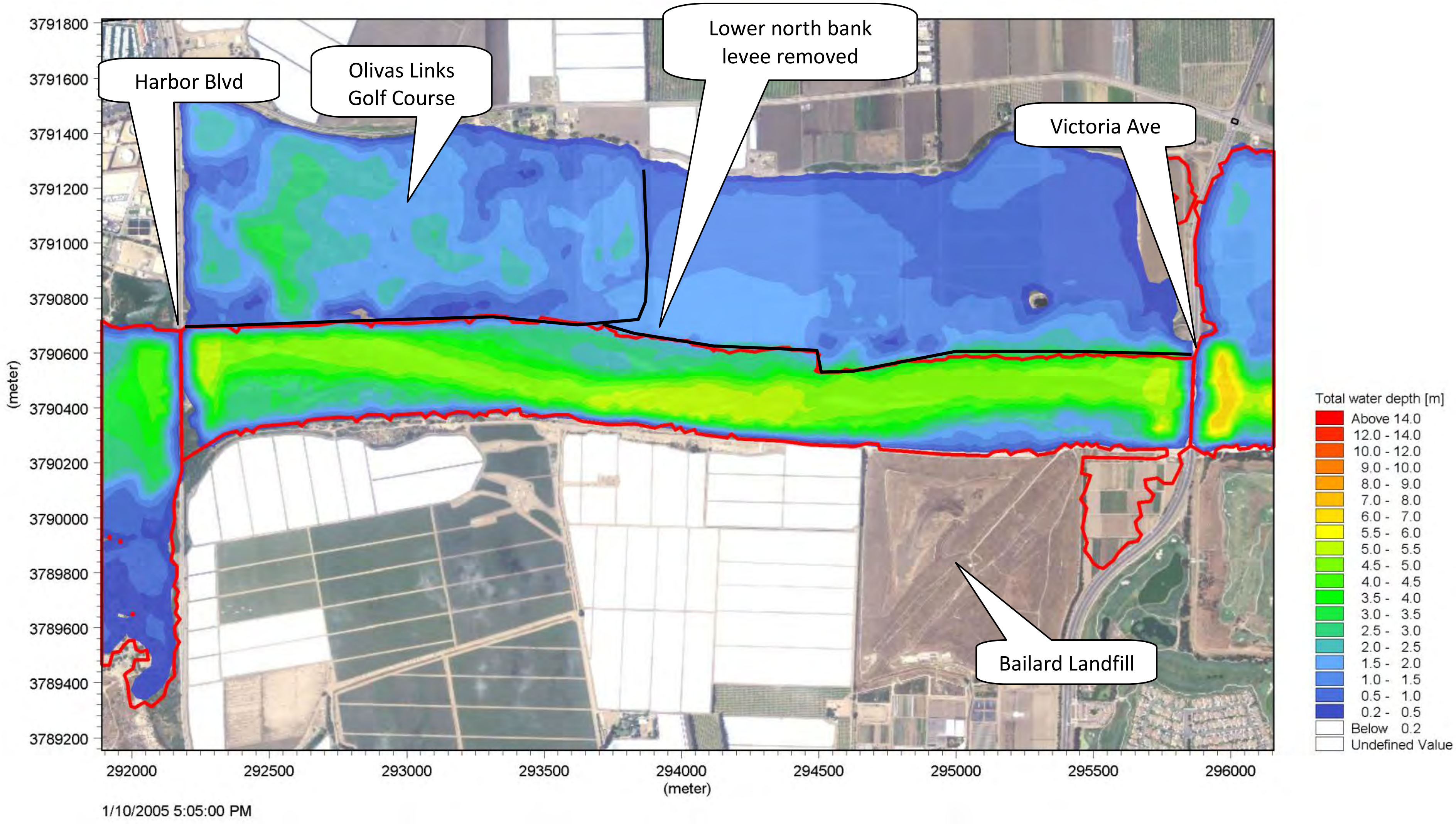
Q25 inundation mapping – Scenario 3

Project No. 09-1005	Created By: AMS	**Figure 18**



Notes: water surface elevation (WSE).		*Santa Clara River Levee Setback Assessment* **Q25 WSE comparison – Scenarios 4 and 5**		
	cbec eco engineering	Project No. 09-1005	Created By: AMS	**Figure 19**

R:\Projects\09-1005_Santa_Clara_River\Reporting\Figures\parts\Fig19_Q25_LevScen4-5_WSE.docx
8/24/2011



Notes: red outline denotes the Q25 existing conditions inundation extents; projected coordinates in WGS1984 UTM11N.

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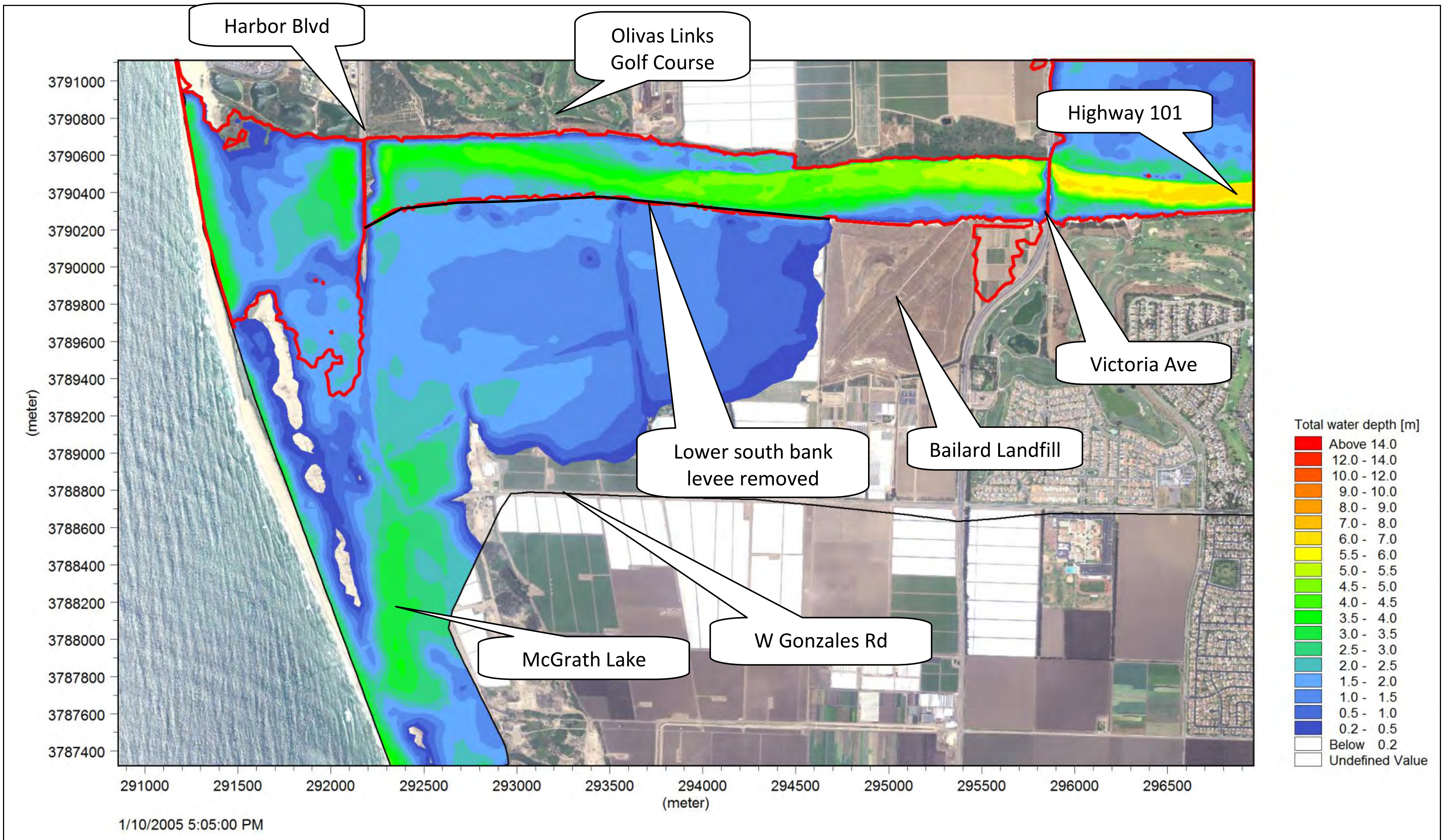
Santa Clara River Levee Setback Assessment

Q25 inundation mapping – Scenario 4

Project No. 09-1005	Created By: AMS	**Figure 20**

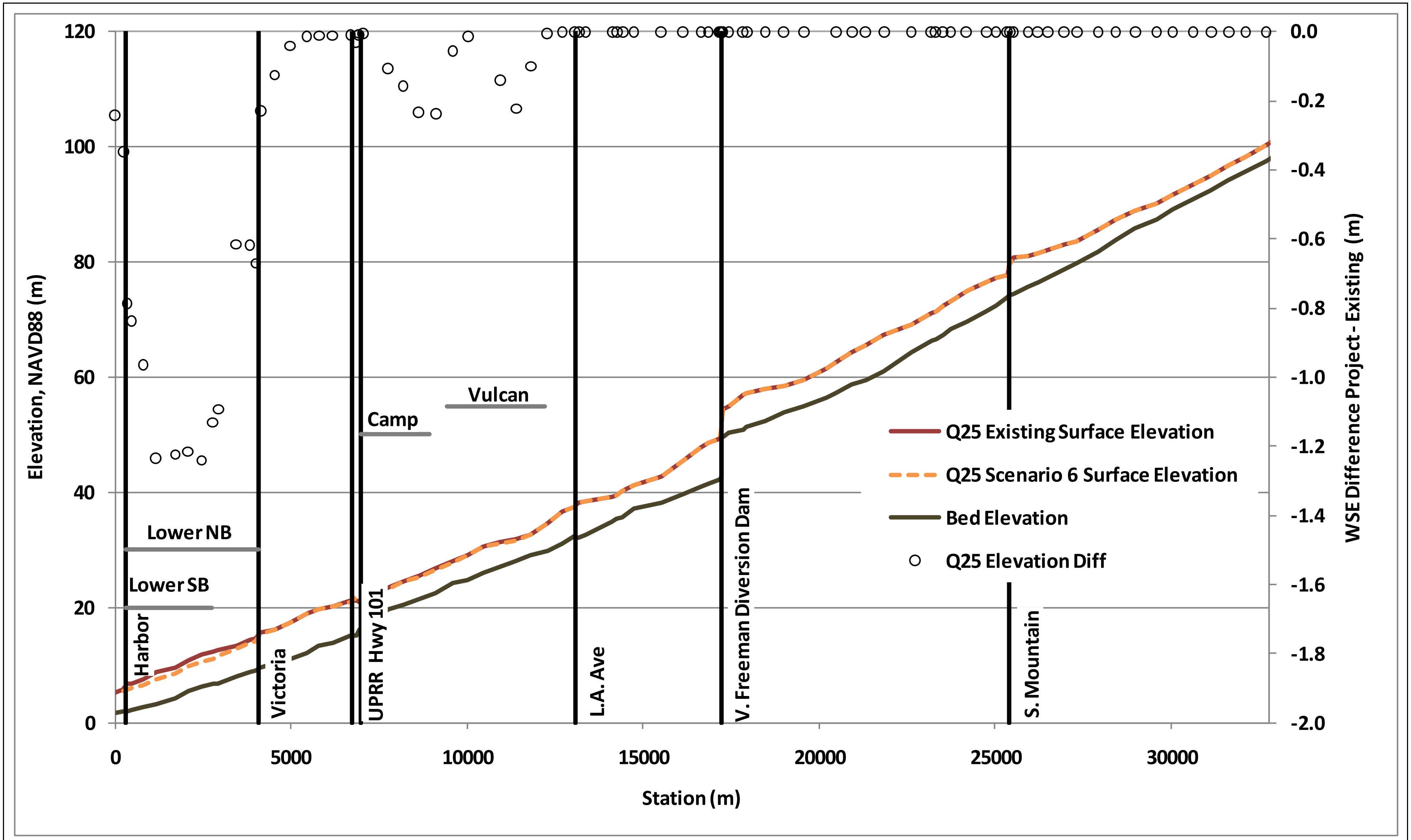


Notes: red outline denotes the Q25 existing conditions inundation extents; projected coordinates in WGS1984 UTM11N.

Santa Clara River Levee Setback Assessment

Q25 inundation mapping – Scenario 5

Project No. 09-1005	Created By: AMS	**Figure 21**



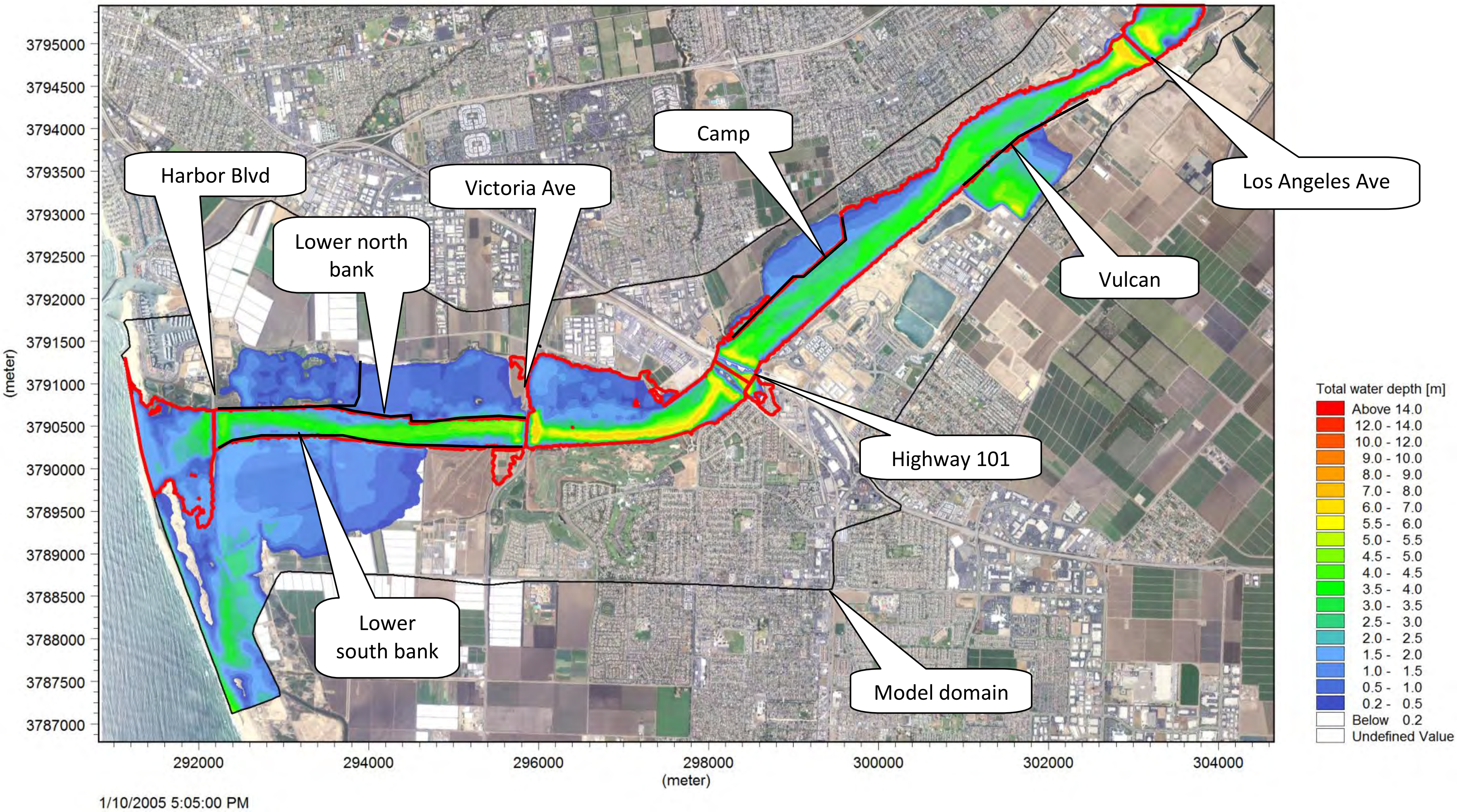
Notes: water surface elevation (WSE).

Santa Clara River Levee Setback Assessment

Q25 WSE comparison – Scenario 6

Project No. 09-1005	Created By: AMS	**Figure 22**

R:\Projects\09-1005_Santa_Clara_River\Reporting\Figures\parts\Fig22_Q25_LevScen6_WSE.docx
8/24/2011



Notes: red outline denotes the Q25 existing conditions inundation extents; projected coordinates in WGS1984 UTM11N.

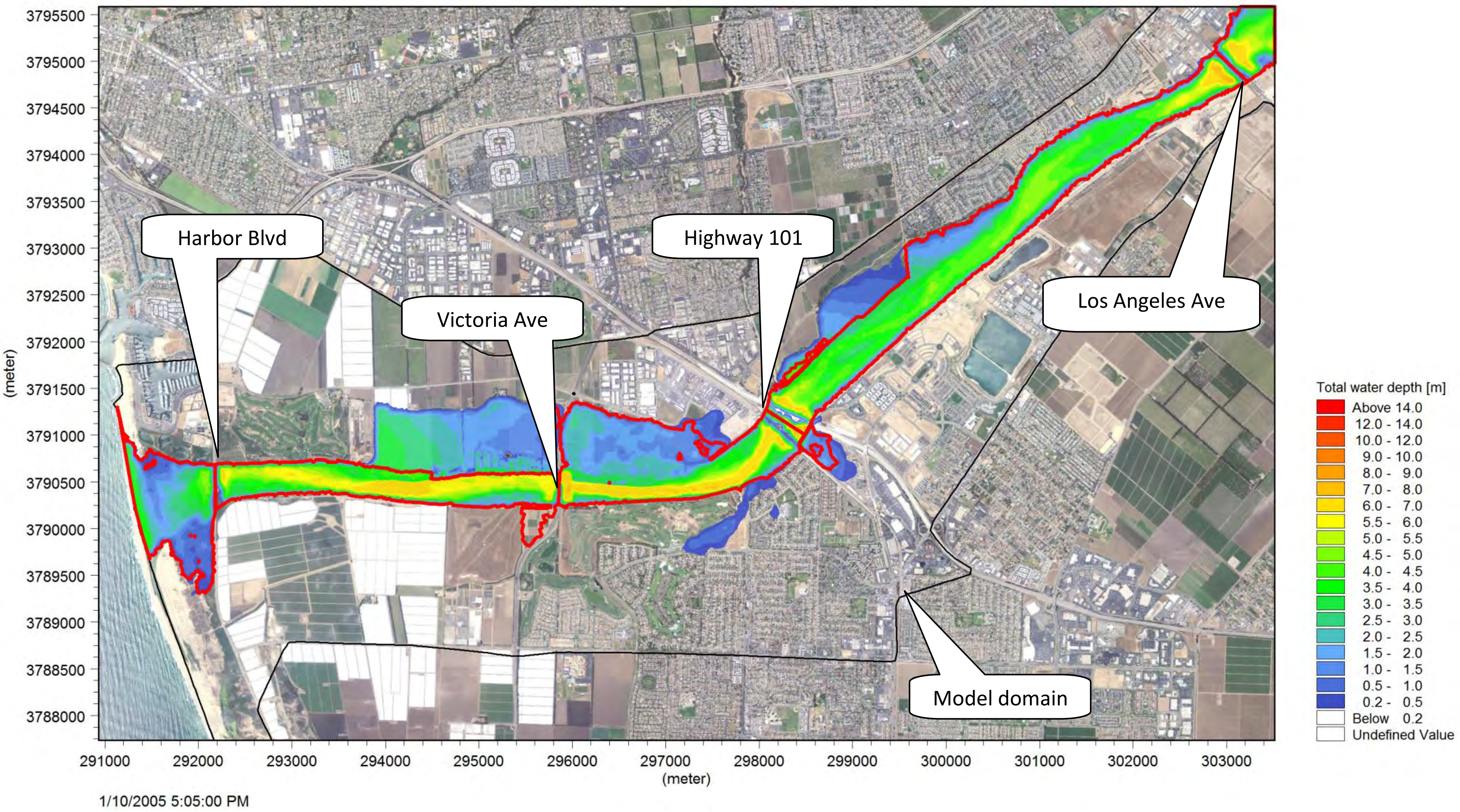
Santa Clara River Levee Setback Assessment

Q25 inundation mapping – Scenario 6

Project No. 09-1005

Created By: AMS

Figure 23



Notes: red outline denotes the Q25 existing hydrology and topography conditions inundation extents; projected coordinates in WGS1984 UTM11N.

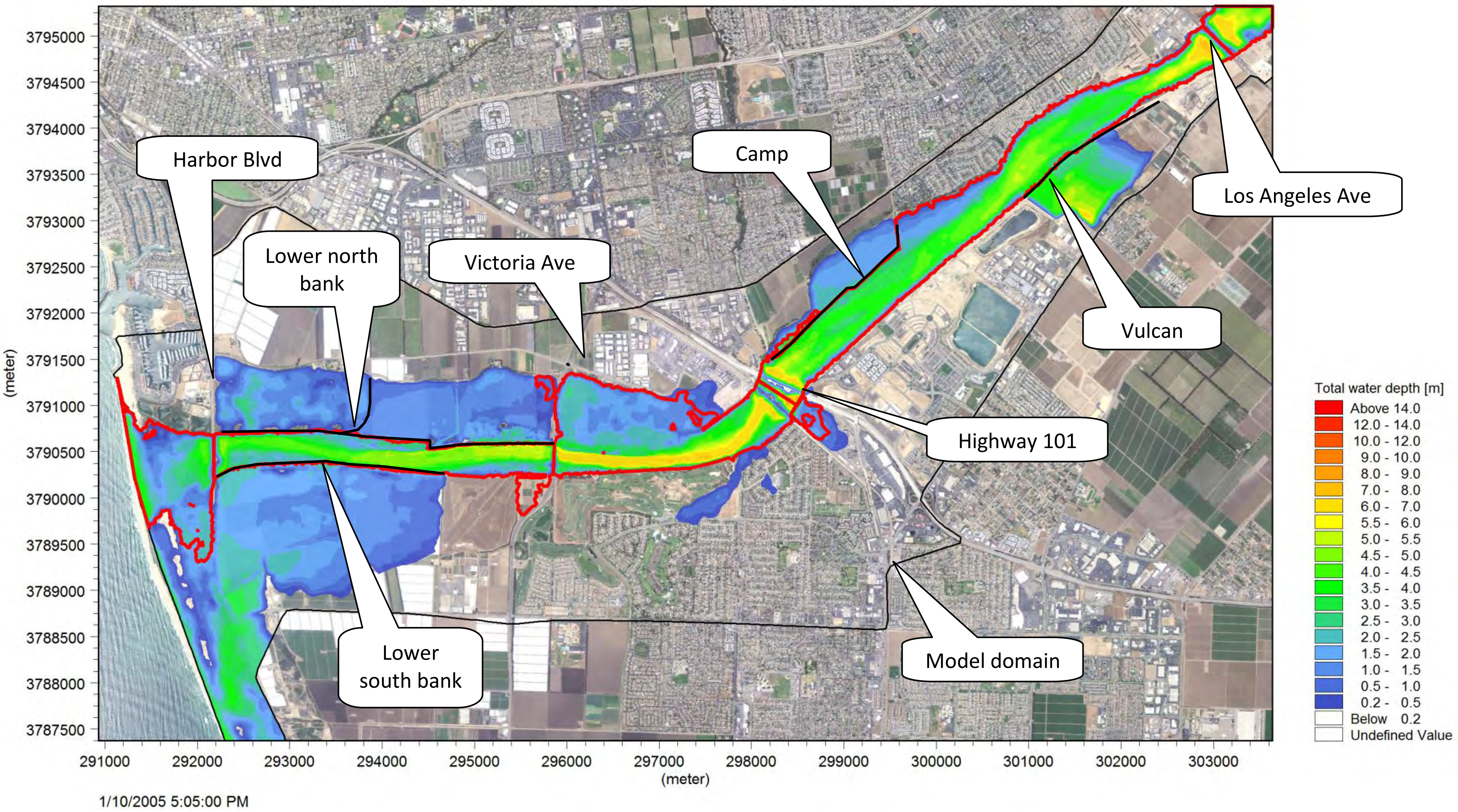
Santa Clara River Levee Setback Assessment

Future Q25 inundation mapping - Existing

Project No. 09-1005

Created By: AMS

Figure 24



Notes: red outline denotes the Q25 existing hydrology and topography conditions inundation extents; projected coordinates in WGS1984 UTM11N.

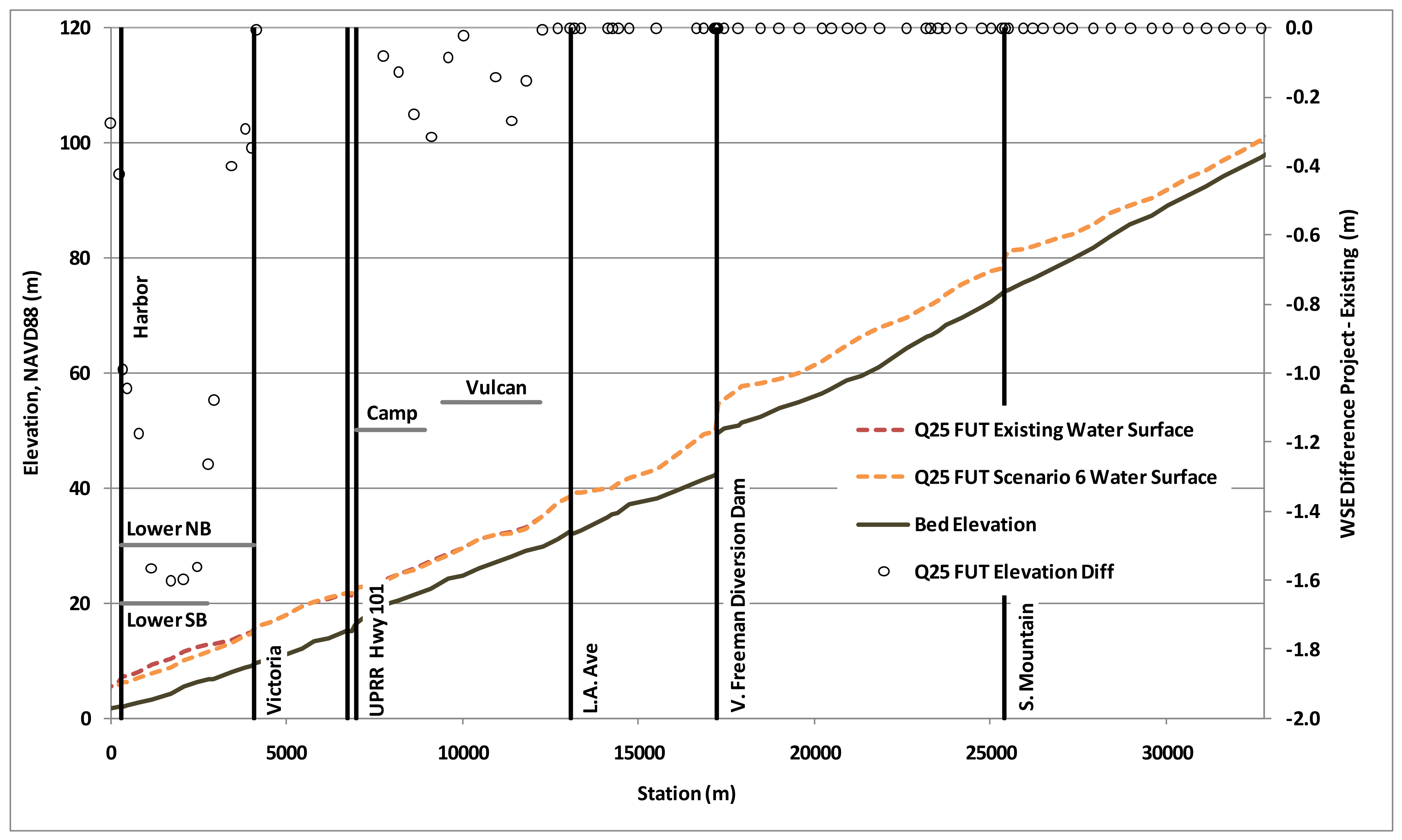
Santa Clara River Levee Setback Assessment

Future Q25 inundation mapping – Scenario 6

Project No. 09-1005

Created By: AMS

Figure 25



Notes: water surface elevation (WSE).

Santa Clara River Levee Setback Assessment

Future Q25 WSE comparison – Scenario 6

Project No. 09-1005	Created By: AMS	**Figure 26**

R:\Projects\09-1005_Santa_Clara_River\Reporting\Figures\parts\Fig26_Q25_LevScen6_WSE.docx
8/24/2011