Appendix I

Hydrodynamic Modeling Analysis

Lower Otay River Salt Marsh
and Wetland Restoration:
Hydrodynamic Modeling Analysis

Prepared for

The United States Fish and Wildlife Service

and

Ducks Unlimited, Inc.

Prepared by

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1. INTRODUCTION

The U.S. Fish and Wildlife Service (FWS) and Ducks Unlimited (DU) contracted Philip Williams & Associates (PWA) to conduct a hydraulic analysis of the Lower Otay River, within Planning Unit A of the South San Diego Bay Unit of the San Diego National Wildlife Refuge. More specifically, PWA evaluated potential changes in flooding conditions associated with wetland restoration alternatives. FWS and DU staff had developed general alternative concepts for Planning Unit A to enhance and restore tidal and freshwater wetland habitats. PWA translated these general restoration concepts into representative surface and channel models of the site for use in the hydraulic analysis. PWA developed a one-dimensional hydrodynamic model to simulate surface water elevations for existing conditions and project alternatives.

Section 2 of this report describes the project site's physical setting and introduces restoration opportunities at regional and site-specific scales. Section 3 describes the hydraulic analysis including a discussion of the modeling approach, data sources, and modeling results for the existing baseline condition. In Section 4, restoration alternatives developed by the DU/FWS team are presented and compared to the baseline condition in terms of water surface elevations, changes in wetland area, excavation volume required, and potential scour conditions near the railroad bridge. In Section 5, this report concludes with a discussion of next steps to continue the restoration effort of the Lower Otay River site.

2. LOWER OTAY RIVER PROJECT SETTING

2.1 HYDROLOGIC AND GEOMORPHIC SETTING

The Otay River watershed is located in southwestern San Diego County encompassing approximately 143 square miles (Figure 2-1). From its mouth at the southern end of San Diego Bay, the elongated pear-shaped basin extends 25 miles east into the Cleveland National Forest. The maximum watershed elevation is 3,300 ft at White Mountain. The Otay basin is bordered by the Telegraph and Sweetwater basins to the north and the Tijuana watershed to the south. The Otay watershed includes two water supply reservoirs (Upper and Lower Otay Reservoirs), which influence downstream hydrologic conditions. The upper watershed (upstream of the reservoirs) is comprised of steep mountainous slopes with mostly igneous and metamorphic substrate. The steep tributary channels of the upper watershed have slopes averaging from 3 to 6%. Downstream of Savage Dam (Lower Otay Reservoir) tributary channels are generally less steep with average slopes between 2 to 3%. The western lower portion of the watershed is generally underlain by marine sediments that have been uplifted to create the characteristic mesa landscape. In the vicinity of the Highway 5 bridge crossing (towards the project site), the Otay River has a channel slope of less than 1% and is generally a sand and cobble bed stream. Towards the project site, bed materials tend towards finer sands, silts, and ultimately muds upon reaching the estuarine zone. The majority of the upper Otay watershed is unincorporated, but the lower watershed includes portions of the cities of Chula Vista, Imperial Beach, Coronado, National City, and San Diego.

The lower Otay River project site (between the Highway 5 crossing and San Diego Bay) represents a transitional hydrologic zone between a fluvial dominated riverine system upstream and a tidally dominated estuarine system downstream. As such, the project site involves a complex mixing of freshwater, brackish, and tidal flows and hosts a mosaic of habitat types. An early map of San Diego Bay from 1859 (Figure 2-2) provides an excellent reference to understand how the system functioned historically prior to subsequent impacts. As seen in the map of Figure 2-2, in 1859 the Otay river mouth was a deltaic feature that sloped northwesterly towards San Diego Bay. Three to four principal drainage channels crossed the deltaic plain, with the central bolder channel most likely being the direct conduit to the Otay River upstream. Depending upon the frequency and magnitude of episodic flood events, these principal channels would have shifted across the deltaic marsh plain. The hachuring, in Figure 2-2, between the principal channels indicates a tidal marsh environment that was regularly inundated. Towards the bay-ward fringe of the salt marsh, smaller tidal-slough type channels are seen that would have conveyed ebb and flood tides to and from the outer marsh plain.

Since the 1859 mapping, several significant impacts to the lower Otay River project area impaired its hydrologic, geomorphic, and ecologic functioning as a river-mouth/delta/marsh plain complex. The more significant of these impacts include: (1) constructing several dikes and levees to support salt ponds north of the project site; (2) relocating and reshaping of Otay and Nestor creeks through the project area; (3)

construction and operation of railroad dyke and bridges through the project area; (4) placing up to several feet of fill in a variety of places within the project site, to support agricultural practices; and (5) developing and operating a sanitation treatment plant in the 1950s and 1960s which was later reduced and transformed into a pumping station and pipeline.

2.2 PROJECT SITE CHARACTERISTICS

The Planning Unit A site is bordered by levees and ponds of The Western Salt Works Company to the west, northwest, and north; and Interstate-5 to the east. The southern project boundary bisects the Pond 20A site, Nestor Creek, and joins Interstate-5 near the southern most of the two Otay River bridge crossings (Figure 2-3). The Planning Unit A site is approximately 140 acres. The Pond 20A site is approximately 110 acres; 68 acres of which are administered under the authority of the Port of San Diego and 32 acres administered by the FWS. While Pond 20A is not formally a piece of the National Wildlife Refuge, for future planning and restoration purposes it is useful to consider Pond 20A in coordination with Planning Unit A. Topographically, the project site is generally flat, with a gradual slope from the southeast to the northwest (Figure 2-4). Ground elevations range from roughly 18 ft (NAVD88) near the Interstate-5 crossing and along the tops of the surrounding levees (Pond 20A and Western Salt Works levees) to approximately 6 ft (NAVD88) within Pond 20A. The channel profile of the Otay River ranges in elevation from about 8 ft (NAVD88) near Interstate 5 to –2 ft (NAVD88) at the San Diego Bay confluence.

The project site contains two river channels: Otay River and Nestor Creek. The Otay River enters the site from the east (beneath Interstate 5) then flows to the northwest for approximately 2500 feet before turning sharply to the west, and then southwest (south of the levee-salt ponds system to the north). From this point downstream to San Diego Bay, the river is bound by the salt pond levees, which constrain the river to the north (and to the east and west further downstream towards the Bay). Previous modeling analyses, observed flood levels, and published FEMA Flood Insurance Studies all indicate that during extreme flood events, excess flows from the Otay River will overtop this levee system at several locations and flood the neighboring salt works. FEMA Flood Insurance Rate Maps (FIRM) for the project area are shown in Figure 2-5.

Nestor Creek, a comparatively small tributary to the Otay River, conveys local runoff from the community of Nestor, northward under Palm Avenue and flows east of Pond 20A until it joins the Otay River. FEMA (FIRM maps 060732C2153F, 060732C2154F) indicate that the urban community near Nestor Cr. north of Palm Avenue (in the vicinity of Boundary Ave., Canal St., and Thermal Ave.) is mapped as being inundated by the 100-yr flood event (Zone AE: base flood elevations determined. Within the project area, the 100-yr event causes overbank flooding out from Nestor Cr. towards the east and towards Pond 20A to the west (Figure 2-5).

Downstream of the Otay River/Nestor Creek confluence, the Otay River channel is confined between the Pond 20A levee to the south and the salt works levees to the north, resulting in a hydraulic constriction

(Figure 2-6). At 1000 ft downstream of the Nestor Creek confluence, the Otay channel splits into two parallel reaches, separated by the abandoned San Diego & Eastern Railway line. This side-by-side channel configuration (as seen in Figure 2-4) that is split by the railway line continues for roughly 1500 feet until the two parallel channels join and leave the Planning Unit A project site to the west. The railway line within this 1500 ft segment is supported by a dyke and two trestle bridges (Figures 2-7). The Otay River then continues to flow approximately one mile northwest and then north, discharging into South San Diego Bay.

Between Nestor Creek and the Otay River channel is a broad flat floodplain expanse (Figure 2-6). This floodplain, which historically formed a significant portion of the Otay River fresh and saltwater wetlands, was filled in the early 20th century to facilitate agricultural uses of the site. Today, this portion of the project site consists of very little vegetation, limited habitat and no fresh or saltwater wetlands.

Tidal flows influence the Planning Unit A site, enter from San Diego Bay and extend up the Otay River to approximately 1500 feet upstream beyond the Nestor Creek confluence. This inland tidal extent was field verified by the appearance of tidal mud flats, which typically indicate the presence of daily inundation. The wildlife refuge also experiences seasonal or intermittent flows from Otay River and Nestor Creek. These flows may come in the form of extreme flood events with discharges exceeding 25,000 cfs. Such stormflows have the potential to modify the site through channel scour, levee overtopping and/or breaching, and sediment deposition. Tidal and fluvial characteristics related to the modeling analysis are described in greater detail below in Section 3.

2.3 RESTORATION OBJECTIVES, SITE OPPORTUNITIES AND CONSTRAINTS

Developing an appropriate restoration concept for the lower Otay River project area requires an understanding of the complex hydrologic processes occurring at the site. Additionally, the restoration concept should incorporate an appreciation of how historic processes and features governed the site over the longer term and consider how recent impacts have altered the physical system, reduced habitat areas, and impaired ecologic functioning. The principal objectives for a restoration project at the lower Otay River site include:

- Restoration of functioning wetland habitat (tidal, freshwater, brackish) in areas that have become drier uplands
- Enhancement of existing wetland areas to increase circulation and improve habitat conditions
- Develop a sustainable, relatively self-maintaining wetland design
- Maintain or decrease current flood elevations to avoid exacerbating predicted flood conditions in the vicinity of the project
- Minimize environmental impacts and excavation and earth work costs associated with restoration
- Develop a restoration plan that is flexible enough to integrate other regional restoration efforts including the restoration of the south San Diego Bay salt ponds.

Current conditions at the lower Otay River (Planning Unit A) site provide both positive opportunities for restoration, as well as, limitations (or constraints) to reaching a successful restoration. Many of the site's primary physical, natural resource, and planning opportunities and constraints were described in the MKEG Wetland Enhancement Plan (Michael Brandman Associates, 1989). The key physical opportunities and constraints based upon Lower Otay River Wetland Enhancement Plan report include:

Opportunities

- Expanded tidal circulation is feasible
- Seasonal freshwater flows from Otay River and Nestor Creek can potentially support in-channel habitat
- Groundwater is available to support riparian vegetation
- Flood hazard reduction is also achievable through ecologic/habitat restoration
- Increased tidal prism on site will help reduce on-site sedimentation and channel in-filling
- Soils underlying fill historically supported salt marsh vegetation and could likely do so again successfully after restoration
- Site topography can be modified (with fill removed or relocated) to restore appropriate wetland elevations

Constraints

- Freshwater flows delivered by Otay River and Nestor Creek are episodic and infrequent
- Groundwater is slightly brackish potentially limiting vegetation to species with salt tolerance
- Extreme flood events may deliver large amounts of sediment to the project site (as observed in 1916)
- High groundwater levels might require special grading and excavating techniques
- Existing site elevations are high enough that a comprehensive wetland restoration effort would require extensive grading and earth moving
- Much of site is designated as a FEMA Floodway, potentially limiting the scope of work done on the site

3. HYDRODYNAMIC MODELING DEVELOPMENT

3.1 MODELING APPROACH

PWA used the hydrodynamic module of MIKE 11 to evaluate the hydraulic conditions of the Lower Otay River, Nestor Creek and South San Diego Bay. MIKE 11 is a one-dimensional hydrodynamic model, developed by the Danish Hydraulics Institute (DHI), which solves the vertically integrated conservation of mass and momentum equations (Saint-Venant equations). For the Otay setting, the model expands upon basic channel hydraulics by more realistically portraying interactions between river and creek channels, salt ponds, overbank floodplains, and the dynamic tidal and hydrologic boundary conditions. This added complexity allows the model to more accurately represent current site conditions and evaluate site conditions under different alternative configurations. However, it is important to remember that the hydraulic model developed for this study is at best an analytical tool used to simulate flow conditions and does not depict actual events.

3.2 DATA SOURCES

A number of existing information sources were collected and reviewed to provide input to the present hydrodynamic analysis. Project data were compiled into a spatial database (GIS) by thematic type (coverages) using ArcGIS software. This included site topography for existing and proposed alternative conditions and both tidal and surface runoff hydrology. The following sections describe these different input data sets.

3.2.1 Topography

The baseline topographic data used for this analysis was collected using differential GPS equipment and compiled into an AutoCAD contour map (1-foot resolution) by Ducks Unlimited Inc. This information was collected in 1999 and 2000 as part of a broader survey of the entire wildlife refuge area, salt works, and surrounding areas. Certain additional data were collected in June 2002 (as requested by PWA) including supplemental ground topography along the project boundary, additional channel cross-sections and invert measurements, and a more detailed survey of bridge crossings. All topographic data were collected in the State Plane (California Zone VI - feet) horizontal datum and North American Vertical Datum 1988 (NAVD88 - feet) vertical datum.

The GPS field survey data were integrated with the baseline contour maps to develop an ArcGIS Triangular Irregular Network (TIN). This TIN was used to generate a surface model which became the topographic foundation for the existing conditions model (Section 3.4). All MIKE 11 cross-sectional information for the existing conditions model was extracted from this surface model. For the alternatives analysis, the baseline surface model was modified according to the restoration concepts. Planform channel alignments and grading adjustments were made in accordance with the restoration concepts provided by FWS and DU (Appendix A). Similar to the digital terrain model developed for existing conditions topography, an ArcGIS TIN surface was developed for each alternative.

3.2.2 Hydrology

As a transitional estuary setting, the lower Otay River and wildlife refuge site are subject to tidal and river flows. These flows form the boundary conditions for the hydrodynamic model. These boundaries were limited to tides in San Diego Bay and river discharge from the Otay River and Nestor Creek. Other localized runoff sources were not considered significant relative to the volume and discharge of tides and river flows and were not included in the present analysis. The following sections present the tidal and surface runoff hydrology conditions adopted for the current modeling analysis and any limitations associated with their use.

3.2.2.1 Tidal Hydrology for Hydraulic Modeling

The tidal flows in San Diego Bay can be characterized by diurnal (daily) and spring-neap (monthly) variations, which inundate the bottom portion of the Otay River and Nestor Creek channels twice daily. Considered independently, these tidal flows do not increase water level on the project site enough to flood overbank areas that were historically salt marsh and fluvial wetlands.

Tidal hydrology reference levels refer to statistical stillwater tidal conditions in San Diego Bay and forms the downstream water level boundary condition for the hydrodynamic model. The National Oceanographic and Atmospheric Administration (NOAA) operates and maintains a long-term primary tide gage (9410170) located at Navy Pier near downtown San Diego. This gage, which has been in operation since 1900, is approximately 9 miles north of the project site. Tidal measurements collected over a previous tidal epoch (19-year period from 1960 – 1978) have been statistically reduced to obtain long-term average values of Mean Lower Low Water (MLLW), Mean Lower Water (MLW), Mean Tidal Level (MTL), Mean Higher Water (MHW), and Mean Higher High Water (MHHW). Table 3-1 presents the two published tidal datums for San Diego Bay.

Table 3-1. Published Tidal Datums for NOAA Tide Gage No. 9410170 in San Diego Bay

Mean Tidal Datum	**Tidal Statistics for San Diego Bay (Feet)**	
	Local MLLW Datum	**NAVD88 Datum**
MHHW	5.73	5.08
MHW	4.98	4.33
MTL	2.96	2.31
MLW	0.94	0.29
MLLW	0.00	-0.65

Tidal datums presented in Table 3-1 were converted into a representative tide cycle for San Diego Bay. This was accomplished by applying a cosine interpolation to each neighboring published tidal datum from Table 3-1 at a 5-min time interval. The result of this analysis is presented in Figure 3-1 which represents a typical diurnal tide cycle for San Diego Bay. A monthly tide cycle (Figure 3-2) exhibiting spring-neap variations was also developed using Tides & Currents Software (1993) and the published NOAA datum conversion from MLLW to NAVD88 or -0.65 feet.

According to the FEMA Flood Insurance Study (FIS) for San Diego County, California (Unincorporated Areas, January 2001), the 100-year water surface elevation for San Diego Bay at Chula Vista is 7.08 feet (NAVD88). Due to various coastal flooding mechanisms (e.g. river runoff, wind, storm surge), this published flood elevation is 2 feet higher than the representative MHHW datum used to form the tidal boundary condition for the present river flooding analysis. While acknowledging this difference, the MHHW datum was adopted as the high water tidal boundary condition to maintain consistency between the modeling analysis and upstream riverine flood insurance studies which use the 5.08 ft datum. For example, the current Otay River FEMA analysis uses the 5.08 ft MHHW datum as a downstream boundary condition. The current PWA analysis is consistent with Otay River FEMA study.

3.2.2.2 Surface Runoff Hydrology

In contrast to the tides which inundate the lower Otay River daily, watershed derived runoff to the Otay River and Nestor Creek is relatively sparse throughout the year. However, during extreme rainfall events, the runoff typically exceeds channel capacity and flooding occurs throughout the project site. Following a thorough review by PWA of available hydrologic data sources, it was determined that no compatible stream gage data was available within the Otay River watershed, nor had a comprehensive hydrologic analysis been previously completed. This was supported by a phone conversation with Joe Evelyn (Chief of Hydrology and Hydraulics Division, Army Corps of Engineers, Los Angeles District) who was reasonably certain that no such hydrologic analysis has ever been performed. Furthermore, several requests to FEMA to obtain the hydrology associated with the surrounding flood insurance studies provided no additional information as of the completion of this report.

In place of a comprehensive watershed derived hydrologic analysis or a complete statistical analysis of stream gage measurements, a simple equilateral triangular hydrograph (SCS method) was adopted. With the triangular hydrograph, storm duration was 24 hours, base flow was 10 cfs, and the peak discharge corresponded to the published FEMA 100-year stream flow. FEMA peak discharges were referenced from the most recent FEMA Flood Insurance Study[1] (FIS) for the reach of the lower Otay River through Planning Unit A (Table 3-2). A second triangular hydrograph was similarly developed for Nestor Creek. Nestor Creek and Otay River peak flows were modeled to occur simultaneously to simulate maximum flooding conditions on the site. The lower flow regime for the lower Otay River is significantly impacted by the upstream reservoir, which stores much of the low flows with no release. It does not impact the predicted major floods, as the available storage is small in comparison to the predicted flood volumes.

[1] FEMA Flood Insurance Study, January 19, 2001, San Diego County, Unincorporated Areas

Table 3-2. Summary of FEMA Published Peak Discharges for the Otay River

Return Period	Published FEMA Peak Discharge (cfs)	
	Otay River	Nestor Creek
10	1200	730
50	12000	990
100	22000	1135
500	50000	3630

3.3 USING DATA SOURCES TO DEVELOP INPUT MODEL PARAMETERS

Using the data sources described above, a model drainage network schematic was developed for the project site (Figure 3-3). The schematic included a delineation of the likely flow paths (channels, overbanks, ponds, levee overflows, etc.) and their flow relationship (inter-connection) to one another. In addition, the location of each cross-section was assigned to the network. This cross-sectional information was extracted and compiled into the MIKE-11 cross-section database, using the appropriate topographic surface as discussed in Section 3.2.1.

Following the development of a representative model schematic, channel roughness characteristics were assigned. Estimates of Manning's roughness coefficients (n) for the open channel portions were assigned based on field evaluations. Manning's *n* values for roughness varied according to in-channel or overbank positions and varied spatially across the project site according to existing or anticipated (for the alternatives) roughness conditions. Roughness designations for specific types of conditions (i.e. immediate overbank levee area, or channel bottom in mud) were held consistent for the alternatives. Roughness values for the mature marsh condition were used in modeling Alternatives C1 and C2. Manning's roughness values used in the numerical model are presented in Table 3-3. Modeled roughness values were consistent with the roughness coefficients applied in the FIS[1].

Table 3-3. Manning's Roughness Coefficients (*n*)

San Diego Bay	0.02
Otay Bridge	0.07
Otay Channel Bypass	0.06
Nestor Creek	0.06
Floodplain Areas	0.04

Boundary conditions were prescribed at three locations within the model drainage network representing tidal conditions in San Diego Bay (Section 3.2.2.1) and river discharges from Otay River and Nestor Creek (Section 3.2.2.2). As noted earlier, all other localized runoff was considered non-significant compared to the combined volume and discharge of water from the tides and river flows.

3.4 EXISTING CONDITIONS MODEL

An existing conditions model was developed for Planning Unit A of the lower Otay River project area between Palm Avenue to the south, Interstate 5 to the east, and the Western Salt Company salt pond levees and San Diego Bay to the north and west. The model includes 12 channels interconnected by 50 linking channels and 110 cross-sections. Figure 3-3 shows the location and extent of the channel network and cross-sections superimposed on a recent aerial photo. Two calculations were made using the existing conditions model: (1) an extreme flood event caused by 100-year river flows in Nestor Creek and the Otay River; and (2) a typical daily tidal cycle with no river discharge. The following two sections (3.4.1 and 3.4.2) describe the results of these analyses.

3.4.1 100-Year Flood Results

The extreme flood event simulation consists of 100-year flows occurring simultaneously for the Otay River and Nestor Creek with a typical daily tide cycle as a downstream boundary condition. The model was run for four days. Days 1 and 2 provided a spin-up time to achieve equilibrium tidal conditions throughout the model. The flood hydrographs were introduced on the third day, with the final day remaining to allow for complete draining of the system. Peak flows from Otay River and Nestor Creek were modeled to occur simultaneously with MHHW as shown in Figure 3-4.

Localized overbank flooding begins almost immediately with the onset of the flood event. As water levels continue to rise in the project site, flooding is further aggravated by the hydraulic constriction between the Pond 20A levee to the south and the salt works levees to the north. Relative to the hydraulic constriction caused by the Pond 20A levee (south) and the salt works levees (north), the railroad features (dyke and bridges) are not as significant as these other levees under the 100-yr flood condition for the existing topographic condition.

As shown in Figure 3-4, water levels continue to rise upstream of the constriction until overflow into the neighboring salt ponds begins. At flows of about 8000 CFS (approximately 25-year event) the salt works levees begin overtopping 4 to 5 hours after the initiation of the flood event (depending on the location and height of the levees). After about 10 hours into the flood event, the Pond 20A levees to the south are also overtopped. The maximum flood crest elevation (17.9 ft, NAVD88) at the confluence of Nestor Creek and the Otay River occurred roughly midway through the flood event at a time of 12 hours. From this point, water levels began to recede slowly draining the project site. Approximately 27 hours after the flooding began, and 3 hours after the river returned to baseflow conditions, the project site was completely drained and the diurnal tide cycle, which was the downstream boundary condition, predominated. Figure 3-4 provides a graphical representation of the flooding sequence. Modeling results indicate that Pond 20A is flooded mainly from Nestor Creek overflow. In Section 4 below, results for the alternatives are presented whereby Pond 20A is not flooded for alternatives C1, C2, Alt 3 and Alt 5. Potential flooding is also reduced along the Otay River (Figures 4-2 and 4-3).

Much of the 100-year flow volume for Otay River and Nestor Creek (combined) is not contained within the project site during a 100-year event. As flood levels overtop the neighboring salt works levees, over 60% of the event's flow volume is lost to the north. Table 3-4 and Figure 3-5 indicate volumetric losses and the locational sequence of overflowing based on the existing conditions model.

Table 3-4. Volumetric Overflow of Planning Unit A During 100-Year Flood Existing Conditions

Overflow Location	Volume (ac-ft)	Flooding Order
A	1321.0	1rst
B	0.0	no overtop
C	6188.3	4th
D	4563.9	2nd
E	302.3	5th
F	1504.9	3rd
Total Overflow	***13880***	
Total Model Inflow	***23413***	
% of Total Inflow Lost to Neighboring Salt Works	***59.3***	

PWA sought to verify existing conditions modeling results by comparing water surface elevations with published findings in the FEMA FIS. However, since the FEMA model was based upon a different modeling approach than the current PWA study (steady-state versus dynamic) and used different downstream boundary conditions, comparing results from the two studies is not considered meaningful. Section 4 below includes a discussion of potential scour conditions at the railroad bridge under existing and alternative conditions.

3.4.2 Typical Diurnal Tide Cycle Results

Results from the typical tidal analysis indicate that without modifications to the existing topography, the diurnal tide cycle will not exceed bankfull conditions. Furthermore, the maximum inland extent of the tides was predicted to be roughly 11,500 feet from the river mouth or approximately 1,500 feet upstream from the confluence of the Otay River and Nestor Creek. No direct verification was preformed for this calculation, although field observations and surveyed mud-line information (correlating to the MHW to MHHW range) supported modeling estimates. Figure 3-6 provides a graph of existing tidal water levels on the Otay River (just upstream of the railroad bridge) compared to downstream tides in San Diego Bay. This graph indicates some degree of tidal muting on the ebb tide. The role of tidal muting and its potential influence on the alternatives is discussed below in Section 4.7.

3.4.3 Consideration of Geomorphology & Habitat

It is useful to consider the existing conditions model in terms of geomorphology and habitat since this model provides the comparative basis for the alternatives analysis. Since both fluvial and tidal processes shape the existing Otay River channel, a long-term equilibrium channel geometry should exist whereby inputs/outputs of water and sediment are relatively balanced for fluvial and tidal sources. This geometry is best represented by historic conditions, when anthropogenic features did not strongly impact channel conditions. Such conditions, as illustrated in the 1859 map of Figure 21, indicate that a long-term geomorphically stable system would include a large deltaic marsh plain originating from the river source upstream. This marsh plain would include both freshwater and tidal wetlands, with the predominance of salt marsh increasing towards the Bay fringe.

Watershed alterations during the past century have significantly altered the hydrologic regime of the lower Otay River. The reservoir captures upstream sediment and reduces freshwater flows to the downstream channel reaches and the Bay. Concurrently, urbanization and other land use changes have affected the hydrology, sediment and water quality regime in the lower river. Urbanization around the project site perimeter is located in the floodplain, and is subject to damage during the design (100-year) storm.

The current lower Otay River configuration represents a significantly altered condition from the long-term geomorphic model. This is very evident in considering that areas inundated by tides under current conditions represent less than 1% of the historically inundated regions in the project area. Such reductions in tidal areas directly equate to reductions in habitat area and quality. Improving hydrologic and ecologic conditions at the existing Planning Unit A site is the goal of the subsequent alternatives analysis.

4. ALTERNATIVES ANALYSIS

4.1 DEVELOPING ALTERNATIVES

Four conceptual design alternatives for the lower Otay River project area were analyzed and compared to the baseline conditions model. The initial planning and development of the alternatives was conducted by FWS with review and suggestions provided by DU and PWA. FWS and DU provided PWA with general descriptions of the alternatives with conceptual site maps that included the principal restoration elements. These maps are shown in Appendix A. In general, the alternatives differ in: (1) the relative allocation of restored tidal or freshwater wetland habitats; (2) the alignment of channels; (3) the degree of earth moving and levee modification; and (4) project costs.

Based on the concepts shown in the alternative maps of Appendix A, PWA developed new surface topography (ArcGIS TIN) and representative channel cross sections to apply in the hydraulic modeling process. PWA also added a number of refinements in translating the alternative concepts shown in the Appendix A maps into more developed depictions of future site conditions. This process included refining channel geometry conditions and defining tidal slough channels and other wetland topographic elements. In refining these alternatives, PWA maintained consistency with the overall restoration goals of the project (Section 2.3). These are reiterated as follows:

- Restoration of functioning wetland habitat (tidal, freshwater, brackish) in areas that have become drier uplands
- Enhancement of existing wetland areas to increase circulation, improve habitat conditions
- Develop a sustainable, relatively self-maintaining wetland design
- Maintain or decrease current flood elevations to avoid exacerbating predicted flood conditions in the vicinity of the project
- Minimize environmental impacts and excavation and earth work costs associated with restoration
- Develop a restoration plan that is flexible enough to integrate other regional restoration efforts including the restoration of south San Diego Bay salt ponds.

The alternative concepts provided to PWA characterize the project site into three habitat regions: salt marsh, freshwater wetland, and restored uplands. These generic habitat types represent fundamentally different topographic, hydrologic, geomorphic, and ecologic conditions.

A restored salt marsh encompasses the full range of intertidal marsh habitats between mean lower low water (MLLW) and mean higher high water (MHHW). These include the low marsh region (dominated by intertidal mudflats (+3.5 ft MLLW and below) and cordgrass (Spartina foliosa) (generally +3.5 to +4.5 ft MLLW)); the middle and high marsh (dominated by perennial pickleweed (Salicornia virginica) above +4.5 ft MLLW); and a high marsh/fluvial transition zone including a diverse assemblage of other salt marsh plants. Most likely, channel geometry in this transitional zone is governed by tidal processes below MHHW and fluvial processes above (Mead et. al, 2000). In addition to the main Otay River and Nestor Creek channels, smaller tidal slough channels would be excavated throughout the proposed salt marsh plain area below the MLW level. The number and dimensions of these slough channels would be based on the sustainable area of tidal mud flats within the project site.

Freshwater wetland habitats also have a range of forms including: in-channel freshwater marshes; riparian woodland in the immediate channel bank and overbank floodplain zone; riparian scrub on the higher floodplain elevations; and a transitional zone to upland (non wetland) vegetation at higher elevations. Restored upland areas provide important buffering, foraging, and refuge functions to the neighboring wetland areas and also provide a useful depositional area for removed fill from potential site excavation.

Four alternatives are presented below. The first two involve different habitat configurations across the Planning Unit A site, while the third one focuses solely on channel improvements to the lower Otay River. The fourth presented alternative considers removal of a portion of the Pond 20A levee. The naming of these alternatives is adopted from FWS designations. Since there was originally a pool of several more alternatives, the alternatives that were selected for the modeling study have their original names below and do not follow an intuitive or sequential (A, B, C or 1, 2, 3) naming order.

4.2 ALTERNATIVE C (OPTION 1)

4.2.1 <u>Configuration</u>

Alternative C (Option 1) comprises widening the existing Otay River channel and significantly expanding both tidal and freshwater wetlands (Appendix A, Figure 4-1). To compensate for the excavation required to re-establish these wetlands, areas of restored upland are included to balance on-site cut and fill volumes. Thus, the design configuration of this alternative will minimize off-site earth disposal and its associated costs.

For Alternative C (Option 1), the basic alignment of the Otay River would remain unchanged, flowing generally northwestward to the edge of the existing salt works levee, then southwest, parallel to the levee, to the western edge of Pond 20A (Figure 4-1). The cross-sectional shape of the channel, however, would be significantly altered. The existing bankfull channel would be widened to approximately four times its current width. In the upper sections of the channel, fresh water wetlands would be re-established. A low-flow channel would be developed in this reach, with a meandering planform, that would slowly transition from fresh water wetland to salt water marsh and inter tidal mud flats. This re-established salt marsh area would be constructed with a similar widened channel configuration to the north along the salt works levee. The northern portion of the existing Pond 20A levee would also be removed and setback along the property line, thus creating additional tidal wetlands at the confluence of Nestor Creek. Soils excavated from the wetland areas of the site would be used to raise portions of the site previously identified as restored uplands. The volume of excavated soil in excess of that which can be accommodated on-site would be removed from the site, however for this alternative, off-site removal has been minimized.

4.2.2 Results

The total area of re-established tidal and freshwater wetlands associated with Alternative C (Option 1) is 78 acres, 61 of which would be salt marsh and 17 of which would be fresh water wetland. Under existing conditions, the only areas of sustained wetlands are within the channels themselves, amounting to less than 10 acres. Thus, Option 1 provides nearly a 1000% increase in wetland habitat area for Planning Unit A (Table 4-1).

Table 4-1. Changes in Wetland Area Associated with each Alternative

Wetland Habitat	Existing Conditions	Alternative C (Option 1)		Alternative C (Option 2)		Alternative 3		Alternative 5	
	Area (acres)	Area (acres)	% Increase	Area (acres)	% Increase	Area (acres)	% Increase	Area (acres)	% Increase
Fresh Water	5	17	340	17	340	5	0	N/A	N/A
Salt Marsh	3	61	2030	88	2930	3	0	N/A	N/A
Total	8	78	975	105	1310	8	0	N/A	N/A

Hydraulic results for Option 1 show that setting back the Pond 20A levee significantly increases conveyance capacity of the Otay River, reduces backwater effects extending upstream, and ultimately lowers the 100-year flood elevations by more than one foot. Figure 4-2 shows this reduction in upstream flood levels along the Otay River channel. Additionally, Figure 4-2 demonstrates the change in water surface slope, from relatively steep through the Pond 20A constriction under existing conditions, to generally flatter gradients when the Pond 20A levee is set back as part of the wetland restoration. Furthermore, because of this water level reduction, the upper portions of Pond 20A (south of the realigned levee) would not receive spill over from the Otay River under the modeled 100-year conditions. Significant overtopping of the salt works levees would still occur, however for a shorter period of time. Figure 4-3 shows water surface profiles for existing and alternative conditions along Nestor Creek, with lower water elevations under alternative scenarios. All of the alternatives show a reduced water level in Nestor Creek. The most significant decrease is shown with alternative C1 and results from removal of the levee along Pond 20. Water surface elevations for baseline and alternative conditions are compared for several locations below in Table 4-2. Comparison locations are referenced in Figure 4-4.

Table 4-2. Comparison of Peak Water Surface Elevations Under 100-Year Flow Conditions

	Location[1]	Existing Conditions	Alternative C (Option 1)	Alternative C (Option 2)	Alternative 3	Alternative 5
		Peak Water Surface Elevation (ft – NAVD88)				
Otay River	**A**. Approximately 1000 feet downstream from the I-5 Bridge	18.8	18.0	18.1	18.7	18.0
Otay River	**B**. Where the Otay River meets salt works levee system	18.2	16.8	16.7	18.1	16.6
Otay River	**C.** Confluence of Otay River and Nestor Creek	17.9	15.9	15.8	17.8	15.2
Otay River	**D.** Northwestern edge of Pond 20A	13.0	14.0	14.0	12.5	15.0
Nestor Creek	**E.** 2000 ft upstream of confluence with Otay River	18.2	16.9	17.8	18.1	17.5

1. See Figure 4-4 for comparison locations

Alternative C (Option 1) requires approximately 645,000 cu yd of soil materials to be excavated and disposed from the project site. All of the excavated soil can be accommodated on site into 60 acres of restored upland areas. Table 43 summarizes the excavation and disposal conditions for 3 of the 4 alternatives considered. Excavation volumes for Alternative 5 were not evaluated because a surface elevation model was unavailable (*personal communication with Steve Carroll at DU*).

Table 4-3. Excavation and Disposal Volumes Required for Wetland Restoration

Wetland Creation[1]	Alternative C (Option 1)	Alternative C (Option 2)	Alternative 3
	Volume (cu-yd)	Volume (cu-yd)	Volume (cu-yd)
Total Excavation	726,000	968,000	32,266
Total On-site Disposal[2]	726,000	322,666	0
Off-site Disposal	0	645,333	32,266

notes:

1. Excavation volumes calculated from GIS/CAD surface models discussed in Section 3.2.1.
2. On-site disposal will occur in areas designated as restored uplands.
3. Data for Alternative 5 are not available.

4.3 ALTERNATIVE C (OPTION 2)

4.3.1 Configuration

Alternative C (Option 2) is generally similar to Option 1 involving an expansion of tidal wetlands and setting back the Pond 20A levee (Appendix A, Figure 4-5). However, Option 2 does not include widening the upper portion of the Otay River channel. Instead, a freshwater wetland will be developed east of the northern extension of Saturn Drive (and pipeline easement). To the west of the Saturn Drive extension, complete re-establishment of tidal marsh is envisioned. This expanded tidal wetland zone replaces the restored uplands from Option 1. As a whole, the Option 2 design configuration restores more tidal salt marsh than Option 1, however costs would be significantly greater due to increased off-site soil disposal requirements.

4.3.2 Results

Restored tidal and freshwater wetland areas for Alternative C (Option 2) are presented above in Table 4-1. Option 2 (105 acres) provides 25% more restored habitat than Option 1 (78 acres). Whereas Option 1 provided a balance between required excavation and on-site disposal, the additional 27 acres of new marsh for Option 2 results in about 645,333 cu-yd of off-site disposal (Table 4-3). In terms of the hydraulic impacts, water level conditions for Option 2 are very similar to Option 1 (Table 4-2). Option 2's modified planform and expanded tidal wetland does not significantly alter estimated flood stages from Option 1 results because water levels upstream of Pond 20A are again governed by the backwater effects from the hydraulic constriction. For example, where the Otay River meets the salt works levee system, predicted water levels for Options 1 and 2 differ by less than two inches.

4.4 ALTERNATIVE 3 (HYDRAULIC IMPROVEMENTS TO EXISTING OTAY CHANNEL)

4.4.1 Configuration

Alternative 3 is qualitatively different from the previous two alternatives. Rather than focusing on habitat and wetlands restoration, this alternative reduces downstream channel constrictions along the Otay River by widening the channel at a location that is geomorphically suitable and where land is available for excavation. Thus, the focus of this alternative is solely flood reduction. Figure 4-6 illustrates the location where channel widening was simulated for the modeling analysis. PWA chose this location during a site visit due its channel/overbank form. A benched terrace exists along this reach, which could be modified to accommodate a wider channel. Because flood reduction was the sole focus of Alternative 3, many of the restoration goals outlined previously were not addressed. However this analysis does provide insight into the effect downstream channel capacity has on upstream flooding.

4.4.2 Results

The overall results for Alternative 3 indicate that channel improvements alone do not significantly reduce flood levels throughout the project site. Because the Pond 20A levees were not set back as in the previous alternatives, the hydraulic constriction remained and upstream flood levels were only somewhat reduced through widening the channel further downstream. More substantial improvements would be needed along the entire length of the Lower Otay River channel, especially adjacent to Pond 20A, to provide a more substantial reduction in upstream flooding. A study completed by Rick Engineering (1987) looked at substantially modifying and improving the flood capacity of the lower Otay River channel. The Rick Engineering report suggested lowering and hardening a large portion of the salt works levee system to allow controlled overflow into the salt ponds. Although Alternative 3 and the alternative developed by Rick Engineering address flood reduction, they do not provide the appreciable habitat benefits of the Alternative C options. Tables 4-1, 4-2, and 4-3 also include results for Alternative 3.

The hydraulic improvements of Alternative 3 were combined with the expanded wetland configurations of Alternative C (Options 1 and 2) to evaluate the combined effect of enlarging the downstream channel and expanding the upstream wetland configuration. Results from this analysis indicate that upstream flooding would not be significantly affected, however downstream of Pond 20A, peak flood levels would decrease by roughly 1-foot (Table 4-4, locations referenced in Figure 4-4).

Table 4-4. Alternative C: Comparison of Water Surface Elevations with/without Channel Improvements of Alternative 3

Location		Alternative C (Option 1)		Alternative C (Option 2)	
		w/out Alt 3	with Alt 3	w/out Alt 3	with Alt 3
		Peak Water Surface Elevation (ft – NAVD88)			
Otay River	**A**. Approximately 1000 feet downstream from the Interstate-5 Bridge	18.0	18.0	18.1	18.1
Otay River	**B**. Location where the Otay River meets the salt works levee system	16.8	16.7	16.7	16.7
Otay River	**C.** Confluence of Otay River and Nestor Creek	15.9	15.8	15.8	15.9
Otay River	**D.** Northwestern edge of Pond 20A	14.0	13.6	14.0	13.3
Nestor Creek	**E.** Approximately 2000 feet upstream from confluence with the Otay River	16.9	16.8	17.8	17.8

4.5 ALTERNATIVE 5 (POND 20A: LEVEE REMOVAL AND GRADING)

4.5.1 Configuration

The configuration of Alternative 5, shown in Figure 4-7, was developed by FWS/DU and described to PWA as follows. The portion of the Pond 20A levee that is located within the FWS Refuge Boundary is removed. The refuge land portion of Pond 20A is graded to achieve elevations that support intertidal habitat. Grading occurs to provide a marsh plain slope of approximately 10:1. The envisioned marsh plain consists of about 50% intertidal mud flat and 50% salt marsh habitat. Moving southward along the Pond 20A parcel, at the location/elevation that achieves MHHW, the slope gradient is changed to 2:1 towards the southern boundary of the Refuge parcel. Grading would daylight at the refuge boundary. Additionally, Alternative 5 includes a shallow pilot channel breach from Nestor Creek into Pond 20A. A surface model for this alternative was not available to PWA, all topographic changes and conditions associated with the alternative were modeled based upon received descriptions of the alternative. Representative cross sections, which portrayed the alternative concept, were developed and input to the model.

4.5.2 Results

Results for Alternative 5 indicate that levee removal and marsh plain grading in Pond 20A significantly increases flow capacity through Pond 20A and results in decreased upstream flooding. Maximum water levels decrease by: 0.8 ft near the I-5 Bridge; 2.7 ft at the Nestor Creek confluence; and 1.9 ft at the Otay River salt works levee. However, by removing the Pond 20A northern levee, the railroad bridge channel zone at the northwest corner of Pond 20A would now function as a natural constriction point for the 100-yr discharge. This process results in an estimated increase of surface water elevation by 2.2 ft near the railroad bridge. In this scenario, the bridge is exposed to higher discharge, pressure, and scour conditions. Under Alternative 5, additional bridge and channel modifications are recommended to increase flow capacity and channel/bridge structural integrity under the 100-yr event. It should be noted that the bikeway would be under water during the design (100-year) flood for both existing conditions and the alternatives discussed in this section.

4.6 SEDIMENT ENTRAIMENT AND POTENTIAL SCOUR EVALUATION

Hydraulic conditions and the potential for sediment entrainment and channel scour were evaluated at the railroad bridge location for existing and alternative scenarios. The following methods for computation of maximum potential local scour were used:

a) Laursen – (1960)
b) Laursen modified - (1960)
c) Liu - (1961)
d) Froehlich - (1987)

These equations are empirical and derived mostly with laboratory data. It is generally understood that scour estimates calculated using these equations tend to be greater than the scour observed in field conditions. The actual scour is affected by many variables including the degree of consolidation in channel bed sediments. Also, scour increases other channel hydraulic parameters such as cross sectional area, hydraulic radius, velocity and depth, creating a feedback which modifies flow parameters to reduce the scour potential.

Additionally, three structural factors were considered that could influence the local scour calculation at the railroad bridge.

1. The degree of channel contraction, measured by channel width and structural opening (width of the structure, abutments length or cross sectional area).
2. The degree of increase in flow resistance in the culvert/bridge crossing (obstructed area) relative the main channel. (Laursen 1960). In the case of higher resistance inside of the bridge, the potential scour can increase by 100% or more.
3. The ratio of obstructed flow area to adjacent channel area. (Froehlich). This method indicates the highest potential scour, given the significantly narrowed flow area at the railroad crossing.

The results from the scour analysis for the 100-yr flood event are summarized in Tables 4-5 and 4-6. Potential scour conditions for baseline and alternative conditions are compared for the 4 computational methods used in the analysis. These results should be considered as a basis for relative comparison rather than an assessment of absolute change, owing to the assumptions stated above. That being said, the percent changes for some alternatives exceed 20% increases from existing conditions and this is noteworthy. In the case of Alternative 5, increases in flow velocity, discharge and water level at the bridge crossing should be considered in any site restoration design or re-design of the existing trestle bridge.

Table 4-5. Comparison of Velocity Conditions at RR Bridge (100-yr flood conditions)

RR Bridge Velocity Evaluation (ft/s)	Existing	Alt C1	Alt C2	Alt 3	Alt 5
Velocity at RR Bridge	5.8	8.4	8.5	6.9	11.2
% change from existing conditions		+ 44.6%	+ 46.9%	+ 18.6%	+ 92.66%
Velocity upstream of RR Bridge	4.8	4.4	7.2	6.2	8.2
% change from existing conditions		-6.9%	+ 51.7%	+ 31.0%	+ 72.41%

Table 4-6. Comparison of Potential Scour at RR Bridge (100-yr flood conditions)

RR Bridge Scour Evaluation (ft)	Existing	Alt C1	Alt C2	Alt 3	Alt 5
Larsen 1960	5.1	7.3	5.2	4.9	5.1
Larsen 1960 (modified)	3.0	4.8	3.0	2.8	2.7
Liu 1961	10.0	11.9	11.6	10.7	12.8
Froehlich 1987	20.8	23.4	23.2	21.7	25.9
average	9.7	11.8	10.8	10.1	11.6
% change from existing conditions	-	+ 21.67%	+ 10.65%	+ 3.48%	+ 19.73%

4.7 TIDAL CONSIDERATIONS FOR ALTERNATIVES

The expected tidal functions of the four alternatives were compared to existing conditions in order to assess the feasibility of the proposed tidal restoration concepts. This initial assessment used the numerical model to simulate tidal hydrodynamics under restored conditions, as well as application of hydraulic geometry relations to predict the geomorphic response of lower Otay River.

4.7.1 Tidal Hydrodynamics Under Restored Conditions

Unlike the high-magnitude flood flows, the water level elevation of tidal inundation is not significantly affected by the hydraulic restrictions of the Otay River RR Bridge or its narrow channel between the salt works and Pond 20A levees. This is illustrated in Figure 4-8 which plots water surface elevations (just upstream of the RR bridge) under existing conditions and for each of the restoration alternatives. Figure 4-9 plots water surface elevations at the Nester Creek/Otay River confluence and shows a similar pattern for high water inundation reaching the project area.

These results show no significant muting for the flood tide water condition. However, low water drainage elevations are affected by the restoration alternatives during the ebb tide. This is presumably due to friction losses within the channels that are strongest during ebb flow when water depths decrease. Reduced low water drainage would not have a major effect on wetland establishment, and will improve as tidal scour deepens the main tidal channels (see discussion below). Alternatively, “starter channels” or other features could be included in the restoration design to accelerate development of an equilibrium main channel.

4.7.2 Geomorphic Adjustments to Lower Otay River

The morphology of the lower Otay River system will evolve after restoration due to an increase in tidal current velocities. Based on other restoration experience, we anticipate that increased tidal velocities will result in channel deepening (preferentially along the channel thalweg) until a new channel geometry occurs which is in equilibrium with the systems tidal prism. Numerical simulation of erosion and sediment transport is difficult due to the variability of soil properties and the complexity of the physical processes. Therefore, PWA applied hydraulic geometry relations to estimate an anticipated amount of channel down-cutting along the main channel following tidal restoration.

Empirical relationships between tidal prism and channel geometry have been developed for coastal salt marshes based on survey data collected in San Diego Bay and San Francisco Bay (PWA, 1995). Given the existing morphology of the lower Otay River, a modest amount of down-cutting is expected along the thalweg after tidal restoration. Based on hydraulic geometry relationships (see Figure 4-10), we estimate that the channel bed will eventually deepen about 3 ft after tidal restoration, depending on which restoration alternative is constructed (see Table 4-7). Estimates of the potential tidal prism were based on the footprint of the restored marsh area, and varied between 50 and 65 ac-ft for Alternatives C1 and C2 (see Figure 4-11).

Cross sectional area of Otay River downstream of the restored marsh area is expected to increase by a factor of 3 to 4. The channel will initially deepen in the short-term in response to the additional tidal prism, with channel widening continuing at a slower rate.

Table 4-7. Tidal Prism and Channel Depth Based on Hydraulic Geometry

Alternative	Tidal Prism (ac-ft)	Channel Depth (ft below MHHW)
Existing Conditions	6	5
Alternative C1	50*	7.5
Alternative C2	65*	8

* approximate potential tidal prism based on hydraulic geometry

5. SUMMARY AND RECOMENDATIONS

The primary objective of this hydraulic analysis was to evaluate how potential restoration concepts for the lower Otay River area (Planning Unit A) might impact flooding conditions on site and in surrounding areas to the project site. Results from the hydraulic modeling suggest that the considered restoration alternatives would not negatively impact flooding conditions, but would most likely reduce potential flooding hazards by reducing surface water elevations and durations (as indicated by the 100-yr design storm event). Modeling results indicated that increased channel capacity, either through levee setback or removal could provide moderate to significant additional benefits in flood reduction. As shown by alternatives C and 5, the set back or removal of the Pond 20A levee significantly reduced upstream flood levels. Analysis indicated that each of the alternatives increase flow velocities, water elevations, and scour potential at the railroad bridge crossing. Additional engineering studies and potential refinement of the railroad bridge channel/bridge crossing design is recommended as part of the on-going planning and restoration process. In addition to these primary conclusions, PWA refined project alternatives to maximize restored habitat areas while minimizing earth-moving costs.

While not modeled as part of this report, modifying or removing the Western Salt works levee system between the project site and the Bay is likely to significantly reduce the predicted flood levels at the project site and in upstream off-site areas. Additionally, eventually reconnecting the Planning Unit A and Western Salt Works areas would represent substantial progress towards restoring the historic geomorphic form and function of the lower Otay River floodplain and saltmarsh system, in which the channel mouth and adjacent wetlands function as a less constrained morphologic unit.

Building on the current study, PWA recommends moving into a more thorough restoration pre-design phase that will result in a well-defined project designed to preliminary standards that can be efficiently implemented. Although it is likely that additional environmental and technical aspects for a restoration program will need to be considered, in terms of hydrology/hydraulics, the following three issues are most compelling to support the restoration effort.

- Geomorphic analysis to develop a suitable channel size and network configuration. Channel density, depth, width, and sinuosity should be examined in terms of the expected long-term configuration. Additionally, this geomorphic analysis should be integrated into the design process in order to reduce the amount of earthwork required for restoration.
- Evaluation/refinement of bridge/channel crossing design based on hydraulic conditions of the alternatives.
- Integration of the current modeling analysis into the feasibility analysis of restoring the Salt Works areas north of Planning Unit A. Any hydrologic analysis of the potential salt pond restoration options should include the baseline modeling conditions developed for the current lower Otay River area.

6. LIST OF PREPARERS

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Philip Williams and Associates, Ltd. (PWA), 1995. Design Guidelines for Tidal Channels in Coastal Wetlands. Prepared for the U.S. Army Corps of Engineers, Waterways Experiment Station. January 1995.

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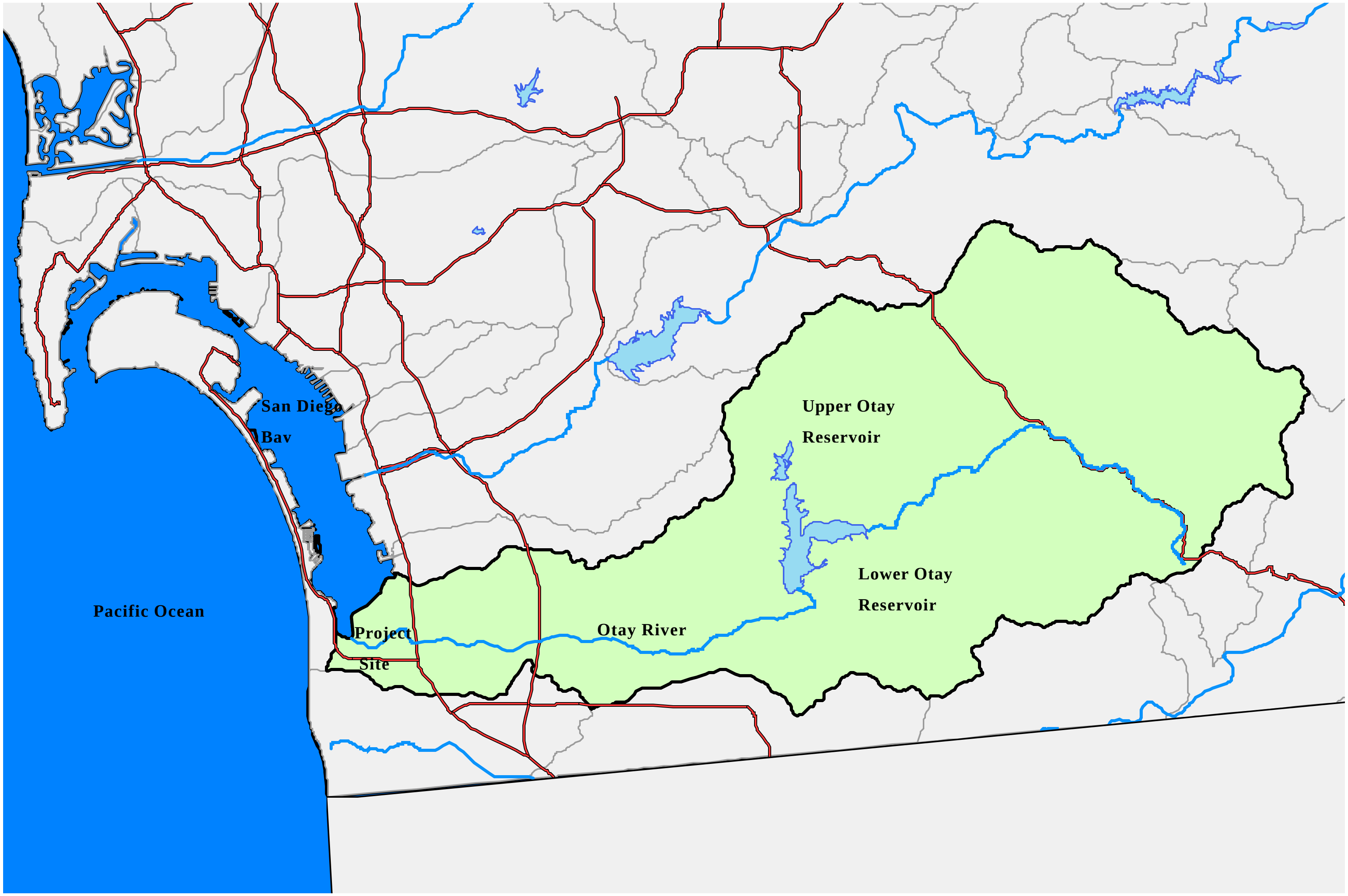
8. FIGURES

Appendix A

Planning Unit A:
Conceptual Restoration Alternatives (FWS)



f i g u r e 2-1

General Vicinity and Otay River Watershed Map
Lower Otay River Salt Marsh and Wetland Restoration

PWA

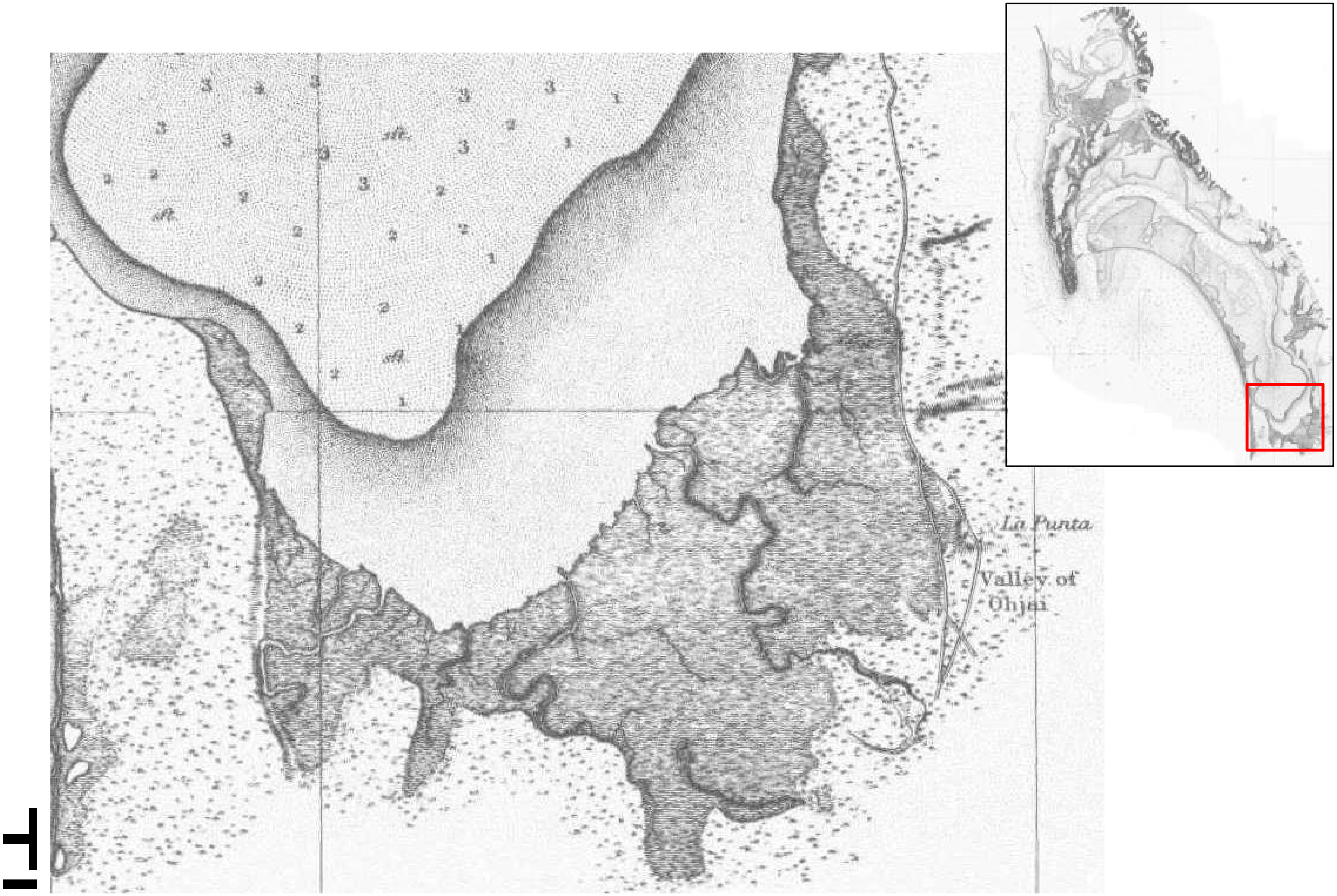


figure 2-2

Historic Site Conditions

Lower Otay River Salt Marsh and Wetland Restoration

Source: Survey of the Coast of the United States, Coastal Survey Office, 1859.

PWA

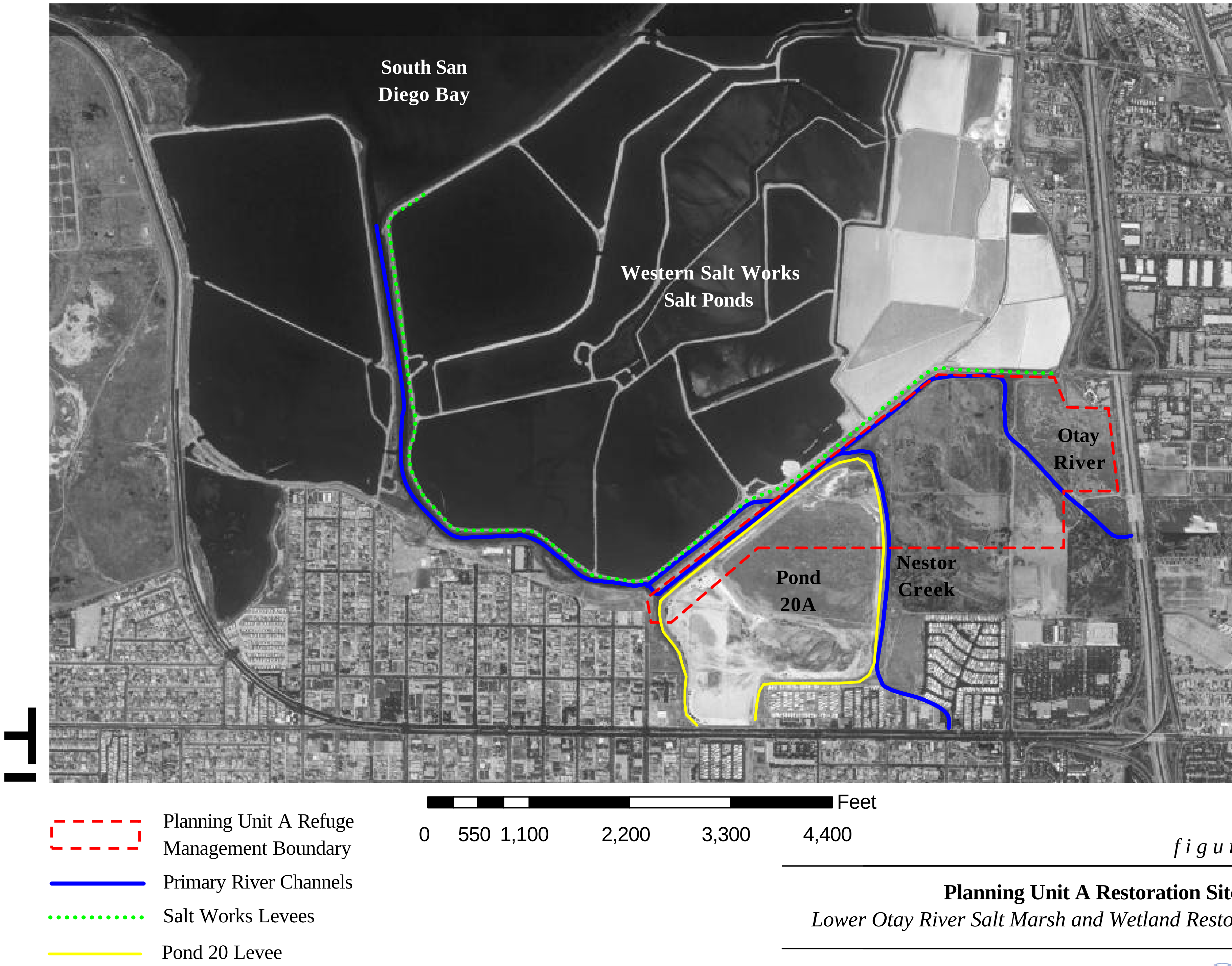
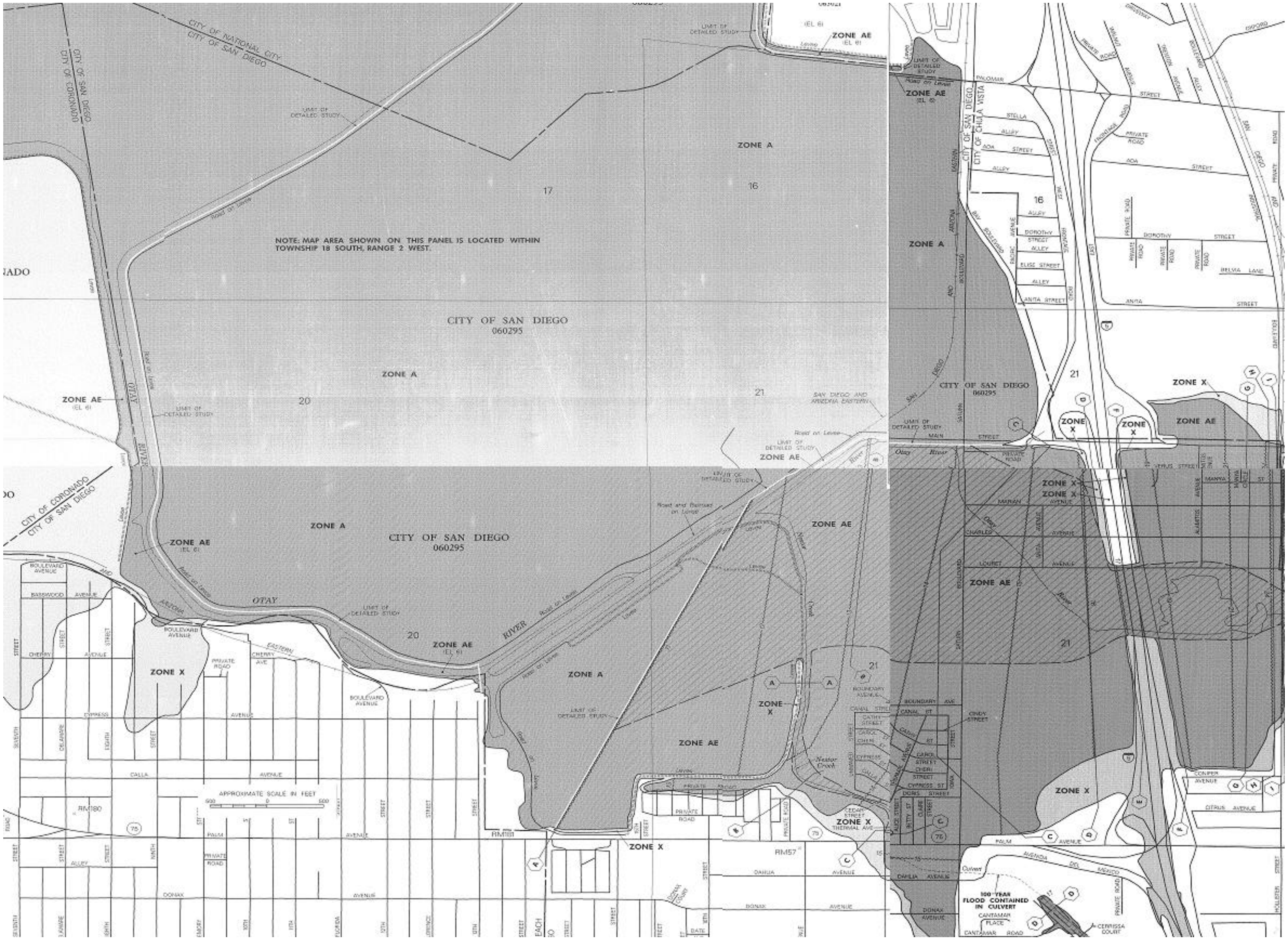


figure 2-3

Planning Unit A Restoration Site Map

Lower Otay River Salt Marsh and Wetland Restoration

PWA



f i g u r e 2-5

FEMA FIS Flood Map

Lower Otay River Salt Marsh and Wetland Restoration

PWA

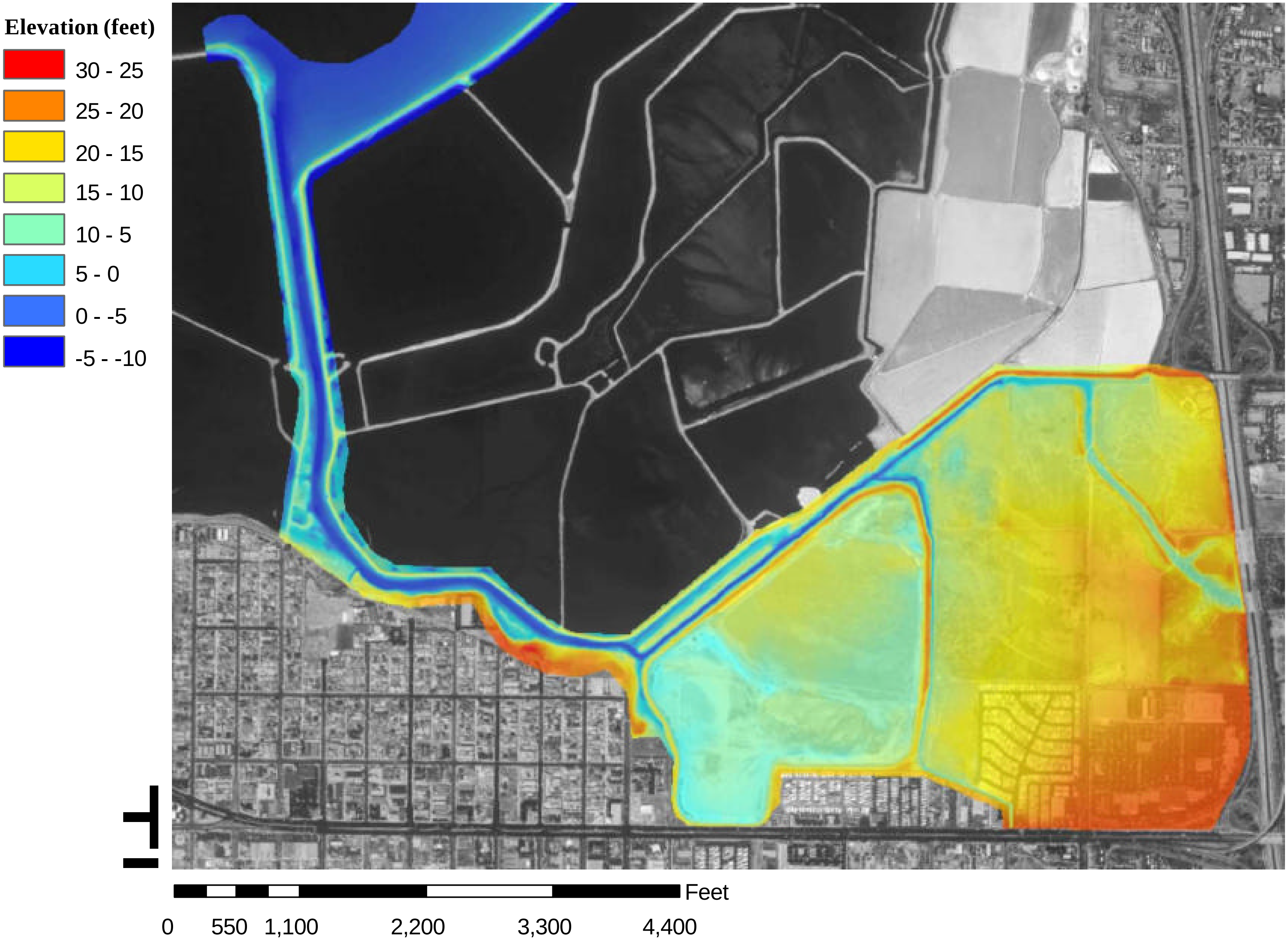


figure 2-4

Topographic Map of Project Site

Lower Otay River Salt Marsh and Wetland Restoration

Note: All Elevations are in the NAVD 88 (feet) Vertical Datum

Otay River – looking southwest between Pond 20 (near) and Salt Works Levee (far)

Otay River – looking southeast from Pond 20A (site of proposed marsh restoration)

f i g u r e 2-6

Planning Unit A Site Characteristics
Lower Otay River Salt Marsh and Wetland Restoration

PWA

Otay River RR Bridge downstream of Pond 20A

figure 2-7

Planning Unit A Site Characteristics – RR Bridge
Lower Otay River Salt Marsh and Wetland Restoration

PWA

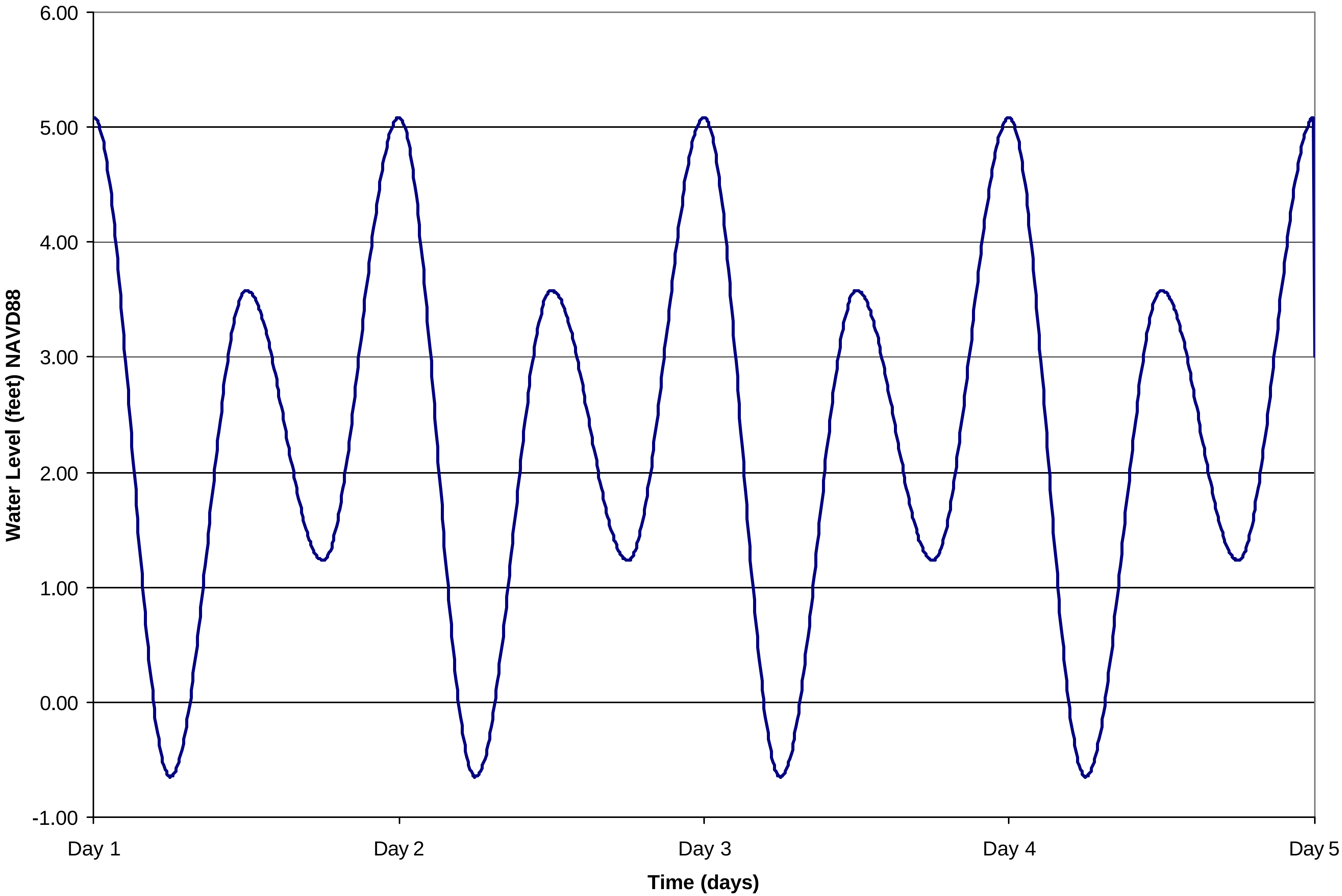


figure 3-1

Synthesized Diurnal Tide Cycle for San Diego Bay

Lower Otay River Salt Marsh and Wetland Restoration

PWA

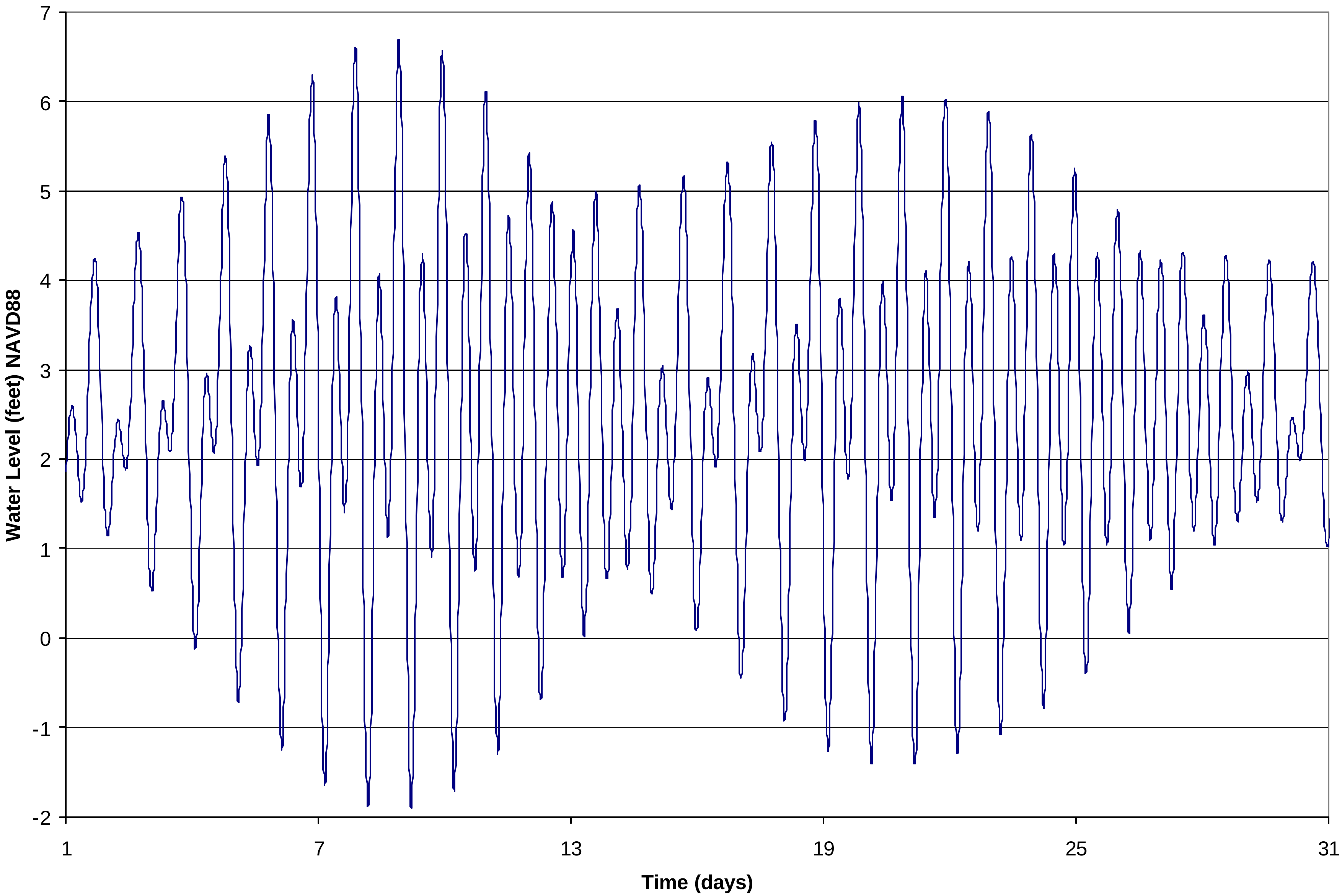


figure 3-2

Representative Spring-Neap Tide Cycle for San Diego Bay

Lower Otay River Salt Marsh and Wetland Restoration

PWA

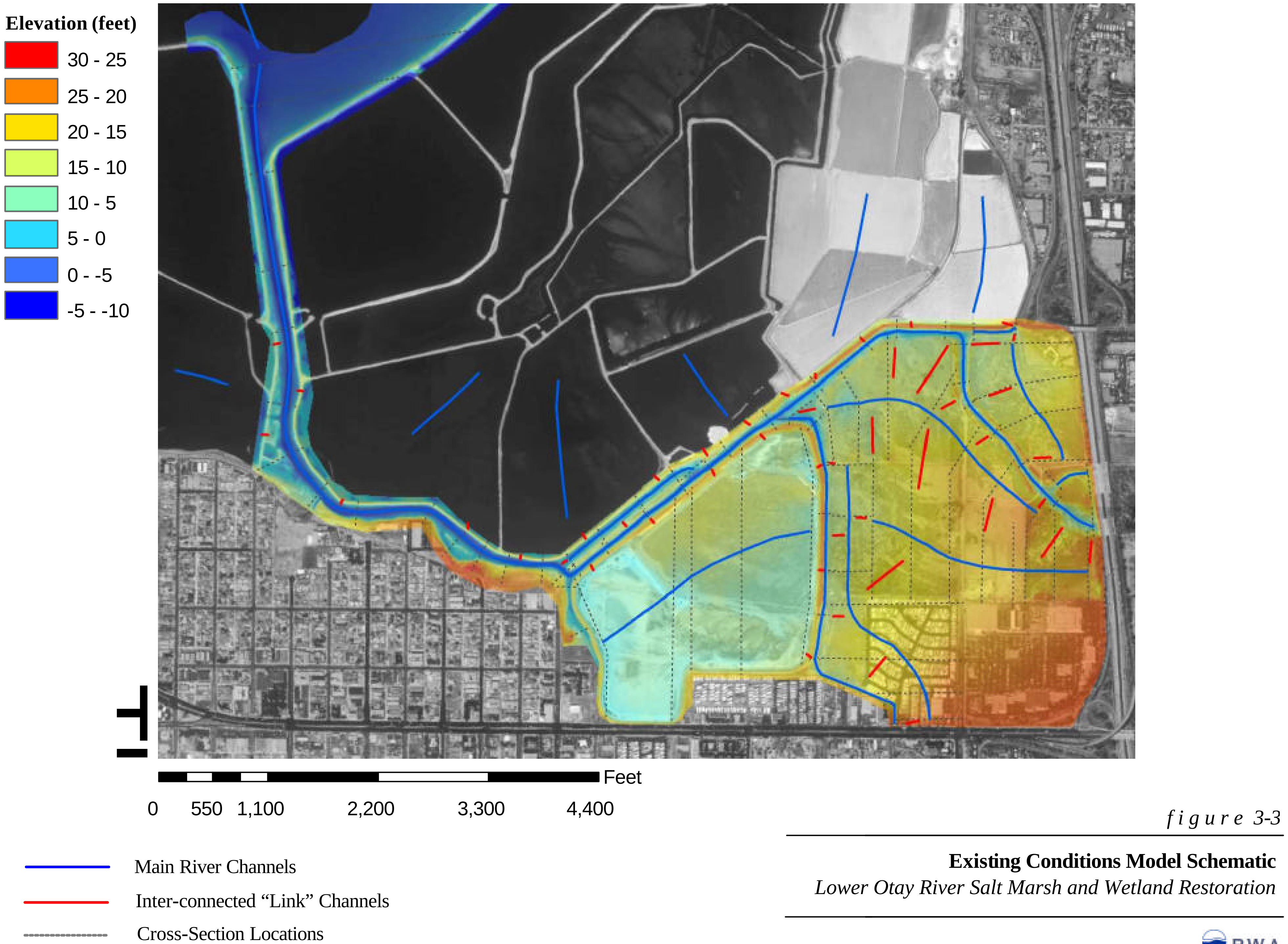


figure 3-3

Existing Conditions Model Schematic

Lower Otay River Salt Marsh and Wetland Restoration

PWA

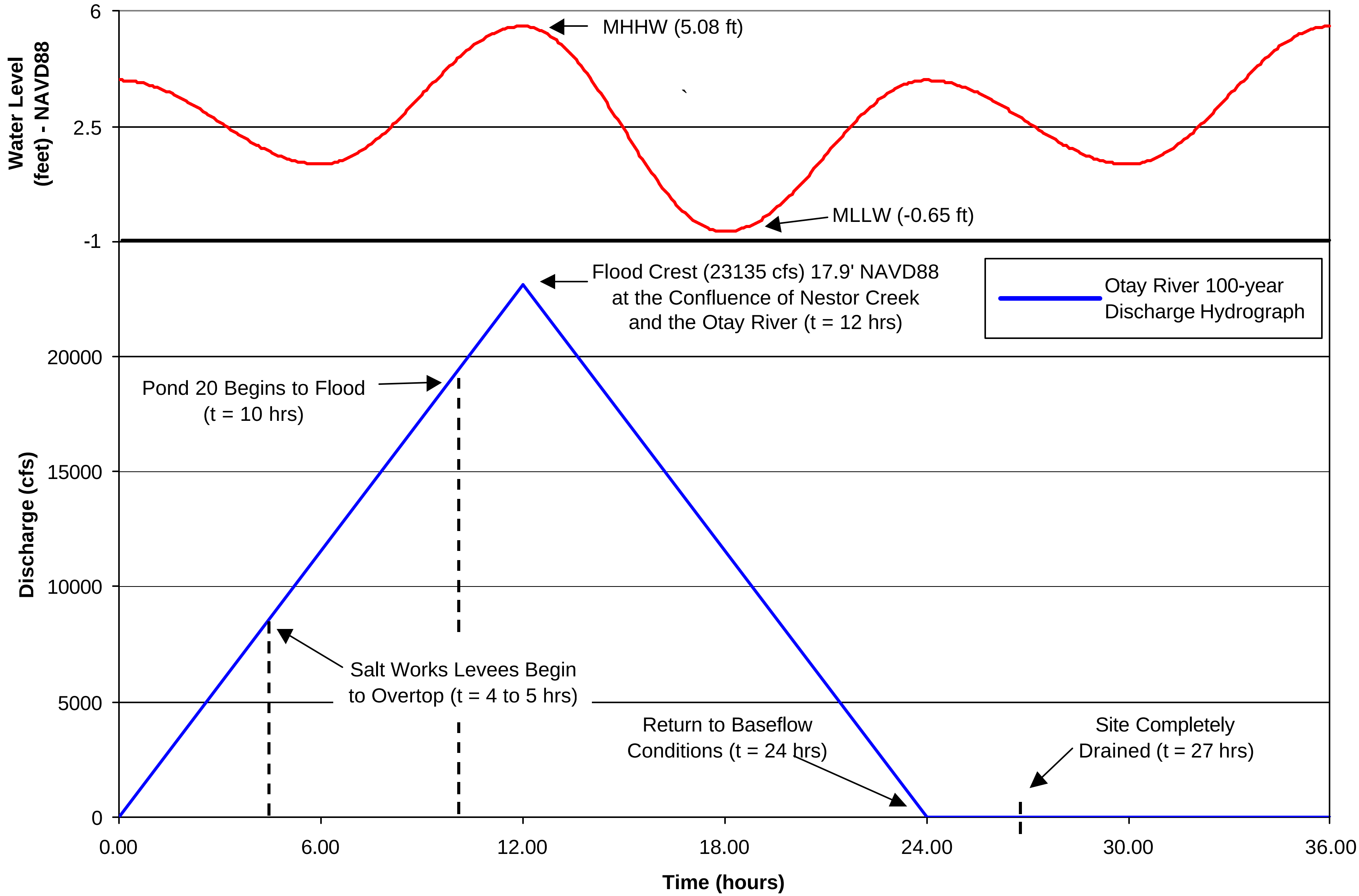
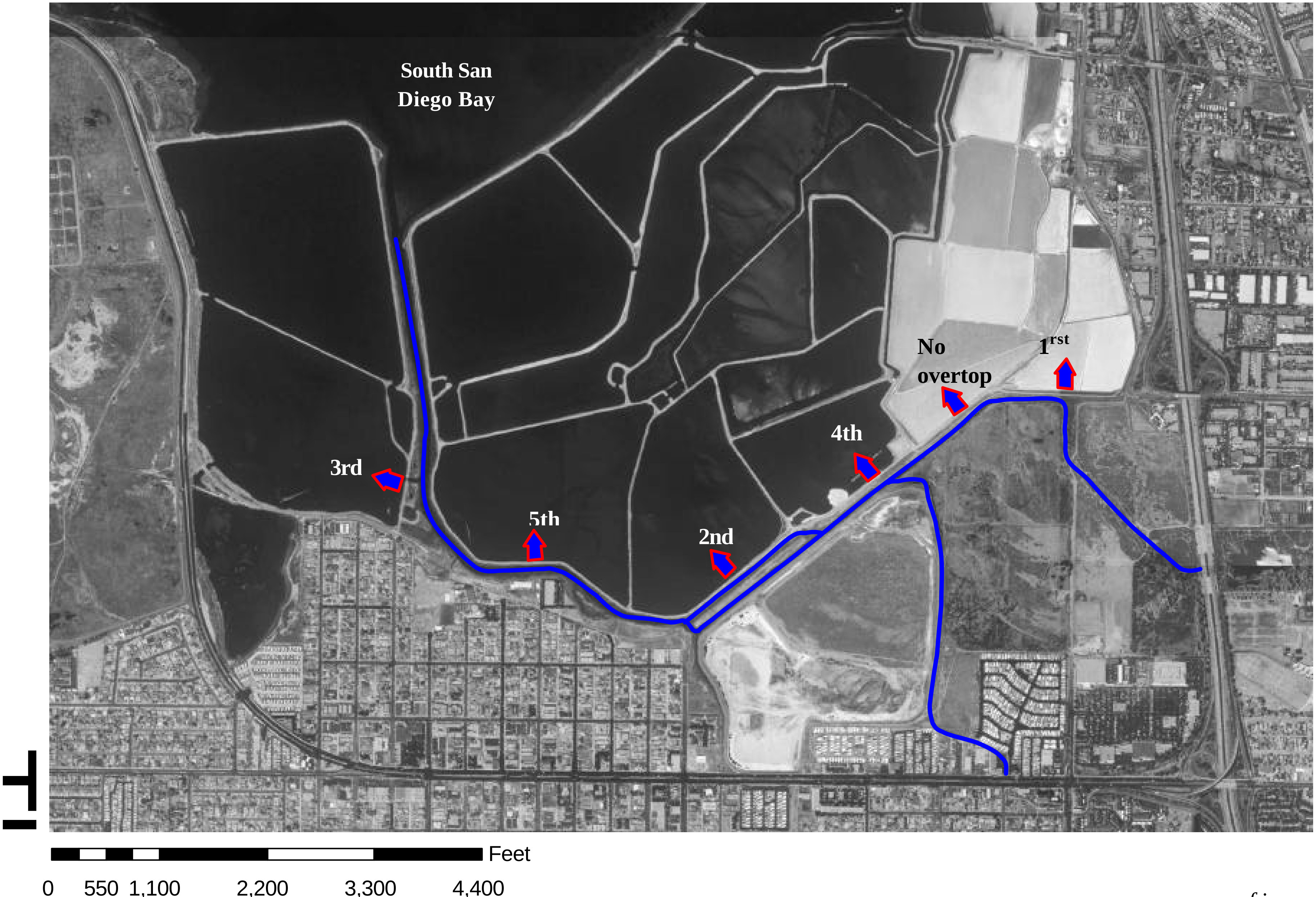


figure 3-4

Graphical Representation of the 100-Year Flooding Sequence on Planning Unit A

Lower Otay River Salt Marsh and Wetland Restoration

PWA

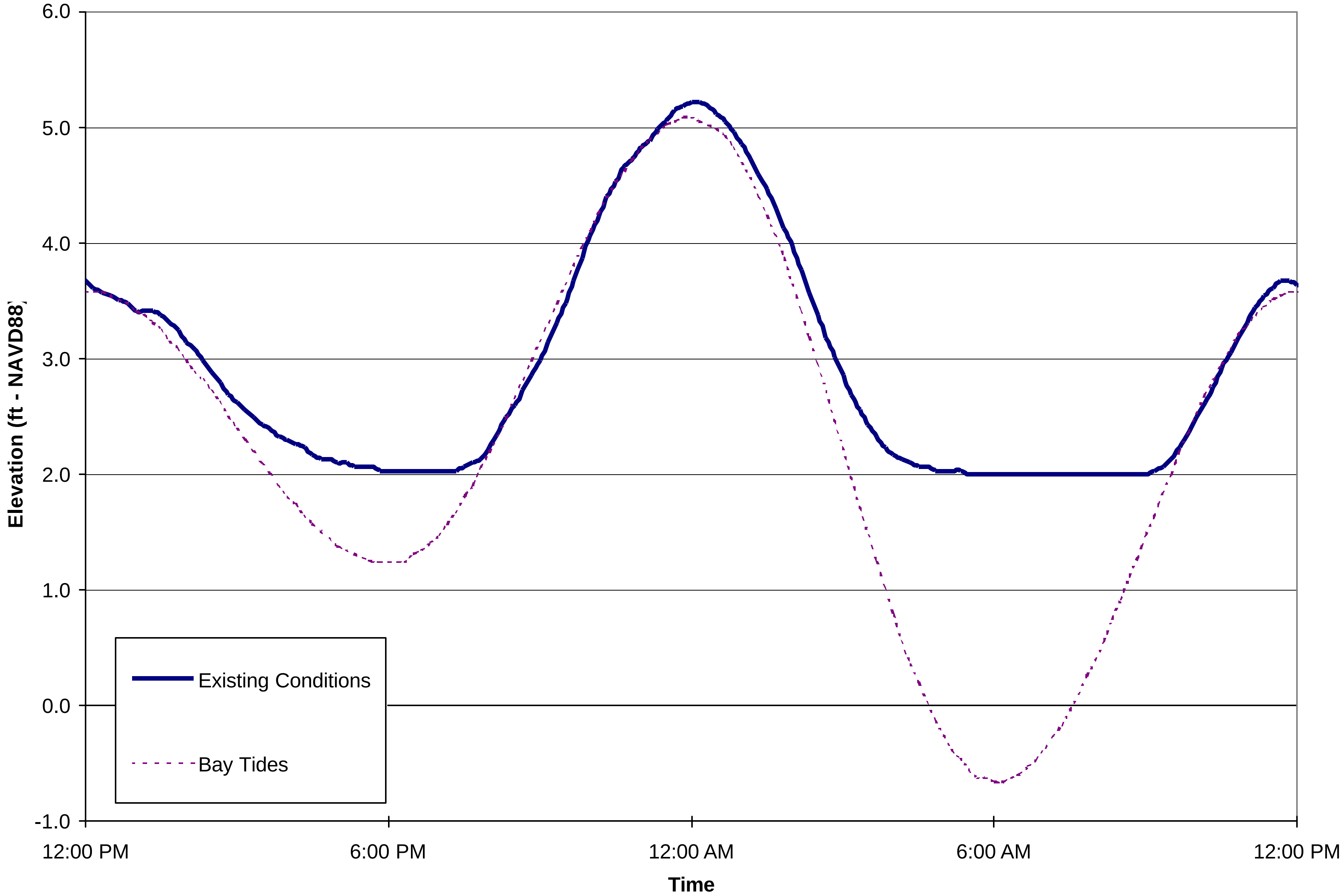


f i g u r e 3-5

Flooding Sequence for Table 3-4 (Existing Conditions)

Lower Otay River Salt Marsh and Wetland Restoration

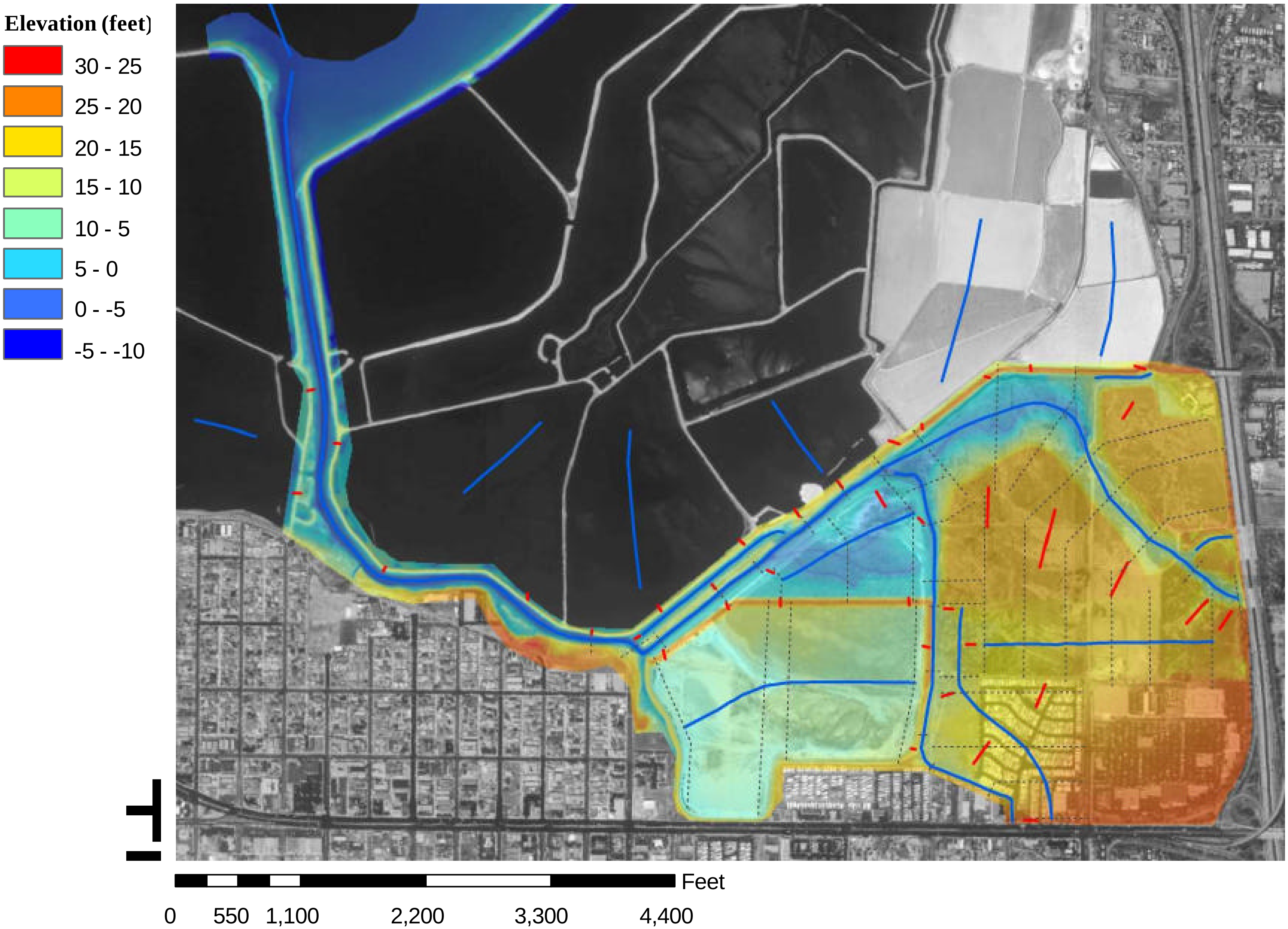
PWA



f i g u r e 3-6

Water Level Upstream of RR Bridge (Existing Conditions)
Lower Otay River Salt Marsh and Wetland Restoration

PWA



Main River Channels

Inter-connected "Link" Channels

Cross-Section Locations

figure 4-1

Alternative C (Option 1) Model Configuration

Lower Otay River Salt Marsh and Wetland Restoration

PWA

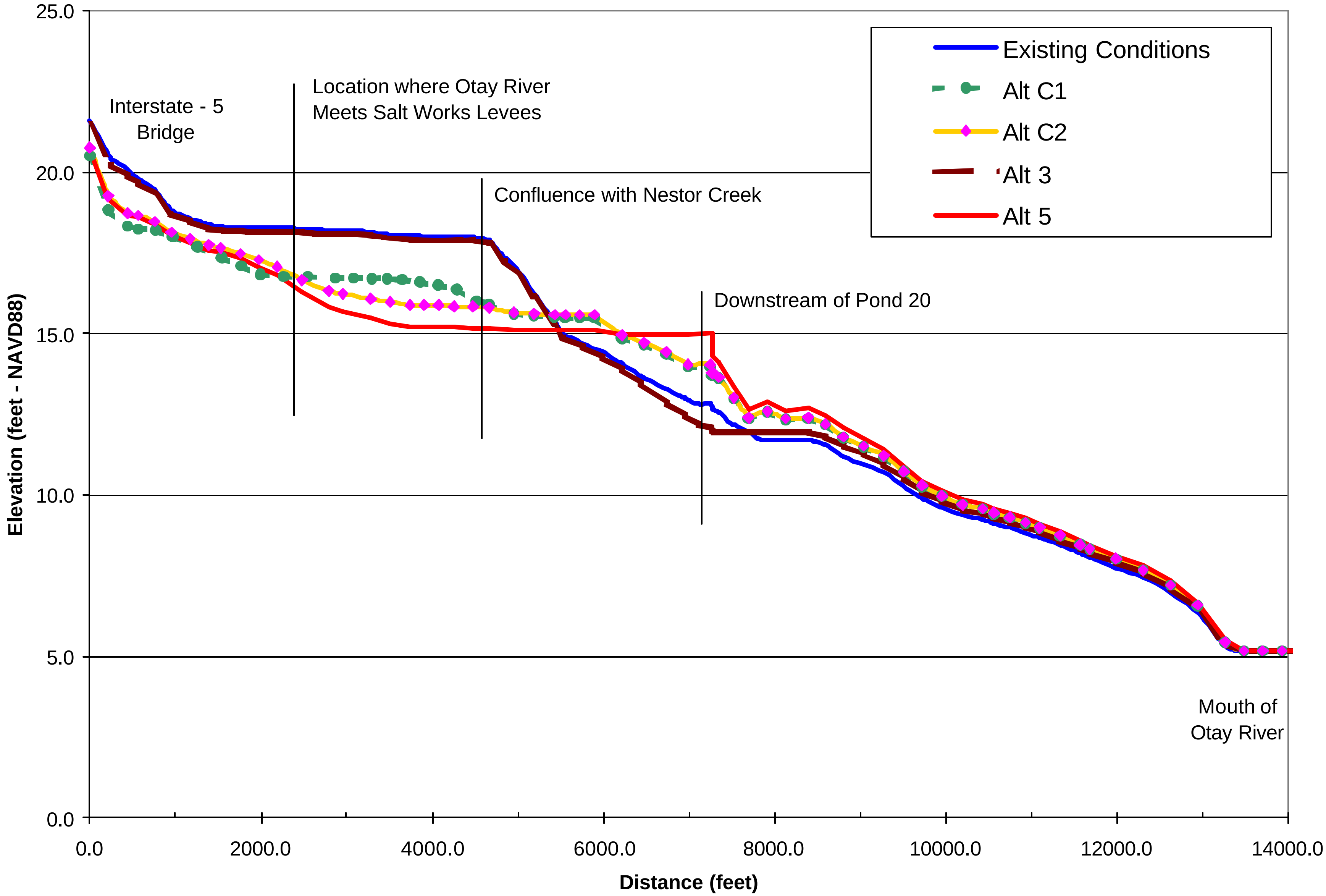
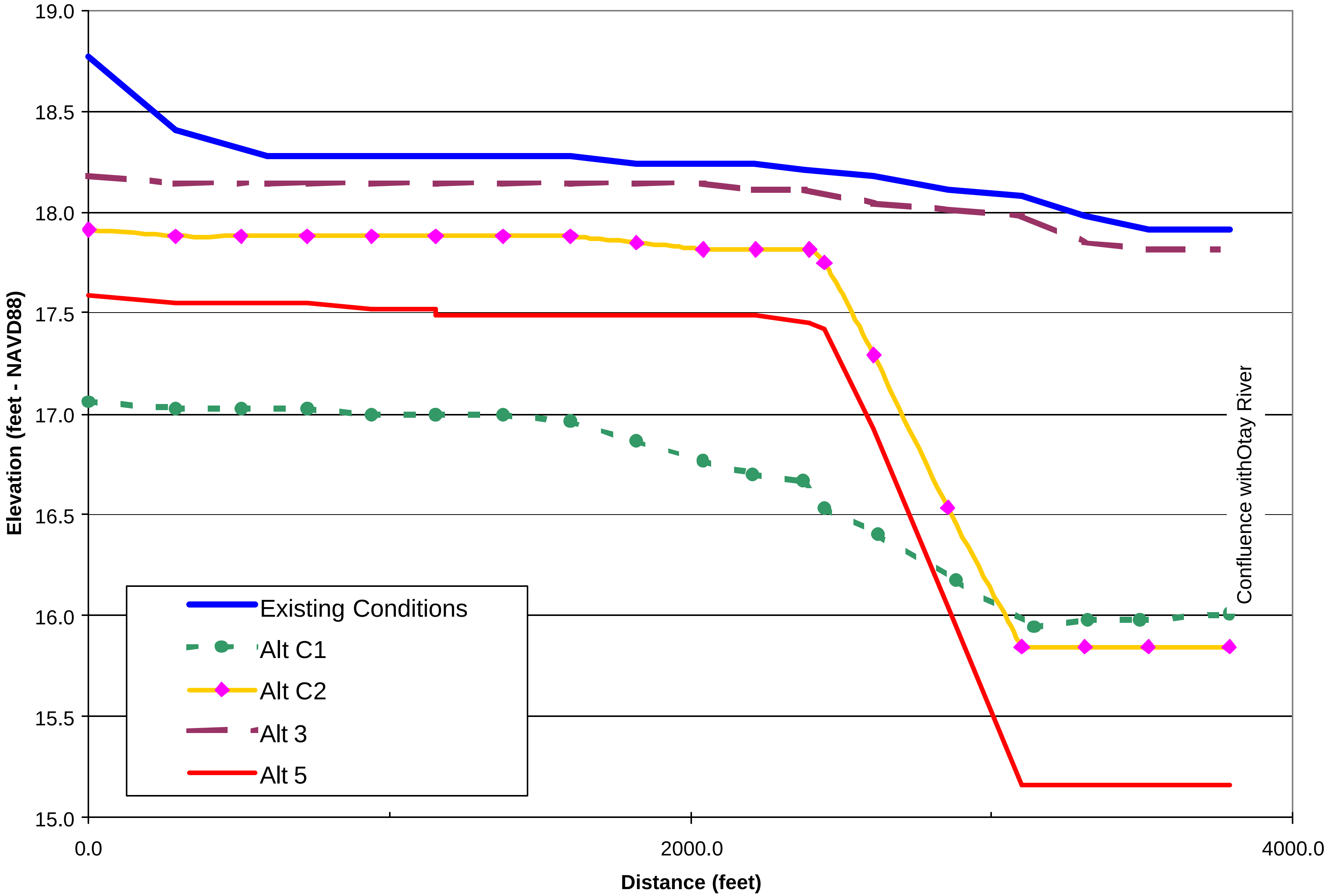


figure 4-2

Water Surface Profiles of Lower Otay River for Existing Conditions and Alternatives

Lower Otay River Salt Marsh and Wetland Restoration

PWA



f i g u r e 4-3

Water Surface Profiles of Nestor Creek for Existing Conditions and Alternatives
Lower Otay River Salt Marsh and Wetland Restoration

PWA

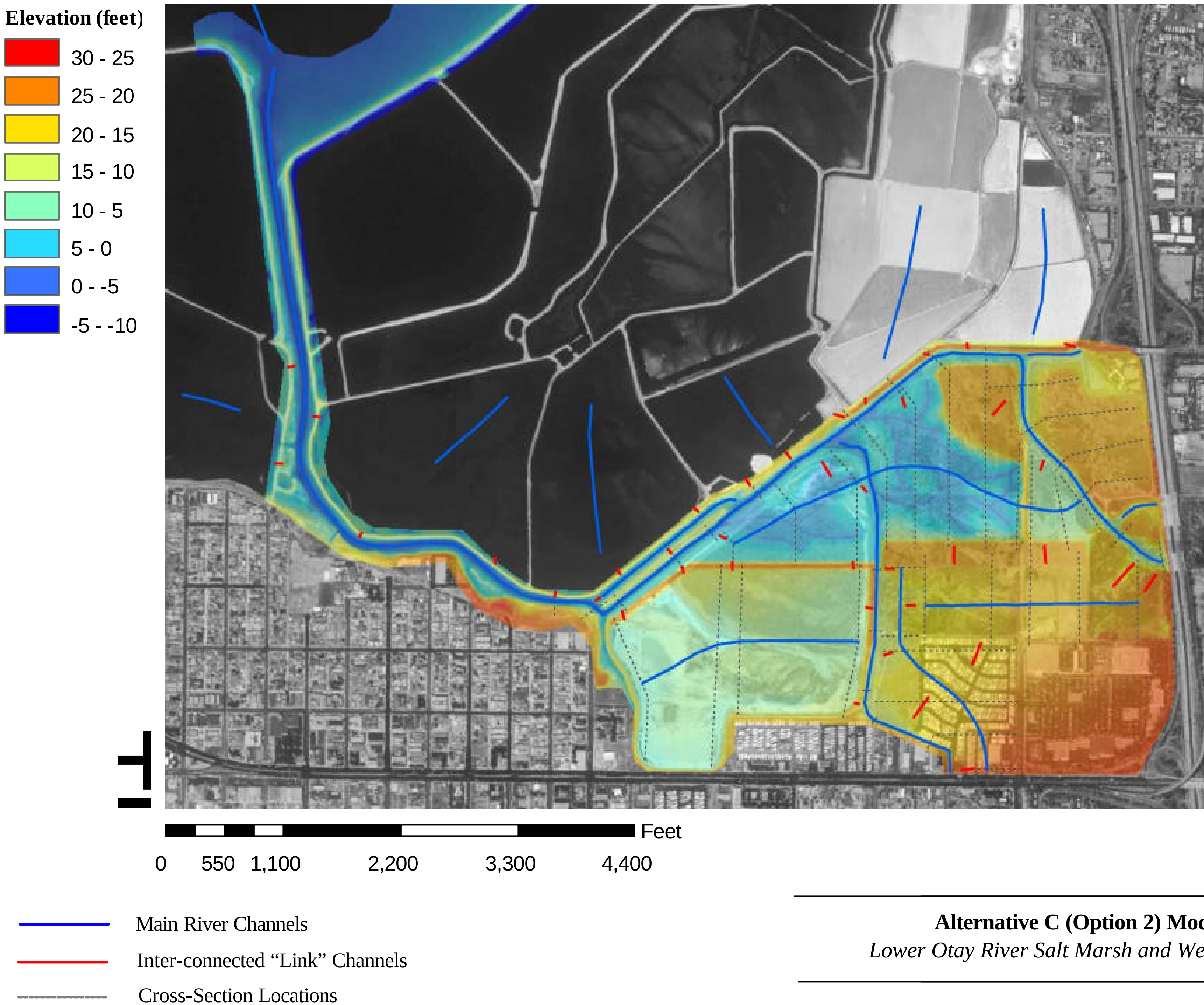


figure 4-5

Alternative C (Option 2) Model Configuration

Lower Otay River Salt Marsh and Wetland Restoration

PWA

figure 4-4

Reference Locations for Tables 4-2 and 4-4 Comparing 100-yr Water Surface Elevations

Lower Otay River Salt Marsh and Wetland Restoration

PWA

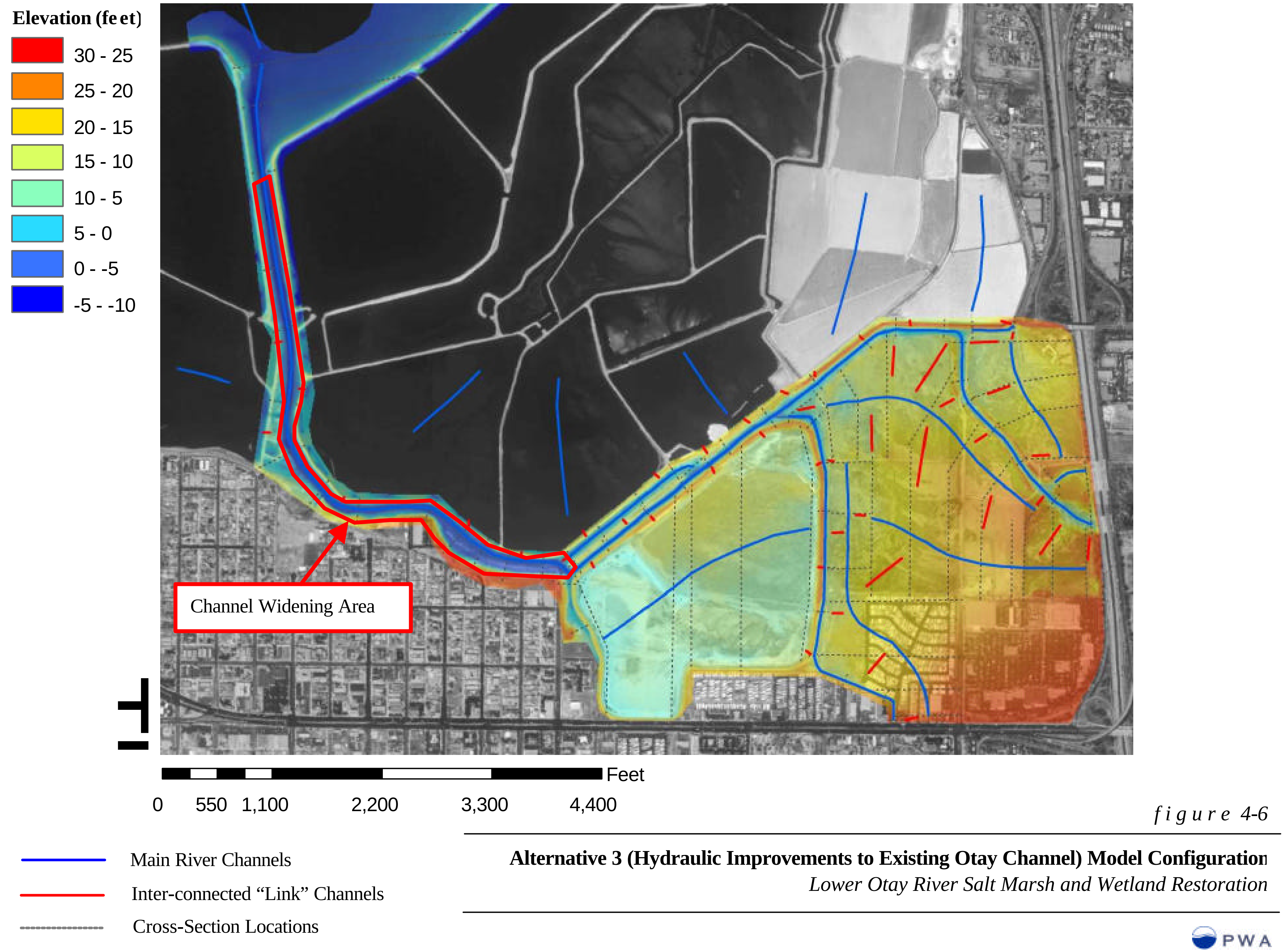
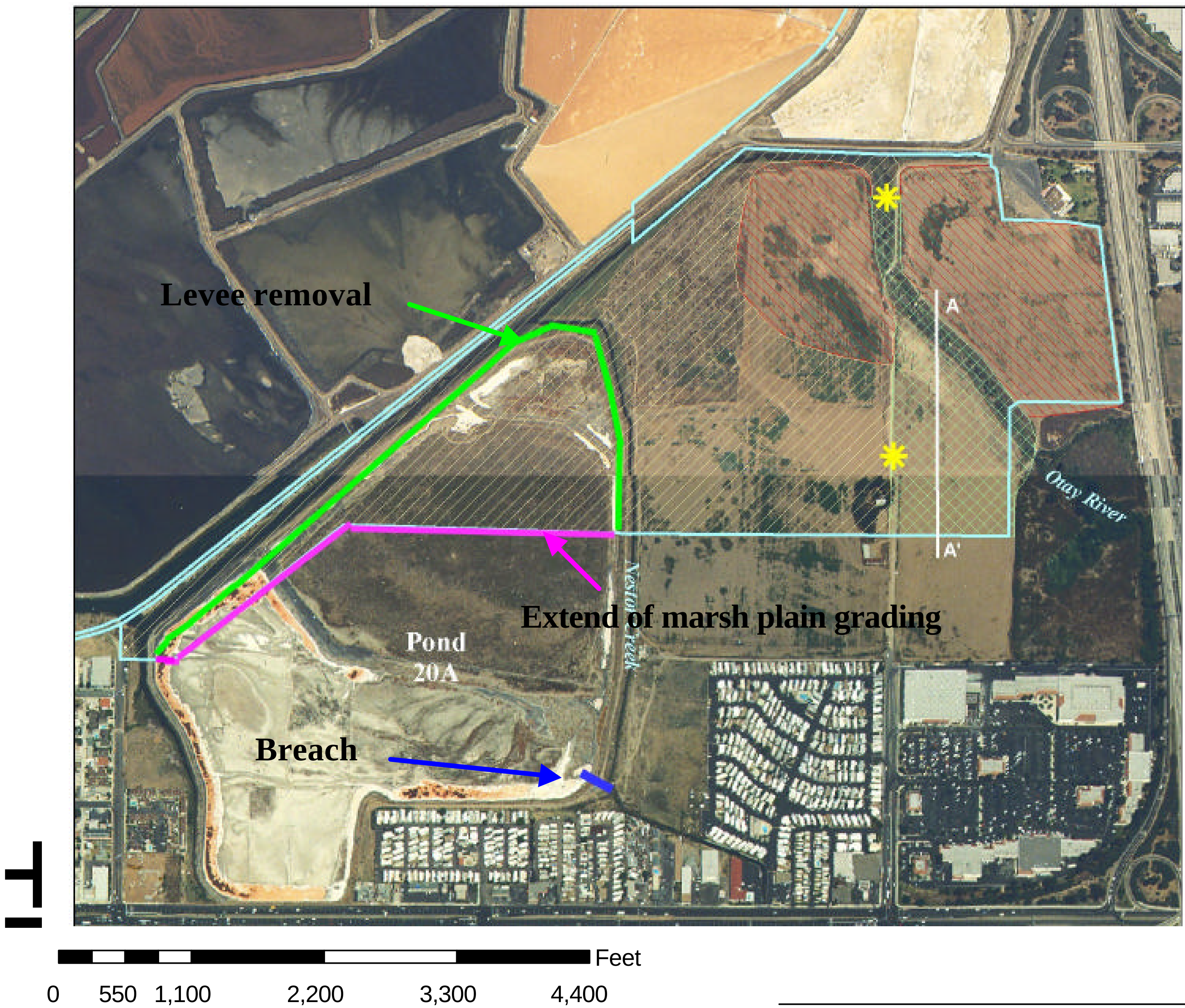


figure 4-6

Alternative 3 (Hydraulic Improvements to Existing Otay Channel) Model Configuration

Lower Otay River Salt Marsh and Wetland Restoration

PWA



Main River Channels

Inter-connected "Link" Channels

Cross-Section Locations

figure 4-7

Alternative 5 (Pond 20: Levee Removal and Grading)

Lower Otay River Salt Marsh and Wetland Restoration

PWA

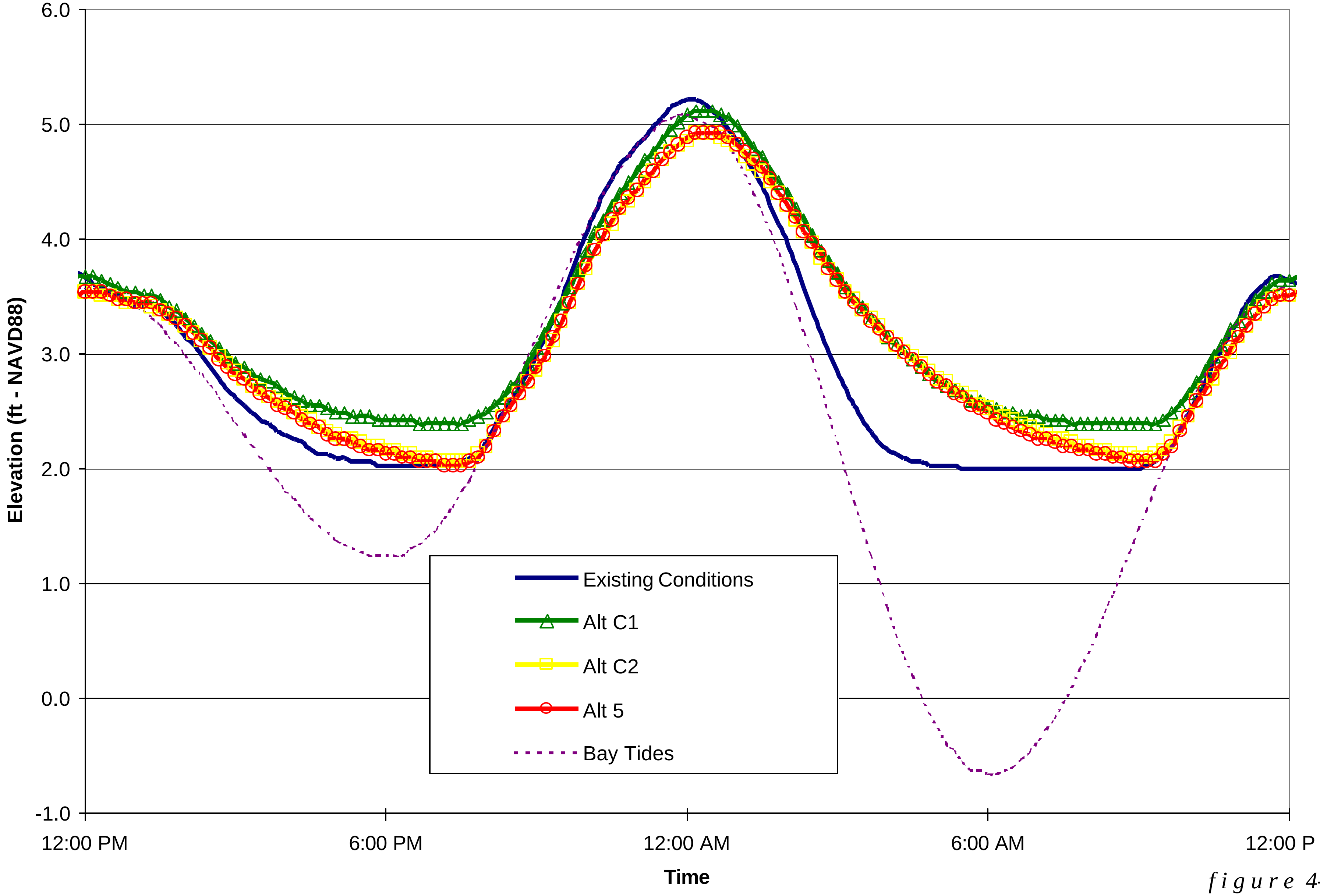


figure 4-8

Simulated Water Levels Upstream of RR Bridge

Lower Otay River Salt Marsh and Wetland Restoration

PWA

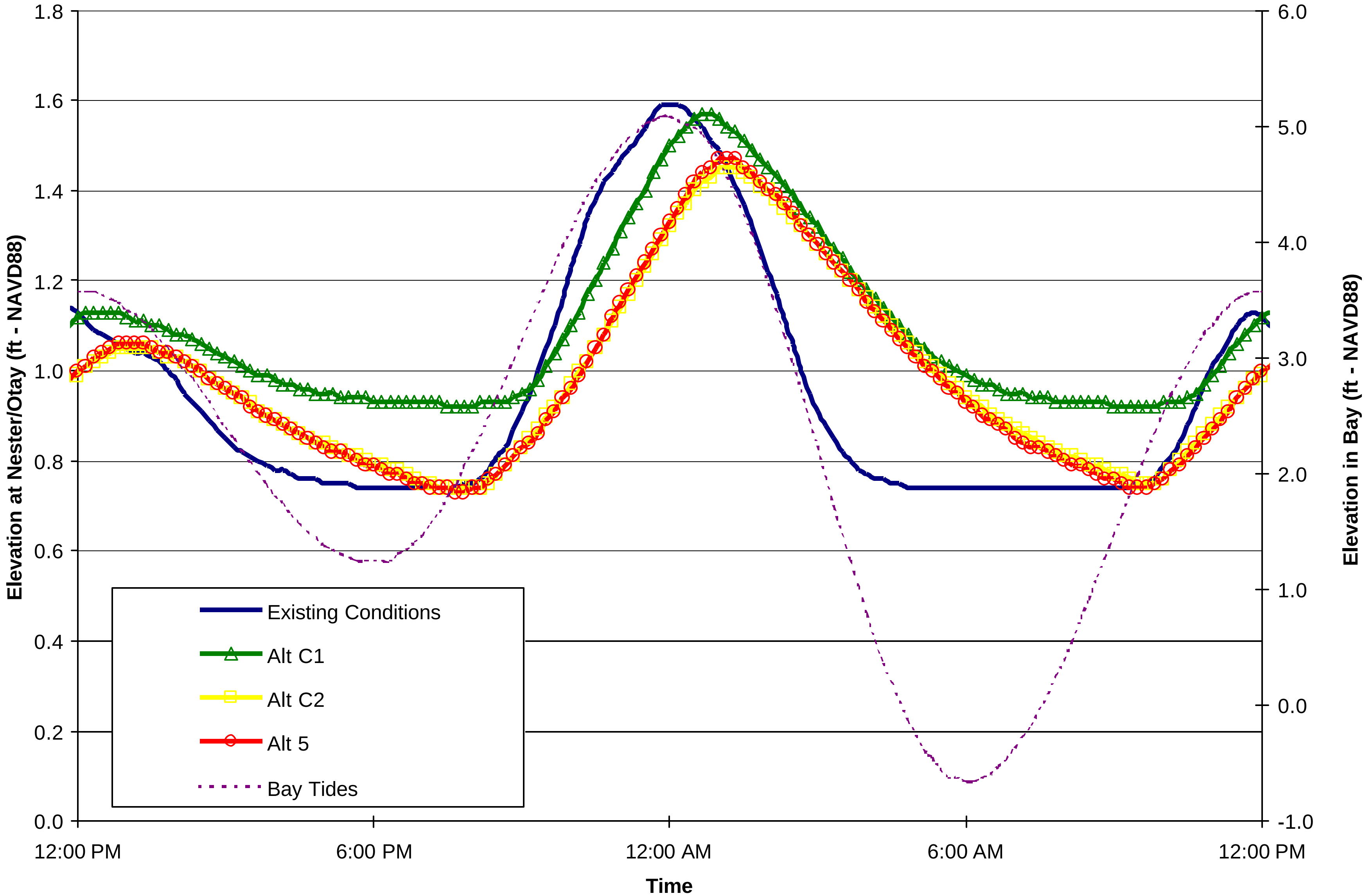


figure 4-9

Simulated Water Levels at Nester/Otay Confluence

Lower Otay River Salt Marsh and Wetland Restoration

Note that different scales are used to plot the tides in South San Diego Bay and at the confluence of Otay and Nester Creeks.

PWA

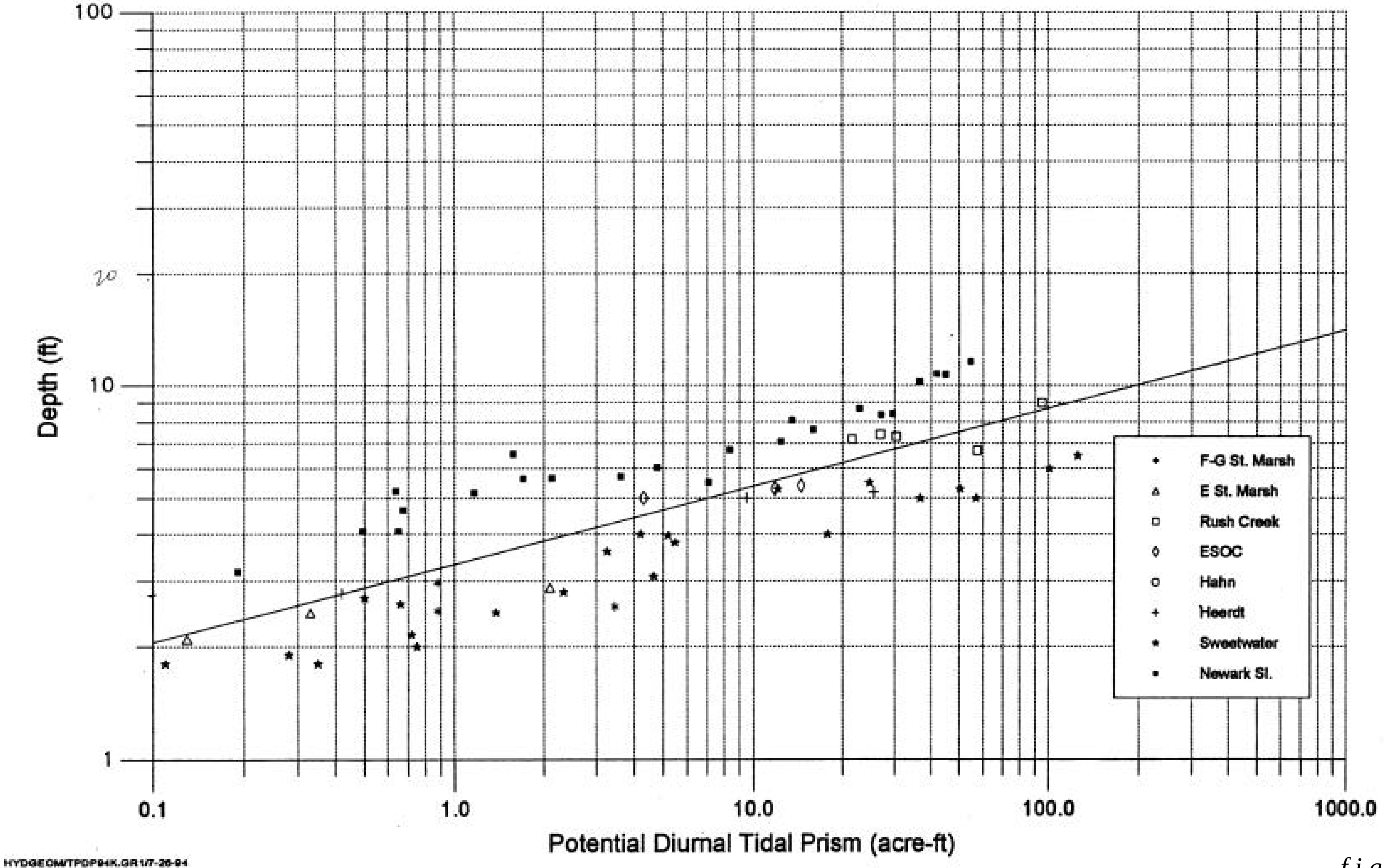


figure 4-10

Hydraulic Geometry for California Salt Marshes – Depth and Tidal Prism

Lower Otay River Salt Marsh and Wetland Restoration

Source: Philip Williams and Associates, Design Guidelines for Tidal Channels in Coastal Wetlands, Prepared for the U.S. Army Corps of Engineers, Waterways Experiment Station, January 1995.

PWA

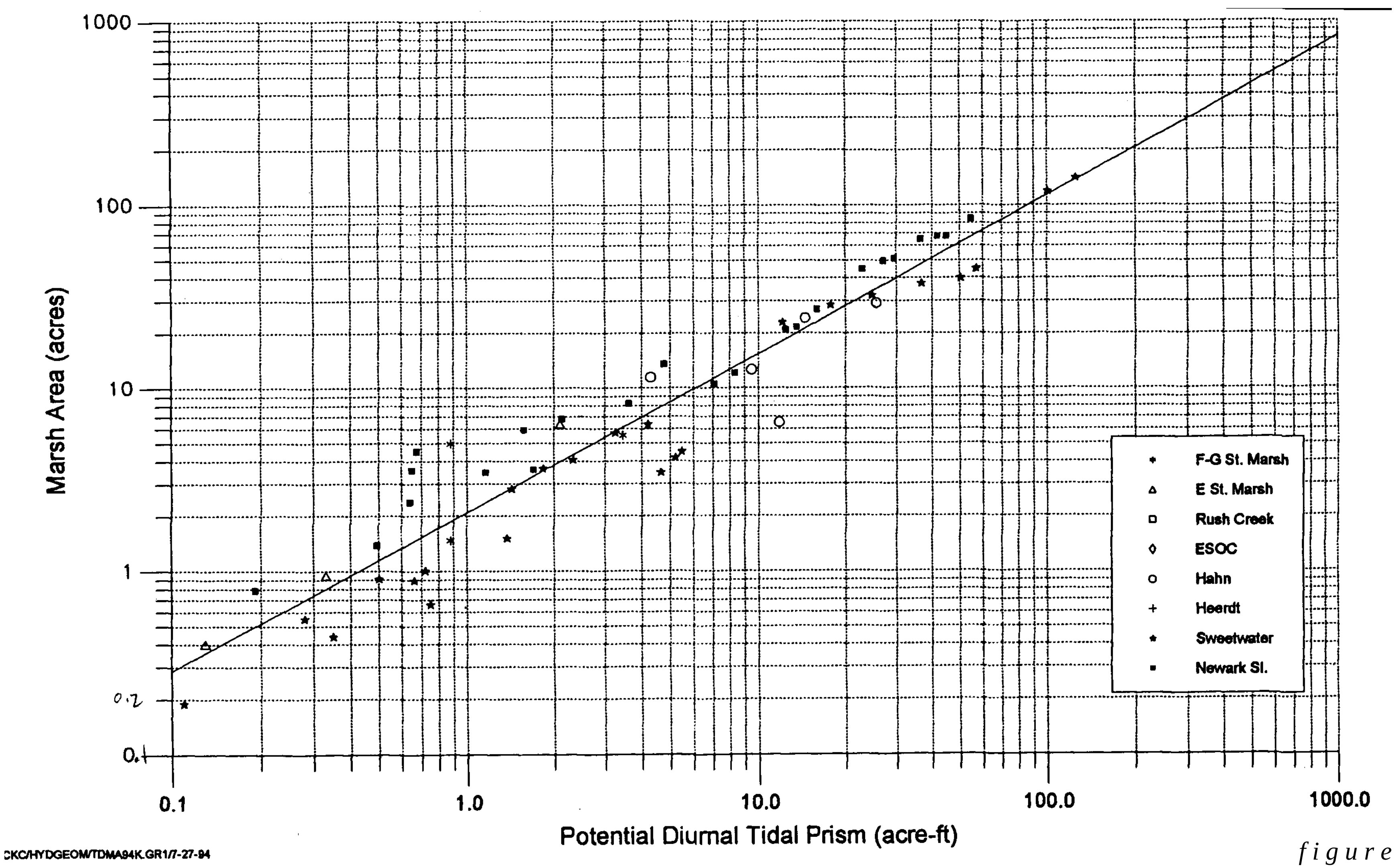


figure 4-11

Hydraulic Geometry for California Salt Marshes – Area and Tidal Prism

Lower Otay River Salt Marsh and Wetland Restoration

Source: Philip Williams and Associates, Design Guidelines for Tidal Channels in Coastal Wetlands, Prepared for the U.S. Army Corps of Engineers, Waterways Experiment Station, January 1995.

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