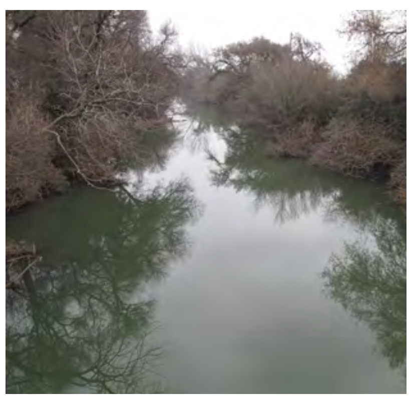
INITIAL PROTOCOL TO IDENTIFY AND DELINEATE THE HEAD OF TIDE ZONE in San Francisco Bay Tributaries



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EXECUTIVE SUMMARY

Within the tributaries that drain to San Francisco Bay, there exists a transition between fluvial and tidal processes and conditions. The upstream boundary of this transition, called the head of tide (HoT) zone, can be defined as the inland limit of the effects of average high tides on tributary flows and water surface elevation. This zone is characterized by unique and diverse assemblages of plants and animals, as well as a vulnerability to out-of-channel flooding during high river flow and high tide conditions. As many Bay Area municipalities are built near the HoT zone, there is a growing concern about managing the land within and around the HoT zone for current conditions and future conditions when rapid sea level rise causes the HoT zone to migrate inland. The first step in developing effective management strategies needs to be creating a process, or protocol, for determining where the HoT zone is now and where it will likely be in the future.

This study focused on creating the framework for a rapid protocol that can be used to delineate the current and future HoT zone for San Francisco Bay tributaries using both "desktop" and field investigations. The protocol framework was developed by examining data collected at six tributary HoT zone sites that represented a broad range in watershed size (used as a proxy for stream discharge) and channel gradient. The desktop investigation used a public online tidal inundation mapping tool with readily accessible, high resolution LiDAR topographic data to provide a "first cut," coarse estimate of the current HoT zone location, which is assumed to be at the local mean higher high water (MHHW) elevation, and a future (i.e., 2050) HoT zone location when MHHW is 1 foot higher. The field investigation involved examining multiple physical and biological indicators of both the current and future HoT zones and is intended to refine the estimate given by the desktop investigation. Data collected as part of the field investigation included channel topography (longitudinal profile and cross-sections), the location of key channel geomorphic features (high tide bank scour line, shifts in bed texture, fluvial depositional bars), the location of high water marks (tidally-desiccated vegetation), the location of shifts from brackish to freshwater vegetation, a time series of water surface elevation, and observations of the inland extent of tidal inundation at high tides. The data were then analyzed to determine the indicators that are most effective at rapidly identifying the HoT zone location and extent.

The study found that a combination of desktop and field investigations can be used to develop rapid yet reasonable estimates of the current and future HoT zones for the San Francisco Bay tributary sites examined. Overall, the field investigations refined the HoT zone estimate provided by the desktop investigations. The study also showed that the key current HoT zone field indicators vary as a function of contributing watershed area and local channel gradient, which was included in the developed protocol framework as a way of guiding data collection efforts catered to site-specific conditions. The location of the future HoT zone was shown to be strongly controlled by local channel gradient, with steeper slopes being associated with a relatively low degree of inland migration for a 1 foot rise in MHHW. In addition, the study found the reliability of the desktop-derived estimates for both current and future HoT zones can be greatly affected by water and vegetation impacts on LiDAR elevation data.

The protocol developed as part of this study is meant to be rapid and ideally will be used by regional agency staff to address issues related to regional planning for sea level rise. The basic requirements for using the protocol are access to the internet, access to GIS software and basic GIS analysis skills, access to spreadsheet software and basic spreadsheet analysis and graphing skills, knowledge of geomorphic processes, and vegetation mapping skills.

The findings from this study are encouraging but not conclusive. In general, development of a validated, widely applicable HoT zone delineation protocol for San Francisco Bay tributaries requires more field data from multiple tributaries with a wider range of physical settings. Such a data collection effort should asses the importance of site geomorphic characteristics besides watershed area and channel slope, and should examine the applicability of additional field indicators capable of rapidly delineating the current and future HoT zones. Continued development of a HoT zone delineation protocol should include close coordination with regional management agencies, including the Bay Conservation and Development Commission (BCDC), Bay Area Flood Protection Agencies (BAFPA), Association of Bay Area Governments (ABAG), and Regional Water Quality Control Board (Regional Board), and the National Oceanic and Atmospheric Administration (NOAA).

1. INTRODUCTION

1.1 Need for Study

The San Francisco Bay-Delta is a large estuarine ecosystem where freshwater mixes with tidal water, forming a spatially and temporally complex mixing zone that drives species composition, water quality, vegetation patterns, and habitat types. Within the tributaries that drain to the Bay, there exists an extension of this transition between fluvial and tidal processes and conditions (i.e., the Riverine Transition Zone [Goals Project 2014]). The upstream boundary of this transition can be defined as the inland limit of the effects of average high tides on tributary flows and water surface elevation. This is commonly regarded as the head of tide (or HoT). Since the height of the high tide varies from one tide cycle to another, and since both tide heights and stream flows vary seasonally, the HoT is essentially a zone along a tidally influenced tributary.

The HoT zone is characterized by a distinct set of physical, ecological and cultural attributes. There are a variety of geomorphic changes in channel form and structure within the HoT zone due to a change in gradient and decrease of kinetic energy of water flowing from a local watershed as it meets incoming tidal waters. The HoT zone is also distinguished by chemical and ecological characteristics such as a transition from saltwater to freshwater and, as such, it tends to support unique and diverse assemblages of plants and animals. Historically, indigenous peoples had settlements near the HoT zone because it was close to freshwater and abundant estuarine food resources. Many Bay Area municipalities, including San Jose, Hayward, San Rafael, Novato, Napa, and Petaluma, were founded along the local HoT zone, in part because it signifies the upstream limit of water deep enough for commercial navigation. However, despite the ecological and cultural significance of the HoT zone, there is currently no standardized protocol to identify, delineate, or map the zone. Furthermore, its past, present, and likely future location in San Francisco Bay tributaries is not well documented on a regional scale.

Delineating the HoT zone can inform management of the lower reaches of Bay tributaries. For example, knowing the HoT zone location can influence decisions about regulatory and jurisdictional boundaries, natural resource management and restoration actions, as well as planning for climate change impacts and sea level rise. Continued climate change is expected to intensify storms as well as cause sea level rise to accelerate, thereby increasing the potential for local flooding in the current HoT zone. The zone is also expected to migrate upstream or compress with a rising sea level. Currently, many flood control engineers and natural resource managers are aware of the HoT zone. However, there is no regional plan for addressing upstream migration of the zone and associated long-term management challenges. Since the HoT zone is characterized by a unique set of physical and ecological conditions, it should be possible to identify, delineate, or map it through a suite of physical and ecological indicators. A practical tool that uses such indicators to delineate the HoT zone could greatly assist future management of Bay Area tributaries.

1.2 Study Goal and Objectives

The primary goal of this study is to develop a scientific protocol to delineate the HoT zone in San Francisco Bay tributaries. The specific objectives of this study are as follows:

- Develop a "desktop" or in-office procedure that provides a coarse estimate of the current and future HoT zones using existing, readily accessible spatial data;
- Develop a field procedure to refine the coarse desktop estimates of the current and future HoT zones based on field indicators; and
- Combine these procedures into an initial protocol for delineating the current and future HoT zones.

These objectives were met through a two-year data collection and analysis effort at six Bay tributaries that represent a broad range in watershed size, salinity regime, and channel gradient. This report presents the data analysis results and the HoT zone delineation protocol developed using data from the tributary sites. The work presented here is in support of the Bay Conservation and Development Commission (BCDC) HoT Zone Risk and Vulnerability Assessment. When combined, the two studies will provide the San Francisco Bay management community with an approach for determining the current and future HoT zones (to the level of resolution necessary for addressing specific questions/concerns) and an indication of likely management issues associated with the inland migration of the HoT zone as sea level continues to rise.

1.3 Study Area

San Francisco Bay, the largest estuary on the West Coast and one of the largest estuaries in North America, has a drainage area that includes almost half of the state of California (~60,000 mi^2) (Conomos et al. 1985). The San Francisco Bay-Delta is fed by the Sacramento River and San Joaquin River watersheds, which include several large rivers that drain the western slope of the Sierra Nevada. These rivers deliver fresh water and sediment to Suisun Bay and San Francisco Bay through the Delta, and to the Pacific Ocean through the Golden Gate. The mixing of freshwater with tidal water in the Bay creates large, complex, physical and ecological gradients.

Over 450 small watersheds drain directly to San Francisco Bay (McKee et al. 2013). These watersheds are dominated by erodible marine sedimentary bedrock, such as the Franciscan Complex that includes chert and serpentinite, the Great Valley sequence, and relatively young volcanics (Blake et al. 1984). Some of the largest watersheds occupy drowned valleys on the northern (Napa River and Sonoma Creek) and southern (Coyote Creek and Guadalupe River) ends of the Bay. Alameda Creek has the largest contributing watershed (700 mi^2), and enters the South Bay along the eastern edge near Union City. Several dozen smaller watersheds drain the steep, uplifting hills of the East Bay and the San Bruno Mountains to the southwest. Many of these channels historically flowed onto alluvial fans before draining to broad depositional plains and then to the Bay. On the western and eastern edges of North Bay, small, steep drainages empty directly into tidal waters of the Bay with little or no depositional zones. Approximately 50% of Bay tributaries are urbanized, with many of the drainages regulated by dams (McKee et al. 2013).

The region experiences a Mediterranean climate (i.e., hot, dry summers and cool, mild winters) with strong regional precipitation gradients. In general, rainfall decreases from north to south and from west to east. North Bay watersheds experience considerably more rain than the South Bay, and the western watersheds are more heavily influenced by the marine weather patterns than the eastern watersheds (Miles and Goudey 1997). Average annual rainfall around the region varies from ~10 in/yr in Livermore Valley to over 50 in/yr in the Santa Cruz Mountains (Leidy 2007).

2. HEAD OF TIDE ZONE CHARACTERISTICS

2.1 Location and Definition

The HoT zone, by its broadest definition, is the location of the upstream-most edge of regular tidal inundation and the transition from saltwater to freshwater environments (Bate et al. 2004, Florsheim et al. 2008, Ensign et al. 2013) (Figure 2.1). The National Oceanic and Atmospheric Administration (NOAA) defines the head of tide as where changes in water level due to tidal influences drop below 0.2 meters, or where tidal influence is no longer measurable[1]. Some researchers have defined the "tidal limit" as where tidal flow reversal stops; however, tides continues to affect fluvial flow well beyond this limit, as velocity and water height continue to fluctuate (Dalrymple and Choi 2007, Martinius and Gowland 2011). Others have defined the HoT zone more broadly as the area in a channel where water level fluctuations are affected by tides, which in turn influences marsh vegetation and wildlife assemblages (Simenstad et al. 2011). In all instances, the HoT zone exhibits a gradient in hydraulic conditions as river flows meet incoming tides, resulting in changing channel geomorphic characteristics (Barwis 1977, Bate et al. 2004, Florsheim et al. 2008, Ensign et al. 2013, Keevil et al. 2013) and a change in salinity regimes and species composition (Odum 1988, Brinson et al. 1995, Rundle et al. 1998).

Because of the complex conditions resulting from the combination of variable freshwater inflows and tidal dynamics, the HoT is a variable zone. The upper limit of the HoT zone shifts with seasonal and inter-annual variation in both tidal range and freshwater input (Flushman 2002, Florsheim et al. 2008). The HoT zone position and extent also vary with the size of the system, the channel slope, and local anthropogenic impacts. The HoT zone can be several miles upstream from the open Bay in a large low-gradient system, creating a broad tidal-freshwater zone and possibly a substantial freshwater-tidal marsh, as seen in the Sacramento San Joaquin Delta (Dalrymple and Choi 2007, Whigham et al. 2009, Ensign et al. 2013). In the smaller watersheds that drain directly to the San Francisco Bay, the channel slope is often relatively steep and the HoT zone may occur less than 1 mile from the Bay (Dalrymple and Choi 2007). Thus, tidal indicators vary between each system and can be found occasionally in reaches which are otherwise completely fluvial. Likewise, fluvial indicators can sometimes be found in reaches that are completely tidal.

In this study, we are focused on the average upstream limit of the tide, which we presume is represented by the inland inundation extent of the local mean higher high water (MHHW) elevation. The central thesis for the development of a HoT zone delineation protocol in this study is that the zone has unique physical and biological characteristics that extend upstream and downstream of MHHW to limits that can be identified using field indicators. While large coastal storm surges and high river flow events can rapidly change geomorphic and ecological conditions in a tributary, the persistent, usual actions of the tides and tributary flows can combine to create patterns of scour, deposition, and vegetation conditions that indicate the location of the HoT zone. The functions that produce these patterns are described below.

[1] http://shoreline.noaa.gov/glossary.html

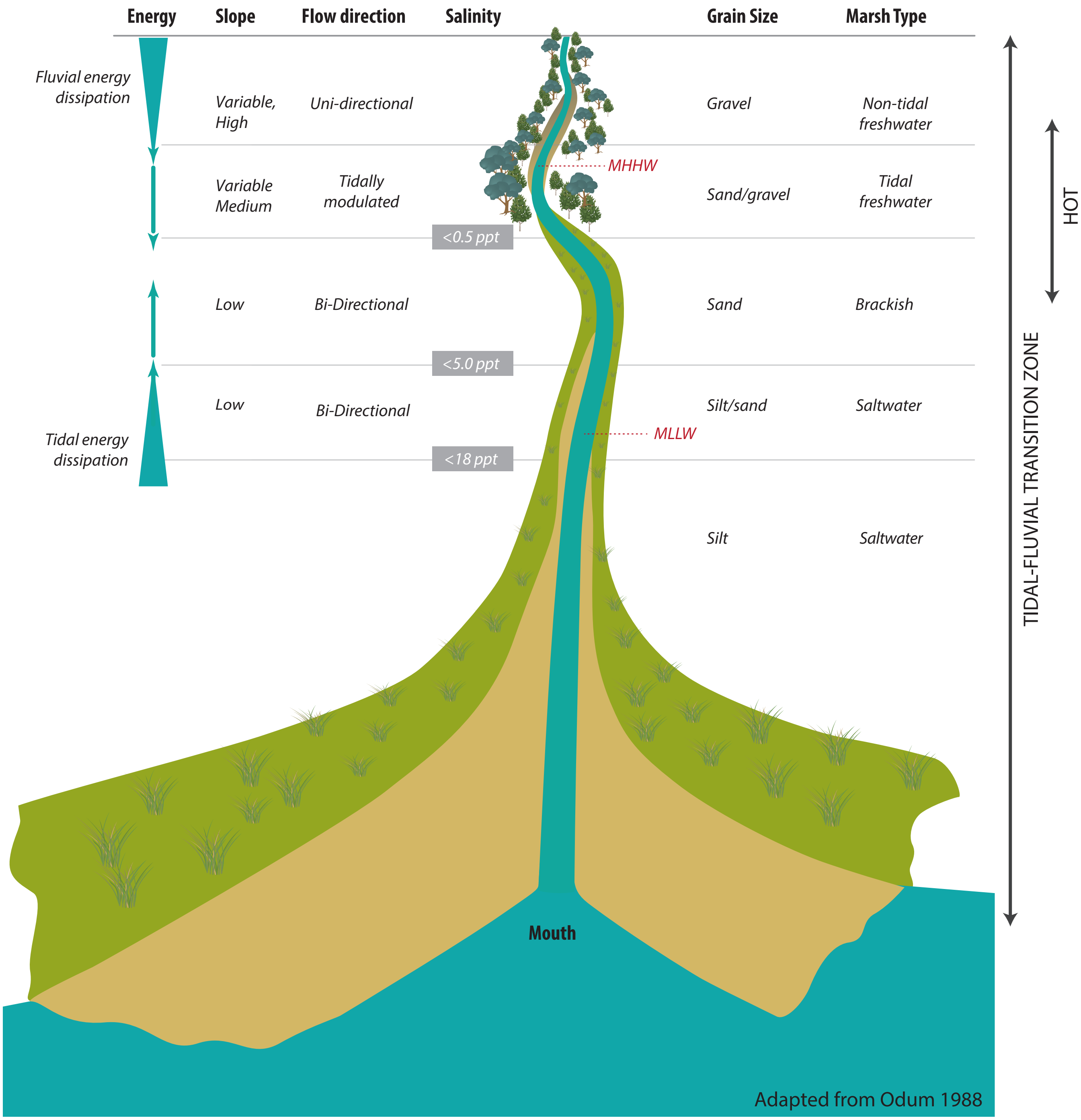


Figure 2.1. Conceptual model of the fluvial-tidal transition. This conceptual model identifies some of the physical and biological changes across the fluvial-tidal interface. Change in slope drives fluvial energy loss which impacts change in grainsize. Flow direction and tidal energy expenditure drives salinity and thus marsh type.

2.2 Physical and Ecological Functioning

The interface between tidal and fluvial flow creates a unique set of hydrologic patterns, which in turn influences sediment dynamics, channel morphology, vegetation, and salinity conditions within the HoT zone (Martinius and Gowland 2011, Ensign et al. 2013, Keevil et al. 2013). Sediment is transported landward by flood tides and bayward by ebb tides and river flows, such that a reach of high turbidity and sediment deposition can occur where tidal and fluvial flows meet and slow. The sediment deposited in this zone is typically very fine (sand and silt), with particles decreasing in size in the bayward direction. Flow and currents within the zone create unique sedimentation patterns, which can be used to identify the HoT zone within the broader fluvial-tidal transition zone (Dalrymple and Choi 2007, Ensign et al. 2013). These patterns can often be observed in the stratigraphic record and can be used to understand the spatial variation of fluvial and tidal influence over time (Pizzuto and Rogers 1992, Martinius and Gowland 2011).

As channels transition between fluvial- and tidal-dominated reaches, they change in both planform and cross-section. In natural, unmodified systems, channel sinuosity can reach a peak at the point in the fluvial-tidal transition zone where flow energy reaches a minimum (Dalrymple and Choi 2007). In addition, there can be a shift from bank-attached point bars to elongate tidally shaped bars across this zone (Barwis 1977, Dalrymple and Choi 2007, Keevil et al. 2013). Downstream of this transition, channels then typically straighten and change in width-depth ratio, becoming larger in cross-sectional area to accommodate an increasing tidal prism (Dalrymple and Choi 2007, Keevil et al. 2013).

In addition to geomorphic changes, the HoT zone is also characterized by shifts in average water salinity and associated biological activity (Odum 1988, Bate et al. 2004). The salinity gradient from seawater (35 ppt) to brackish (~10-15 ppt) to freshwater (<5 ppt) has immense importance to the biological function of a tidal channel, including controlling aquatic and benthic species composition and richness (Morris et al. 1978, Odum 1988). The transition from brackish to freshwater is often considered a boundary within the salinity gradient where biological productivity and diversity in the littoral and benthic zones is either at a minimum (Morris et al. 1978, McLusky 1993) or in some cases, at a maximum (Telesh et al. 2013).

The shift in plant community composition along a tributary from saltwater-tolerant to brackish and freshwater species indicates spatial changes in salinity and tidal inundation regimes that often indicate the HoT zone (Odum 1988). In general, freshwater tidal plants tolerate longer inundation (Atwater 1980, Odum 1988), such that freshwater and brackish marshes extend lower in the tidal fame than salt marshes. The plant communities of brackish marshes are especially diverse, due to many factors, including the overlap of freshwater and saline plant communities, plus the ability of many plant species to wax and wane in relative abundance with inter-annual changes in the salinity regime (H.T. Harvey & Associates 2008). Streamside vegetation near the HoT zone is often characterized by a mixture of salt-tolerant, brackish, and freshwater species (Odum 1988), with some increase in plant cover toward the channel bed. In the San Francisco Bay Area, plant species common at the HoT zone include salt and freshwater marsh plants such as tule *(Schoenoplectus californicus),* common reed *(Phragmites australis),* cat tail (*Typha* spp.), pickleweed (*Salicornia* spp.), and salt grass *(Distichlis spicata)*, as well as woody riparian vegetation such as willows (*Salix* spp.) and valley oak *(Quercus lobata)* (Leck et al. 2009, Watson and Byrne 2009). Species composition can vary widely between systems, depending on channel slope, size of freshwater tidal zone, substrate type, overall salinity regime, and local history of disturbance including invasive non-native species.

2.3 Historical and Current Land Uses

Around San Francisco Bay, the HoT zone was the focus point of early settlements. Indigenous people and then European-Americans commonly settled near the HoT zone since it was associated with abundant aquatic food resources and the upstream limit of navigation from the Bay. Beginning in the 18th century, European-American settlers began establishing transportation routes through the HoT zone. For example, along the Napa River, a cattle crossing (or tranca) was established near the upstream extent of tidal influence where the river was relatively easy to cross possibly due to shallow water and stable bed conditions. This crossing, known as Las Trancas, became an important cultural center (circa 1835-1850), providing a cross valley route near the head of navigation for river commerce (Grossinger and Beller 2007). Later, steamer landings were established close to the historical HoT zone in present-day downtown Napa, between Division and Oak streets (Grossinger 2012).

Currently, major pieces of infrastructure cross creeks in and around the HoT zones. Railroads, highways, fuel lines, and sewer laterals are located in this zone (e.g. Highway 121 crossing over Sonoma Creek), which is essentially the most downstream stable ground before reaching the baylands. These infrastructure features often create flow constrictions and channel bed grade controls that influence the HoT zone location and extent. These features also help control how these areas will evolve with continued sea level rise. Over the past century, in-channel infrastructure has created stationary channel "steps," or sharp drops in bed elevation, along many lower tributary channel reaches just upstream of the Bay. These steps can essentially "stall" HoT zone movement as sea level rises. Once the MHHW elevation rises above the channel step, the HoT zone can very quickly migrate hundreds of feet inland, thereby rapidly increasing the area where regular tidal inundation affects flooding and habitat conditions, and extending flooding laterally under low channel gradient conditions.

3. HEAD OF TIDE ZONE DELINEATION

3.1 Background and Overview

The concept for a HoT zone delineation protocol came directly from conversations with San Francisco Bay watershed management agencies about their needs for tools that would be most useful in addressing management questions. These conversations highlighted the need for a cost-effective and adaptable method for estimating both the current and future HoT zone, particularly adjacent to developed areas with vital infrastructure, as well as the need for a regional map of the current and future HoT zones. To meet these needs, SFEI sought to develop a HoT zone delineation protocol that is both rapid in application (i.e., delineation can be done in a few hours with just a few key pieces of information) and capable of providing a HoT zone delineation that can align with management questions at hand. The ultimate goal of the protocol is to provide the user with the necessary guidance for getting the appropriate information regarding HoT zone position in a quick, yet comprehensive fashion.

The HoT zone delineation protocol recommended in this report is based on a pilot project that focused on just six Bay tributaries. This initial protocol is therefore intended to be used as a start toward developing a more comprehensive and thoroughly tested protocol. Ideas for seeking additional funding and new partnerships that could help move the protocol development forward are presented in the last section of the report.

3.2 Overall Protocol Concept

This study focused on developing a protocol that involves two complimentary procedures. The first procedure is a "desktop" or in-office investigation designed to yield a coarse estimate of the current location of the HoT zone using common GIS tools with readily available, high-resolution spatial data (e.g., LiDAR and NOAA tidal inundation mapping). The second procedure involves field investigations to delineate both the current and future HoT zones and is intended for users seeking a higher degree of resolution over the desktop procedure. For current conditions, the field procedure focuses on multiple physical and biological indicators of the HoT zone and is intended to refine the estimate given by the desktop investigation. For future conditions, the field procedure includes observations of the likely inland tidal extent for a 1-foot MHHW elevation increase (approximate increase expected by 2050, per NRC [2012]) during relatively low stream flow. The field procedure to estimate the future HoT zone is far more qualitative than the field procedure to estimate the current HoT zone, and is therefore intended to essentially corroborate, if not ideally refine, the future HoT zone estimate provided by the desktop investigation.

Development of the HoT zone delineation protocol focused on the following:

1. Assessing the degree to which a desktop procedure can meet the need for coarse estimates of the current and future HoT zone;
2. Determining if a suite of unique field indicators exists for identifying the current HoT zone for a range of physical settings; and
3. Assessing the degree to which a field procedure can refine the desktop estimate of the current and future HoT zones.

The development of the protocol involved compiling a range of data (both physical and biological) and determining which data appear to be the most useful for rapidly delineating the HoT zone for the selected tributaries. If time and budget were not constraints, the best approach for delineating the HoT zone at any given site would be to survey a high-resolution longitudinal profile of the channel bed through the fluvial-tidal transition zone, if one does not already exist, and monitor long-term water surface elevation to determine where the MHHW elevation crossed the channel bed. However, the management community needs a delineation protocol that can be done much more quickly and cheaply than this type of comprehensive field approach, yet provides a robust estimate of the HoT zone. Therefore, this protocol is intended to focus on the most relevant indicators that can meet this need.

3.3 Protocol Development

3.3.1 STUDY TECHNICAL ADVISORY COMMITTEE

At the beginning of the study, a technical advisory committee (TAC) was established to advise and review protocol development. The TAC provided special expertise in coastal and fluvial geomorphology, tidal marsh ecology, GIS mapping, and flood control engineering.

3.3.2 STUDY SITE SELECTION

As previously mentioned, this study focused on developing the first version of a HoT zone delineation protocol using data from six field sites. The six study sites were selected to represent a range of physical conditions around San Francisco Bay that contribute to local differences in the HoT zone location (Figure 3.1, Table 3.1). The primary physical variables considered in site selection were watershed area (as a proxy for discharge), average channel gradient, tidal salinity regime (i.e., saltwater vs. brackish), and degree of modification (e.g., levees, concrete banks and bed). Other considerations for site selection included logistics, access, data availability, synergy with ongoing regional projects, and known flooding issues within the HoT zone. The TAC was very involved in the site selection process, providing initial suggestions for channels to consider and then ultimately approving the final list of study sites. Prior to beginning the field investigation at the selected sites, local management agencies were contacted and access permission was secured. When necessary, data collection permits were obtained to allow for temporary equipment installation.

Following site selection, a Working Group for each site was assembled that included representatives from local flood control agencies, public works departments, water agencies, environmental organizations, and public parks managers. The Working Groups' two primary roles were: 1) to provide feedback regarding the need for and potential utility of a protocol for delineating the current and future HoT zones and the elements that should be included; and 2) to provide an estimate of the current HoT zones based on the members' long-term observations and extensive local experience. Overall, the input provided by the Working Groups was helpful in refining the initial protocol and validating the field-based estimates of the current HoT zone.

3.3.3 DATA COLLECTION AND ANALYSIS

3.3.3.1 Desktop Investigation The desktop investigation focused on combining readily available topographic data and tidal elevation estimates to determine a coarse prediction of the current and future HoT zones. The topographic data used in this analysis came from LiDAR mapping efforts of the Bay shoreline and adjacent low-lying areas undertaken by USGS, NOAA, and Ocean Protection Council between 2010 and 2012[2]. For each of the six study sites, a longitudinal profile of the channel centerline from a location below Mean Tide Level (MTL) to a position well inland of the likely future HoT zone was extracted from a LiDAR derived 1-meter Digital Elevation Model (DEM) in GIS and transferred to spreadsheet software. The longitudinal profile for each site was then combined with estimates of current and future MHHW inundation extent extracted from the NOAA SLR viewer[3]. The SLR viewer gives both "high confidence" and "low confidence" MHHW inundation extents that reflect known errors in the LiDAR data and the local MHHW elevations, which are derived using the NOAA VDatum software[4]. The high and low confidence MHHW extents for current conditions and future conditions (current MHHW + 1 foot) were marked on the longitudinal profile and plan view map of each site as a means of delineating the current and future HoT zone extents.

3.3.3.2 Field Investigation Field efforts for this study were based on the assumption that HoT zone has unique physical and ecological characteristics or attributes that can be identified using standardized field indicators. A list of the field indicators initially considered was assembled from the primary literature and input from the TAC members (see Appendix A). These indicators were then prioritized based on criteria for their usability. A key concern was that each indicator should provide comparable results over time with little temporal variability. For example, water salinity was deemed to be a low priority indicator because it varies greatly over short periods and requires frequent observations making

[2] San Francisco Bay LiDAR website: http://www.opc.ca.gov/2012/03/coastal-mapping-lidar-data-available/
[3] NOAA Sea Level Rise and Coastal Flood Impacts tool website: http://csc.noaa.gov/slr/viewer/
[4] NOAA VDatum website: http://vdatum.noaa.gov/

Figure 3.1. Study site locations. Map of San Francisco Bay showing the six study sites chosen to represent tributaries to SF Bay. The sites were chosen to span geography, watershed size, land use and other criteria such as site access.

Table 3.1. Summary of study site characteristics

Study site	Drainage area (mi^2)	Tidal salinity regime	River flow type	Dominant land use at the fluvial-tidal interface[a]	Channel type at the fluvial-tidal interface[a]	Management Agency
Sulphur Creek	3	Saltwater	Intermittent	Urban/Industrial	Engineered, natural bottom	Alameda County Flood Control and Water Conservation District (ACFC&WCD)
Wildcat Creek	11	Saltwater	Intermittent, regulated by dams	Urban/Developed	Engineered, natural bottom	Contra Costa County Flood Control and Water Conservation District (CCCFC&WCD)
Alhambra Creek	17	Brackish	Intermittent	Urban/Developed	Engineered, natural bottom	Contra Costa County Flood Control and Water Conservation District (CCCFC&WCD)
Novato Creek	36[b]	Saltwater	Perennial, regulated by dams	Urban/Developed	Engineered, natural bottom	Marin County Flood Control and Water Conservation District (MCFC&WCD)
Sonoma Creek	170	Saltwater	Perennial	Agricultural/Developed	Natural	Sonoma County Water Agency (SCWA)
Coyote Creek	320	Saltwater	Perennial, regulated by dams	Urban/Developed	Engineered, natural bottom	Santa Clara Valley Water District (SCVWD)

[a] Designation from the California Aquatic Resources Inventory
[b] Area downstream of Stafford Lake

them unsuitable for rapid assessment, whereas the relative abundance of salt-tolerant vegetation was determined to be a good indicator because it integrates across the temporal variability of water salinity. In general, indicators with considerable inter- and intra-annual variability such as species diversity and water quality were considered low priority for this pilot project.

The field investigation for this study included a combination of quantitative and qualitative data collection. At all six study sites, channel topographic and geomorphic data were compiled throughout the presumed current and likely future HoT zones (Figure 3.2A-F, Table 3.2). Topographic field data collection included surveying a longitudinal profile of the channel thalweg (the lowest line of elevation in a channel bed) and channel cross-sections during low river flow conditions in late spring/summer 2013. Surveying was done using an auto-level and stadia rod (which required tying the measured relative elevation to a local benchmark to get elevation in feet NAVD88) and a survey-grade RTK differential GPS unit (which recorded elevation in feet NAVD88). At study sites where a longitudinal profile was surveyed, the channel thalweg elevation was recorded at 30-foot intervals or more frequently as needed to capture key slope breaks and geomorphic features (e.g., local grade control structures). The field long profile extent was determined based on the length established by the desktop analysis. At study sites where channel cross-sections were surveyed, cross-sections were located within and adjacent to the presumed current HoT zone, and bed elevations were recorded at15-foot intervals or as needed to capture the channel morphology adequately. In addition, key cross-section elevations such as the upper elevation limit of bank scour/lower elevation limit of tidal marsh vegetation (i.e., an indication of the local MHHW elevation) and the height of the adjacent marsh-plain/floodplain were noted (Figure 3.3). Where appropriate, additional information that was useful in delineating the current HoT zone, such as the location of transitions in bed texture and geomorphic

Table 3.2. Summary of data collection activities at each study site

Study site	Data Collection Activities				Data source
	Topographic surveying[a]	Field observations[b]	Vegetation mapping	Water surface elevation monitoring	
Sulphur Creek	✓	✓	✓		SFEI
Wildcat Creek	✓	✓	✓	✓	SFEI
Alhambra Creek	✓	✓	✓		SFEI
Novato Creek	✓	✓			Longitudinal profile from KHE, all other data collected by SFEI
Sonoma Creek	✓	✓			Longitudinal profile from ESA PWA, all other data collected by SFEI
Coyote Creek	✓	✓			Longitudinal profile from SCVWD, all other data collected by SFEI

[a] Included surveying longitudinal profiles and channel cross-sections
[b] Included noting geomorphic features and high water marks

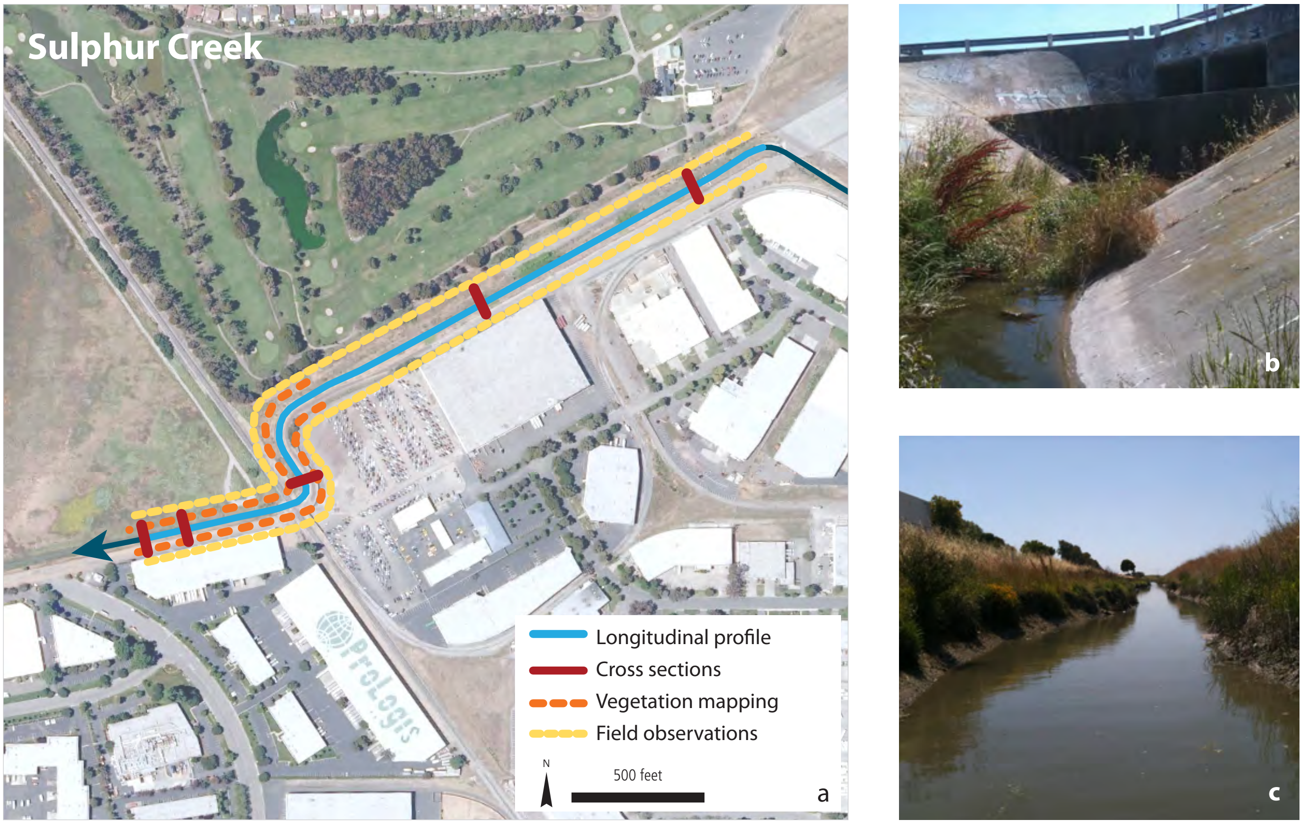


Figure 3.2A. Sulphur Creek field measurements and observations. Showing a) location of field investigations, b) upstream project extent, c) downstream project extent.

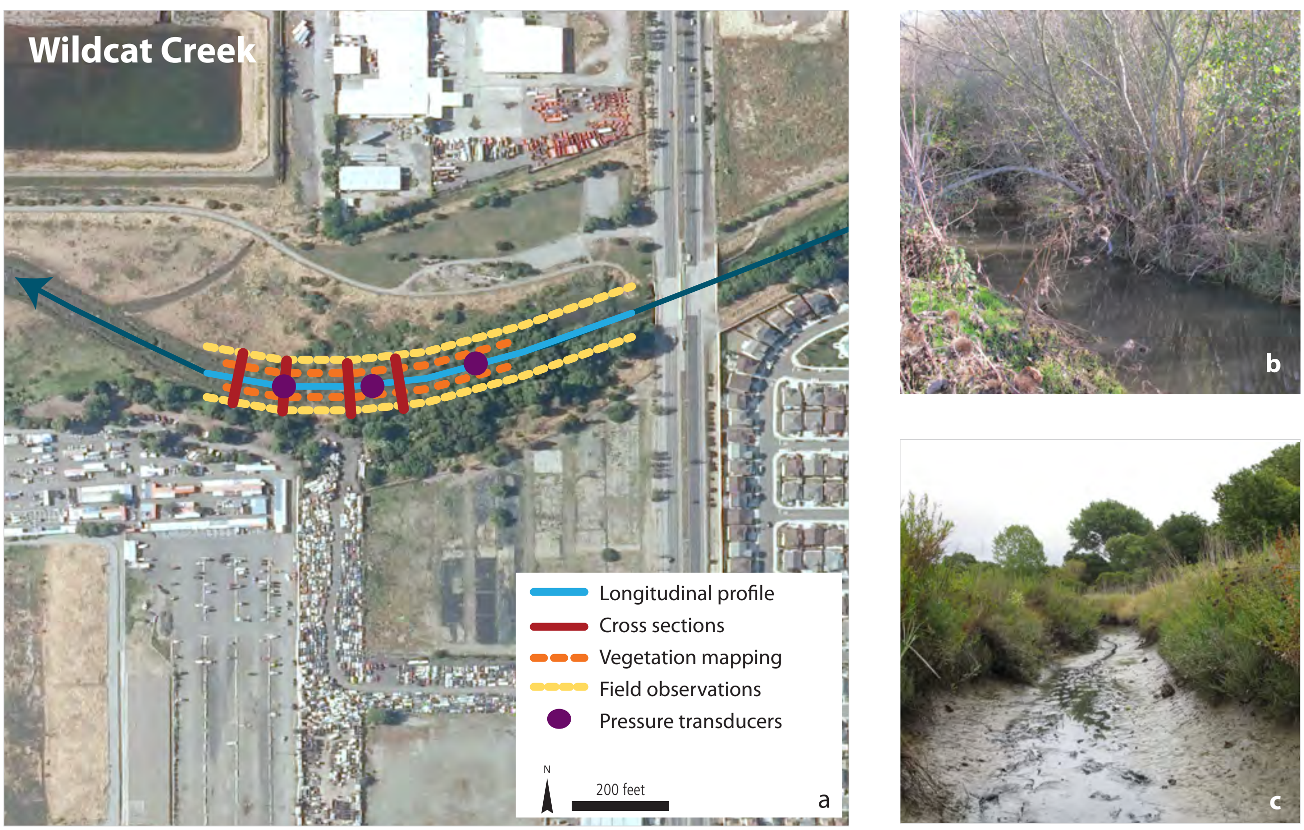


Figure 3.2B. Wildcat Creek field measurements and observations. Showing a) location of field investigations, b) upstream extent of project, c) downstream extent of project. Three pressure transducers (purple dots) were deployed for one month in summer 2013.

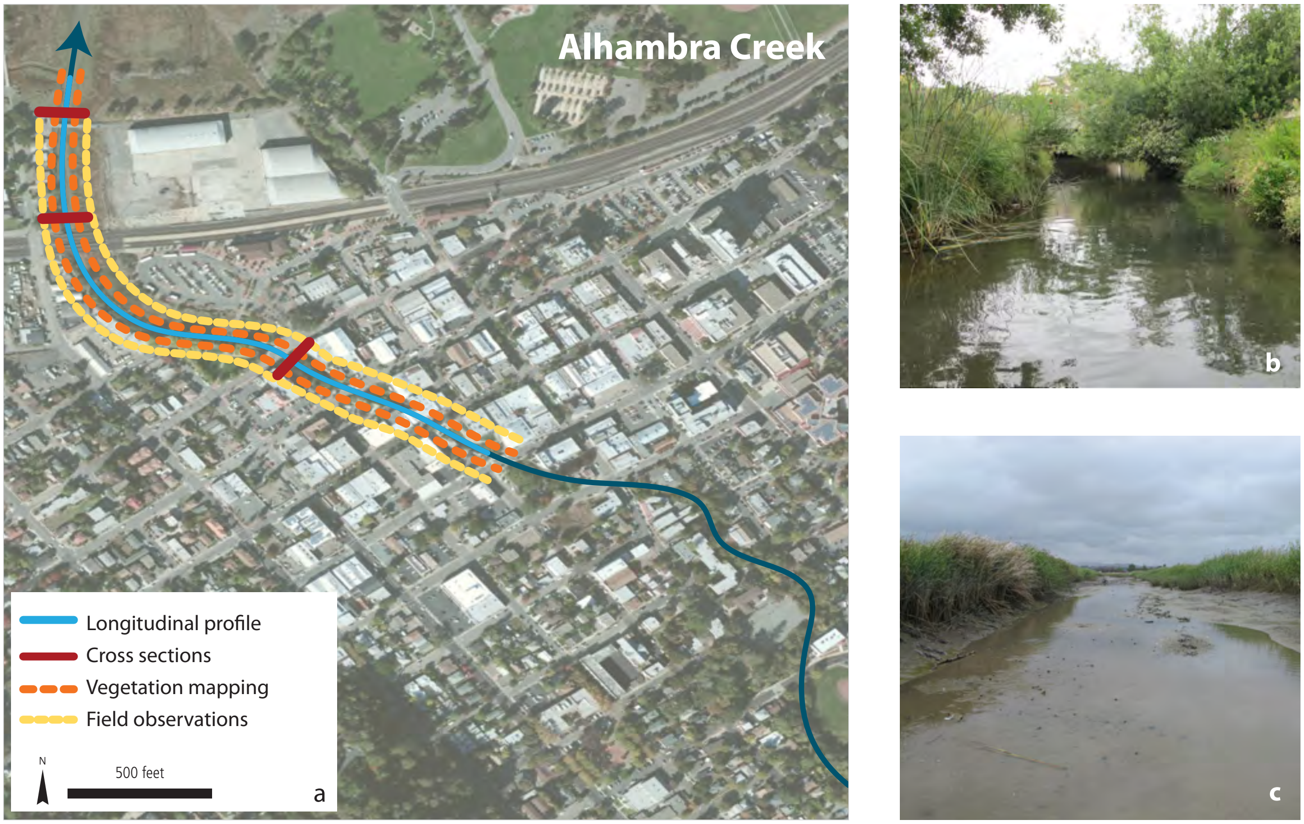


Figure 3.2C. Alhambra Creek field measurements and observations. Showing a) location of field investigations, b) upstream project extent, c) downstream project extent.

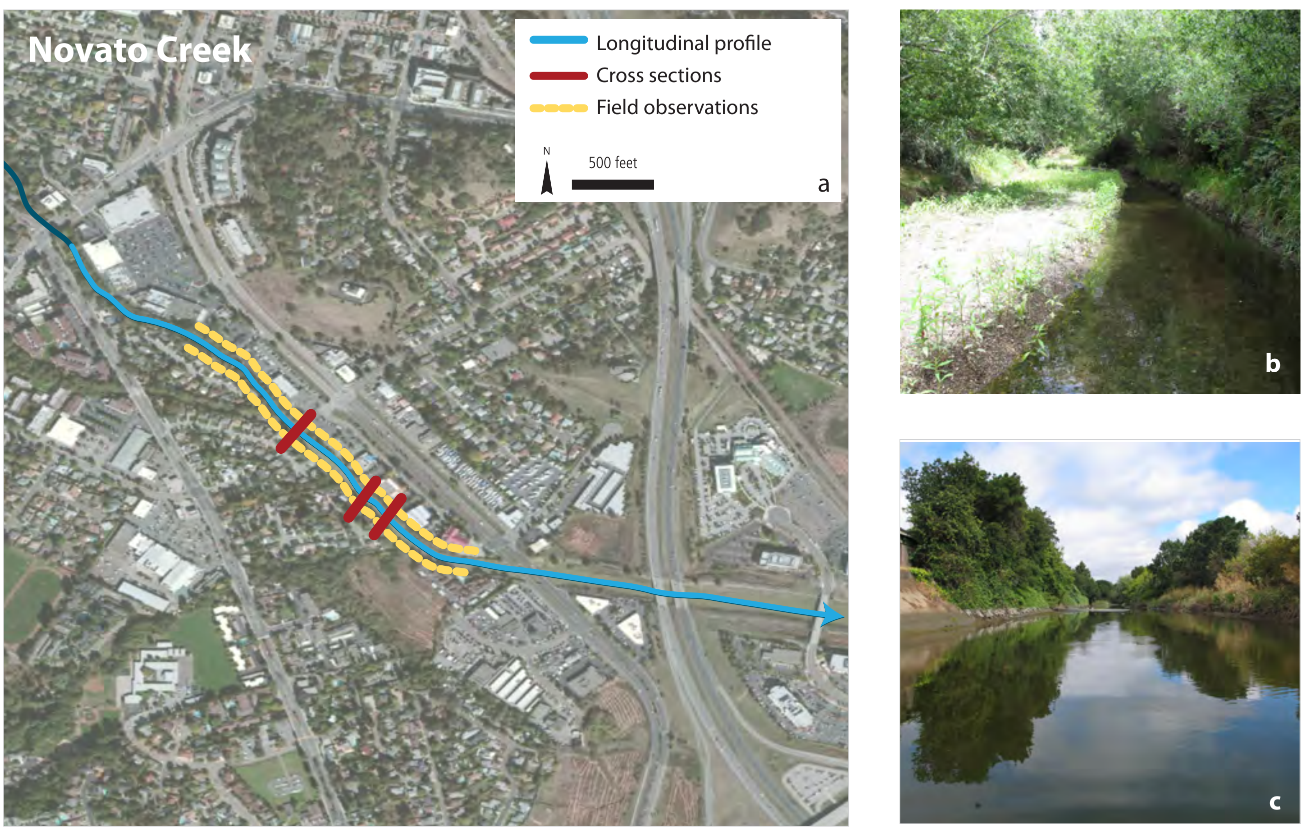


Figure 3.2D. Novato Creek field measurements and observations. Showing a) location of field investigations, b) upstream project extent, c) downstream project extent. Vegetation was not mapped as it was deemed to not be a useful indicator of the HoT at this site.

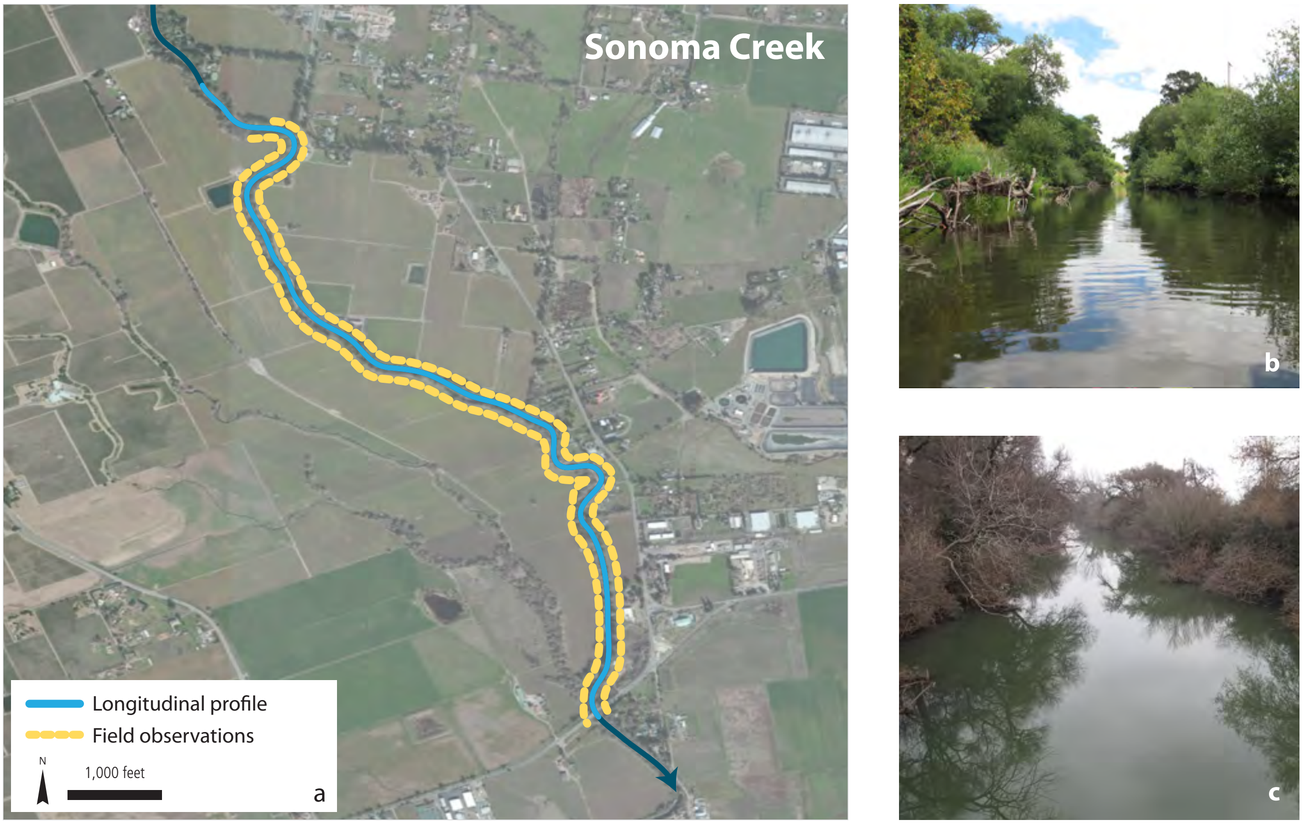


Figure 3.2E. Sonoma Creek field measurements and observations. Showing a) location of field investigations, b) upstream project extent, c) downstream project extent. No cross sections were surveyed because of equipment limitations. Vegetation was not mapped as it was deemed to not be a key indicator of the HoT at this site.

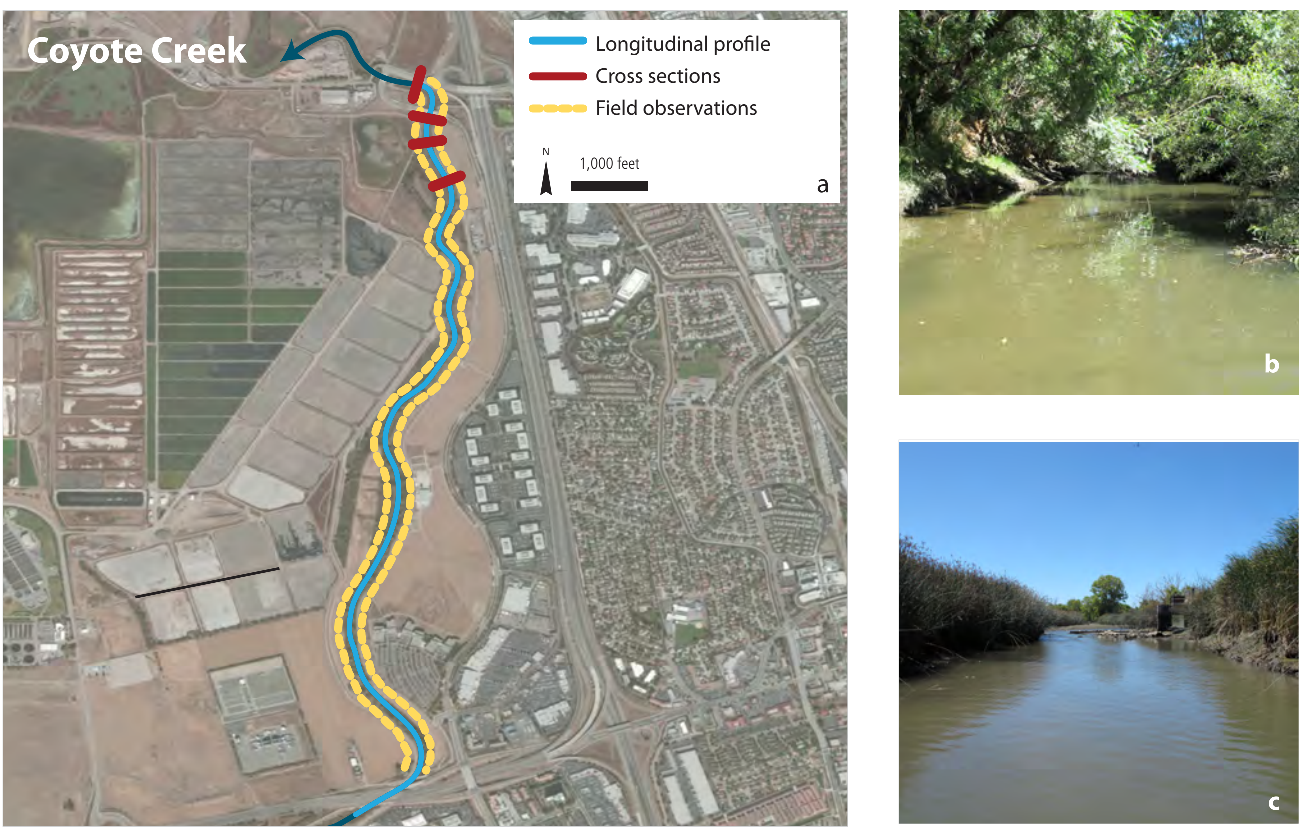


Figure 3.2F. Coyote Creek field measurements and observations. Showing a) location of field investigations, b) upstream project extent, c) downstream project extent. Extent of field observations are shown in dashed yellow. Vegetation was not mapped as it was deemed to not be a useful indicator of the HoT at this site.

features (e.g., depositional bars and pool-riffle units), and the presence of persistent high water marks (e.g., high tide indicators on vegetation) were also recorded (Figure 3.3).

Following topographic and geomorphic data collection and compilation efforts, vegetation mapping was done at selected sites where geomorphic and other field indicators alone were insufficient for identifying the current HoT zone. Vegetation mapping followed the protocol used in the California Rapid Assessment Method (CRAM), a field-based method for rapidly determining the condition of wetlands in both riverine and estuarine environments[5]. This method assesses the variety and interspersion of plant zones present at a site. Mapping included delineating discrete plant zones within and adjacent to the channel along the study site from just downstream of the presumed mean tide level to just upstream of the estimated current HoT zone location. Each plant zone mapped represented a distinct combination of growth form and species composition, with zones defined by a single plant species (e.g., pickleweed) or by an association of species (e.g., pickleweed intermixed with salt grass). Only zones comprising more than 5% of the study site mapping area were considered. Each zone was described by its dominant vegetation. Dominants were defined as species that constitute at least 10% of the total vegetation cover within the zone. Vegetation zones were mapped in the field on hard copies of high resolution aerial photographs while walking the study sites. Following the field effort, the maps were digitized in GIS and attributed with the most relevant information, which included species composition and a general indication of the species salinity tolerance, indicating general local salinity tolerance (i.e., saltwater, brackish, and freshwater species).

In an effort to develop an estimate of local MHHW elevation, water surface elevation was recorded at Wildcat Creek on a 1-hour time step from June 25, 2013 to July 24, 2013 and compared to the tidal elevation from the tide gage at Port Chicago (NOAA gage 9415144). Resource constraints allowed for monitoring at just one study site and the Wildcat Creek site was selected as a good representation of average conditions for all study sites. Water surface elevation was recorded by a set of three pressure transducers placed in stilling wells installed throughout the study site; the downstream well was located below the presumed mean tide level, the middle well was located just upstream of a grade control structure, and the upstream well was located near the presumed inland extent of MHHW. Typical of summertime conditions for this area, the monitoring period was characterized by very little to no river inflow, which was ideal for capturing just the tidal influence on the local water surface elevation. The monitoring period also coincided with the highest spring tides of the summer months.

Field observations of the future HoT zone (i.e., the inland extent of tidal influence when high tide is ~1 foot above current MHHW) at all study sites were made during the "king tides" in January 2013 and 2014. King tides are the highest predicted tides of the year and are used in the San Francisco Bay area as an indication of what typical high tides may look like in the near future with continuing sea level rise (see the California King Tides Initiative website[6] for more detail). During mid-day king tides on January 9 and 10, 2013, the observed inland extent of tidal influence before and after predicted high tide was marked with handheld GPS waypoints at the Alhambra Creek, Novato Creek, Sonoma Creek, Sulphur Creek, and Wildcat Creek study sites. The inland extent of tidal influence was determined qualitatively by observing the local flow direction indicated by floating debris. At the Coyote Creek site, the observed inland extent of tidal influence before and after high tide was determined quantitatively by monitoring water surface elevations during a mid-day king tide on January 2, 2014. We attempted to observe king tides an elevation of 1 ft. above MHHW (as given by the closest NOAA tide

[5] CRAM resources website: http://www.cramwetlands.org/

[6] California King Tides Initiative website: http://california.kingtides.net/

a. Tidal scour line. This indicator refers to the area in a tidal channel, below the elevation of the marsh plain, which is inundated and scoured diurnally by tides and therefore uninhabitable for even salt tolerant plants. Above the line, it is common to observe exposed roots and an under hanging bank, while below the line, the bank is often smooth and steep. This line demarcates the tidal water surface elevation which occurs frequently enough to do geomorphic work (i.e., the MHHW elevation), and therefore affect the channel form and vegetation communities. It can be traced upstream until it disappears, indicating a decrease in tidal energy that shapes the channel. (Location: Sulphur Creek)

b. In-channel bars at the fluvial-tidal transition. This indicator refers to fluvial gravel or sand bars which occur at the transition in a channel between fluvial and tidal dominance. This type of organization indicates a more downstream extent of fluvial energy, often occurring during a high flow event. The disappearance of these bars and associated transition in bed texture from gravel and sand to mud/silt often occurs in the HoT zone. (Location: Novato Creek)

c. Vegetation desiccation line. Like the tidal scour line, this indicator marks an elevation of regular tidal inundation. This indicator is characterized by tidal desiccation of non-tidal bank vegetation that overhangs into the channel. Tidal inundation is thought to render the vegetation white colored in a line at the MHHW elevation. Further observations are needed to determine the relationship between the vegetation desiccation line and the tidal scour line. (Location: Novato Creek)

Figure 3.3. Key HoT zone field indicators. a) tidal scour line, b) in-channel bars at the fluvial tidal transition, c) vegetation desiccation line.

gage), but it was not possible to observe that exact condition. The actual elevations observed during the field investigations at all sites ranged from 0.8 ft. to 1.4 ft. above MHHW based on the closest tide gage. River inflow to the sites during the observations ranged from <10 cfs to ~50 cfs, with the flows proportional to the contributing watershed area. Indicators of the previous days' king tides (e.g., silt and wrack lines) were also useful in determining the inland tidal extent at some sites.

3.3.4 RESULTS

The results from the desktop and field investigations at the six study sites are presented in the following sections, beginning with the site that has the smallest contributing watershed and ending with the site that has the largest, and are summarized in Table 3.3. Here, we show a synthesis of only the most salient information collected and used for determining the current and future HoT zones, and provide a general assessment of management implications associated with HoT zone inland migration at each study site. The complete channel cross-section, vegetation mapping, and water surface elevation data used in the analyses presented in this section are provided in Appendices B, C, and D, respectively.

Table 3.3. Summary of findings from the desktop and field investigations

Study site	Study site channel gradient		Current HoT zone			Future HoT zone			
			Desktop investigation	Field investigation		Desktop investigation		Field investigation	
	LiDAR	Ground survey	HoT zone length (ft)	Key field indicators	HoT zone width based on key field indicators (ft)	HoT zone width (ft)	Distance inland from current HoT zone[a] (ft)	HoT zone width (ft)	Distance inland from current HoT zone[a] (ft)
Sulphur Creek	0.15%	0.10%	~1,700	- bank scour - vegetation	~400	~1,500	~300	~700	~1,800
Wildcat Creek	0.40%	0.20%	~500[c]	- bank scour - vegetation	<100	~300	~200	~2,000[b]	~1,000[b]
Alhambra Creek	0.40%	0.20%	~900	- bed texture/ bar features - vegetation	~800	~1,200	~500	~800	~500
Novato Creek	0.20%	0.15%	~600	- bank scour - high water marks	<100	~700	~300	~500[b]	0[b]
Sonoma Creek	0.15%	0.20%	No data[c]	- bed texture/ bar features	~300	No data[c]	No data[c]	~3,000[b]	200[b]
Coyote Creek	0.10%	0.05%	~2,000	- bank scour - high water marks	~1,800	~3,000	~2,500	~200	~2,500

[a] Measured from the center of the current and future HoT zones
[b] Estimate considerably affected by high river flow coming into the site during the field investigation
[c] Estimate not possible due to issues with the NOAA SLR viewer output at this site.

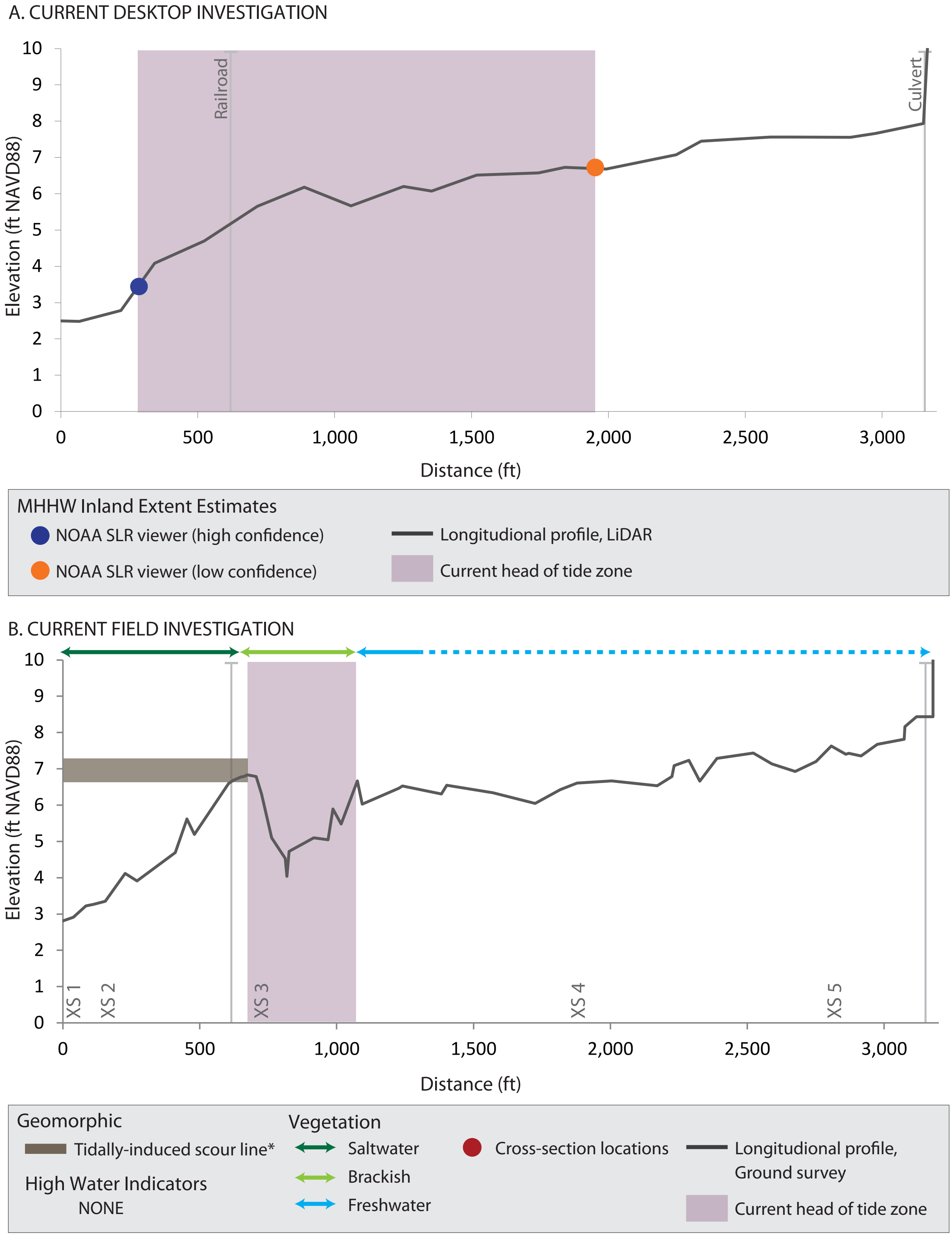
3.3.4.1 Sulphur Creek

Current head of tide The results from the desktop investigation for developing a coarse estimate of the current Sulphur Creek HoT zone are shown in Figure 3.4A. Combining the channel longitudinal profile from the 2010 LiDAR dataset with the NOAA SLR viewer output to show the HoT zone in profile illustrates a relatively long distance between where the lower and upper estimates of MHHW cross the channel bed. The zone is approximately 1,700 ft. long, varies in bed elevation by approximately 3.5 ft., and has a longitudinal slope that is somewhat less than the LiDAR-derived channel slope through the entire study site (0.15%).

The results from the field investigation for developing a finer-scale estimate of the current Sulphur Creek HoT zone are shown in Figure 3.4B. The field investigation included surveying a longitudinal profile and channel cross-sections along the length of the study site (i.e., from a location presumed to be below mean tidal elevation to an 8 ft. tall concrete channel step that marks the end of tidal influence), as well as vegetation mapping. The vegetation mapping showed a transition in vegetation zones from brackish to freshwater, indicating decreasing tidal influence, approximately 400 ft. upstream of where tidally-induced bank scour disappeared (Figure 3.5). Changes in bed texture were not observed, possibly due to sediment delivery disruption associated with the hanging culvert upstream. The current HoT zone estimated from the field investigation is therefore thought to be between the field-observed bank scour disappearance location and the shift in vegetation type. This location is within but towards the downstream end of the desktop-derived current HoT zone. Though the field-based HoT zone is several hundred feet long, it provides a more robust estimate than the desktop-derived estimate.

Future head of tide The results from the desktop and field investigations for developing a future Sulphur Creek HoT zone estimate are shown in Figures 3.4C and 3.4D. The NOAA SLR viewer predicts that a 1-foot increase in MHHW translates into an upstream migration of the center of the HoT zone of approximately 200 ft. For the field investigation, the future HoT zone was determined by observing the inland extent of high tide on January 10, 2013 when high tide was approximately 1.1 ft. above MHHW (as recorded at the nearby NOAA Alameda tide gage). The field investigation results suggest that the predicted future HoT zone will be several hundred feet shorter and the center approximately 1,000 ft. further inland than the desktop-derived future HoT zone. These results suggest that the field investigation provided a more resolute indication of the future HoT zone than the desktop investigation.

General management implications A plan view perspective of the identified current and future HoT zone for Sulphur Creek is shown in Figure 3.6. This figure illustrates that the field-derived HoT zone in this relatively low gradient, engineered channel will migrate over 1,000 ft. inland over the next several decades, ultimately being contained by an elevated culvert that passes beneath the Hayward Executive Airport (see Figure 3.2A). As the HoT zone migrates upstream with a rising MHHW, depending on the channel size, there could be an increase in storm-induced flooding within and adjacent to the zone, which includes the industrial areas on the southern floodplain, the golf course on the northern floodplain, and the railroad crossing just downstream of the current HoT zone. At the same time, an increasing MHHW will increase tidal prism which will result in increased channel scouring and affect in-channel infrastructure. This issue will need to be considered when making decisions regarding best management approaches for lower Sulphur Creek and options for maintaining a high level of flood protection.



*Scour line width determined by the upper and lower scour line elevation field measurements

Figure 3.4A and B. Current Sulphur Creek HoT Zone. (A) The resulting current zone from the desktop indicators (purple box) falls between the high and low confidence points of MHHW inland extent using the NOAA SLR viewer. (B) The current HoT zone from field indicators (purple box) is within the desktop and is between the elevation of tidally induced scour and the transition from backish to freshwater vegetation.

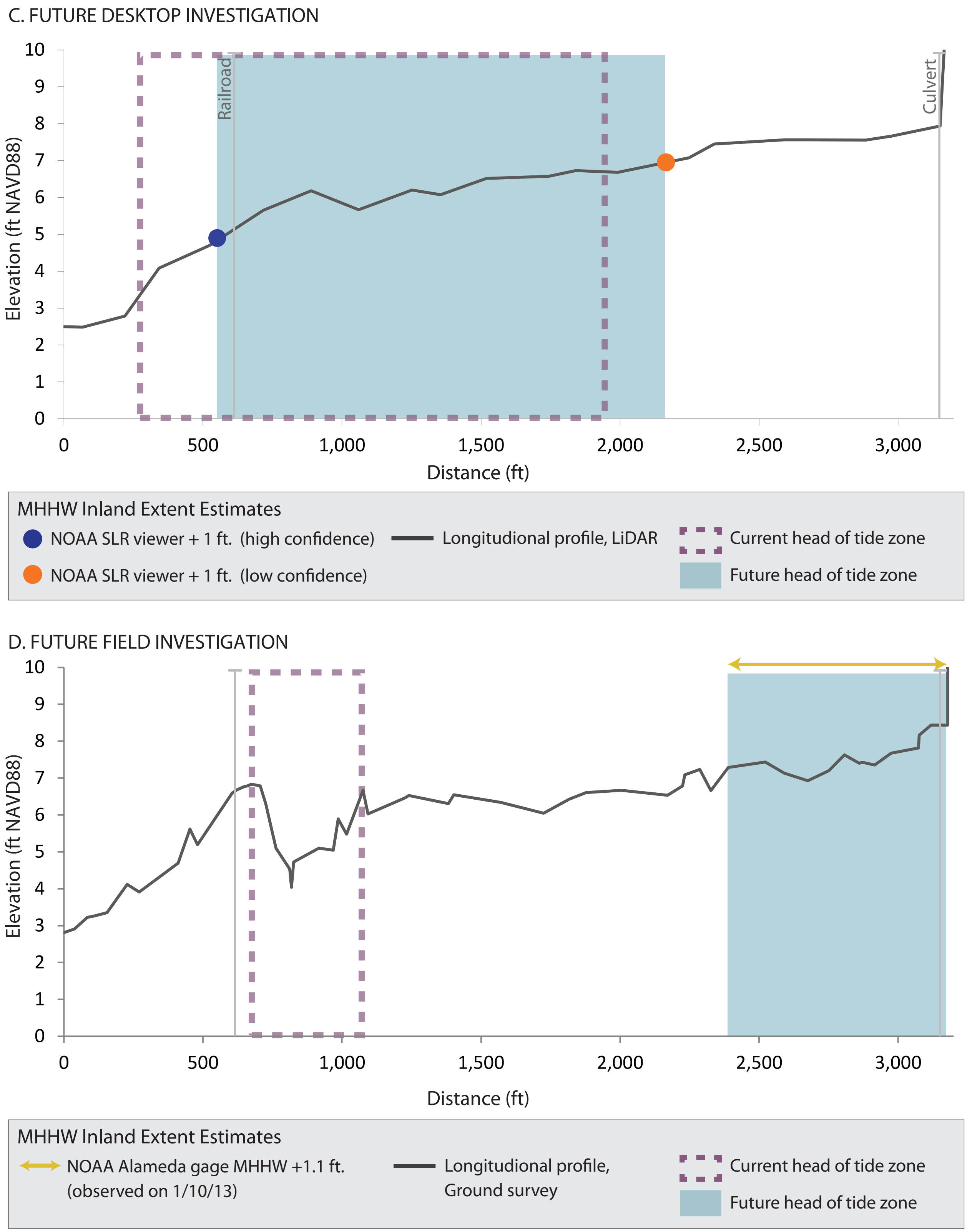


Figure 3.4C and D. Future Sulphur Creek HoT Zone. (A) The resulting future HoT from the desktop indicators (blue box) falls between the high and low confidence points of MHHW + 1 inland extent using the NOAA SLR viewer. (B) The future HoT from field indicators (blue box) is upstream of the desktop result and is based on field observations at high tides.

Figure 3.5. Sulphur Creek looking upstream at fluvial-tidal transition. Showing the reach where tidally-induced bank scour disappears and there is a transition from brackish to freshwater vegetation.

CURRENT
Desktop Indicators
Field Indicators
FUTURE
Desktop Indicators
Field Indicator

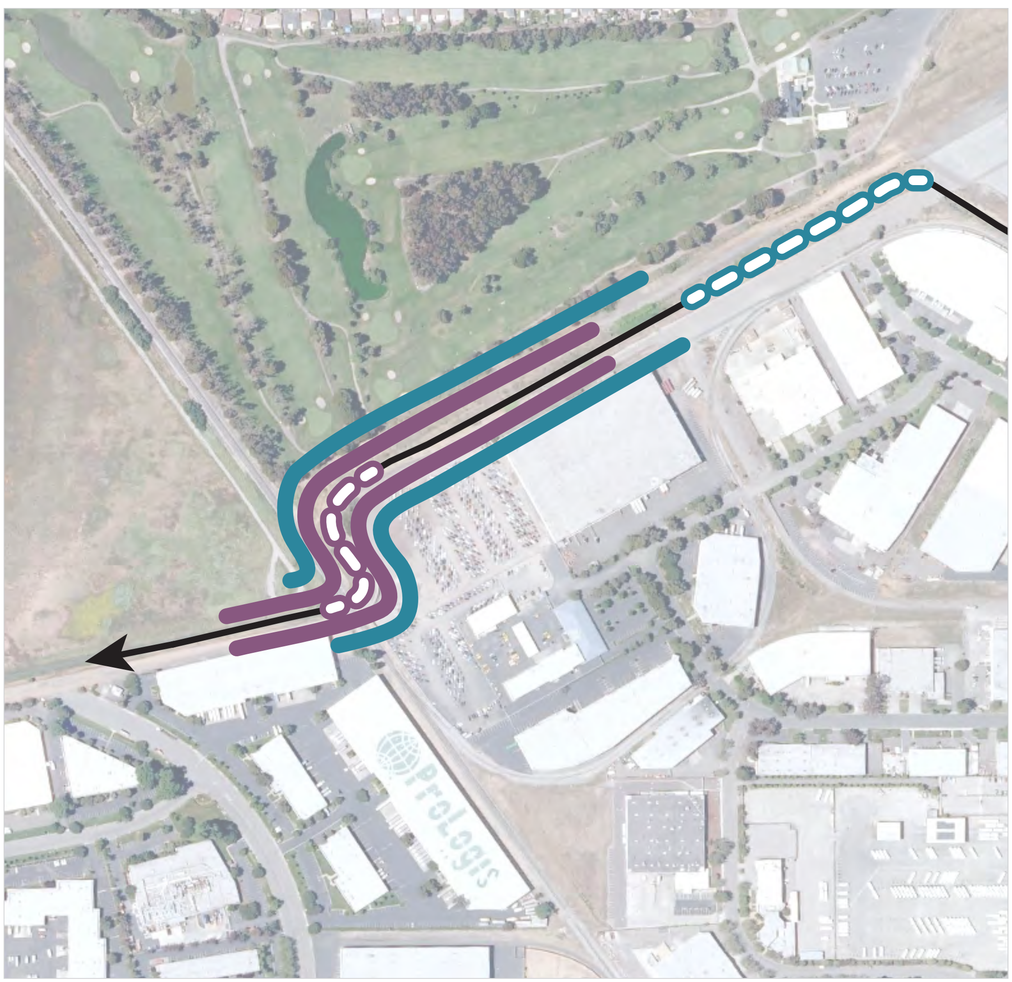


Figure 3.6. Sulphur Creek HoT Zone Summary. This plan view shows the results of the desktop and field investigations for both the current and future HoT.

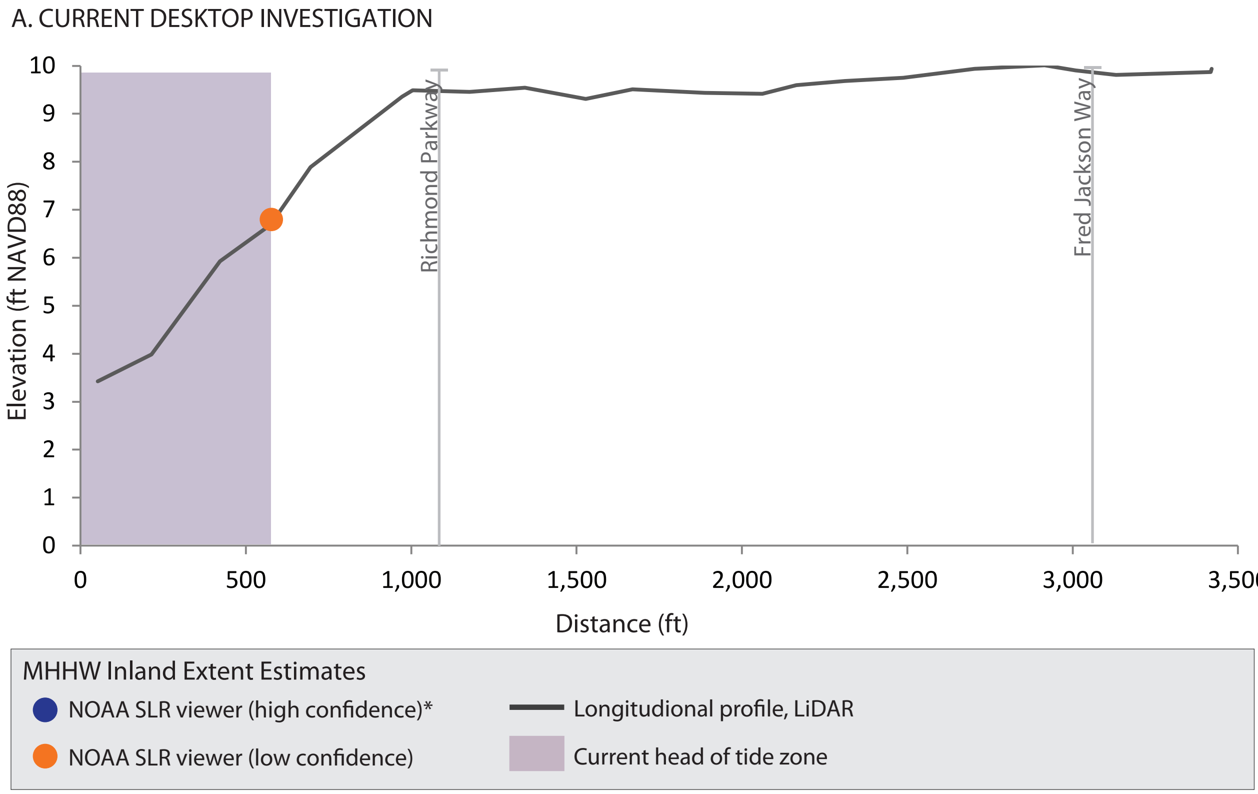
3.3.4.2 Wildcat Creek

Current head of tide The results from the desktop investigation for estimating the current Wildcat Creek HoT zone are shown in Figure 3.7A. Combining the channel longitudinal profile from the 2010 LiDAR dataset with NOAA SLR viewer output shows a relatively small range in predicted MHHW elevations and consequently a relatively short distance between the locations where the lower and upper estimates of MHHW cross the channel bed. The zone is approximately 500 ft. long, varies in bed elevation by approximately 3 ft., and has a longitudinal slope that is greater than the LiDAR-derived average channel slope through the entire study site (0.4%).

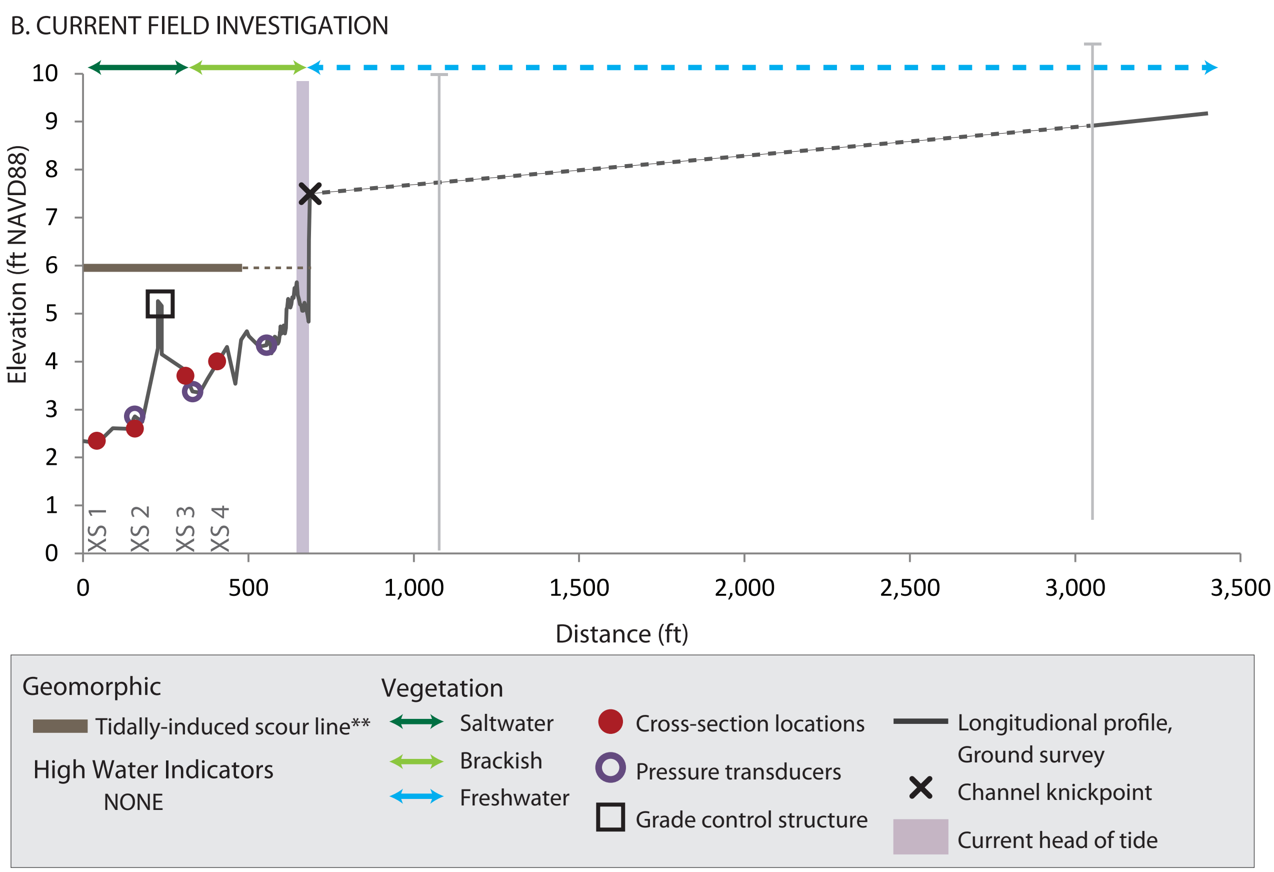
The results from the field investigation for estimating the current Wildcat Creek HoT zone are shown in Figure 3.7B. The field investigation included surveying a longitudinal profile from a location presumed to be below mean tide elevation upstream to a location presumed to be above regular tidal influence based on local vegetation, surveying channel cross-sections in the middle of the site, monitoring local water surface elevation, and vegetation mapping. Local water surface elevation was monitored continuously from late June to late July 2013 and then compared with Port Chicago tide gage data to get a cursory MHHW estimate at the site (under the assumption that Wildcat Creek MHHW occurs around the same time as Port Chicago MHHW, the closest tide gage tied to NAVD88). It was apparent during the initial field effort that the grade control structure in the middle of the site could be affecting tidally-induced bank scour observations and that a detailed vegetation map of the site would be useful in helping to locate the HoT zone. The vegetation mapping shows a transition in plant community composition from "brackish" to "freshwater" at the approximate position where the tidally-induced bank scour line essentially disappears, which is at a similar elevation as the local MHHW estimate derived from the water surface elevation monitoring (5.9 ft. NAVD88). The current HoT zone estimated from the field investigation is therefore thought to be at the bed elevation where the field indictors converge, which is at a channel knickpoint (a location in a channel where there is a sharp change in bed elevation) that likely marks the inland extent of tidal scour into fluvially deposited sediment (Figures 3.7B and 3.8). This location is approximately 200 ft. upstream of the desktop-derived current HoT zone and is considered to be a more robust HoT zone estimate.

It is important to note that the channel bed elevations within the Wildcat Creek study site differ considerably between the LiDAR and field-derived longitudinal profile data sets, with local differences ranging from approximately 1 ft. to over 3 ft. This difference, which is likely due to an overestimate of LiDAR elevation associated with water and/or vegetation interference, results in the LiDAR-derived channel gradient (0.4%) being approximately twice as high as the field-derived value (0.2%), but does not represent a considerable change in the current HoT zone estimate because the channel knickpoint location and elevation are similar for both datasets and therefore they yield comparable estimates of the location of MHHW.

Future head of tide The results from the desktop and field investigations for developing an estimate of the future Wildcat Creek HoT zone are shown in Figures 3.7C and 3.7D. The NOAA SLR viewer predicts that a 1-foot increase in MHHW will cause the center of the HoT zone to migrate inland approximately 200 ft. For the field investigation, the future HoT zone was determined by observing the inland extent of high tide on January 10, 2013 when high tide was approximately 0.9 ft. above MHHW (as recorded at the nearby NOAA



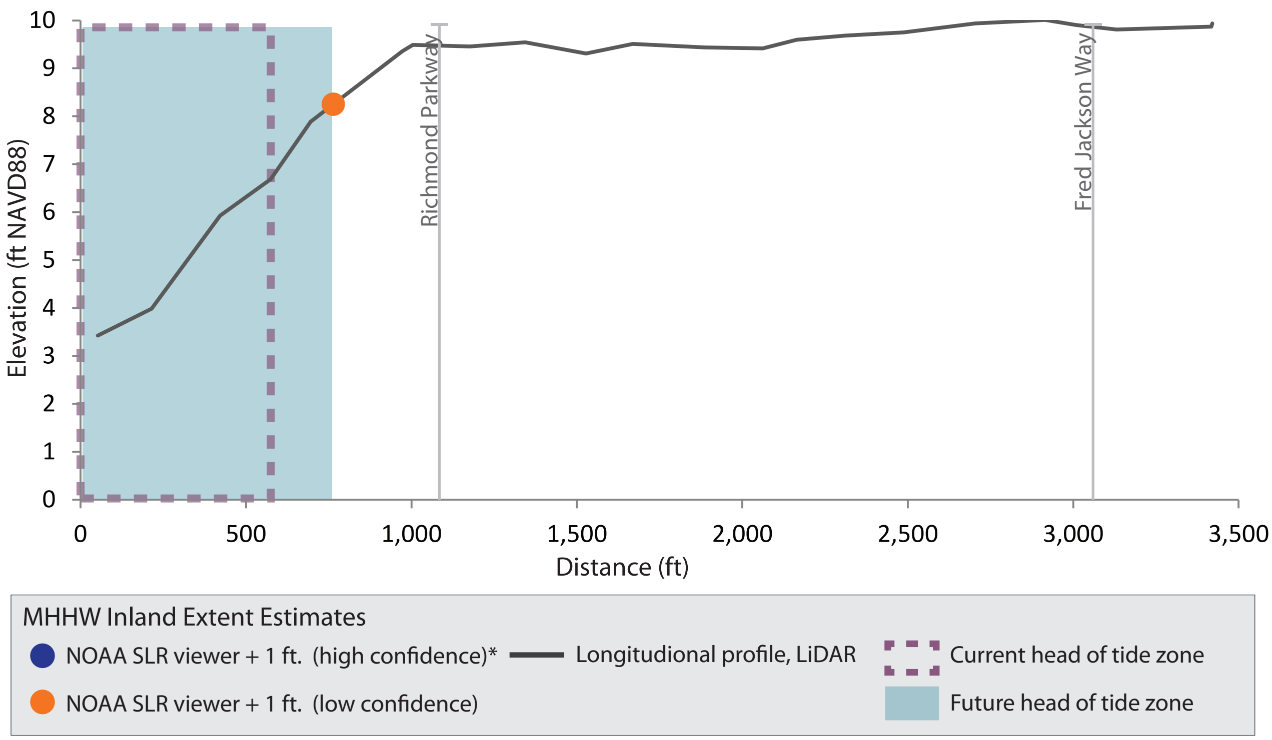
* Location is 740 ft. downstream of long profile extent



**Scour line width determined by the upper and lower scour line elevation field measurements

Figure 3.7A and B. Current Wildcat Creek HoT Zone. (A) The desktop estimate for the current HoT (purple box) is based on the high confidence point of MHHW inland extent using the NOAA SLR viewer and the downstream extent of the long profile. (B) The current field HoT (purple box) is based on field observations including vegetation mapping and field surveys, and is much narrower and slightly upstream of the desktop estimate. Dashed lines indicate assumed continuation of indicators such as scour line and vegetation types.

C. FUTURE DESKTOP INVESTIGATION



* Location is 620 ft. downstream of long profile extent

D. FUTURE FIELD INVESTIGATION

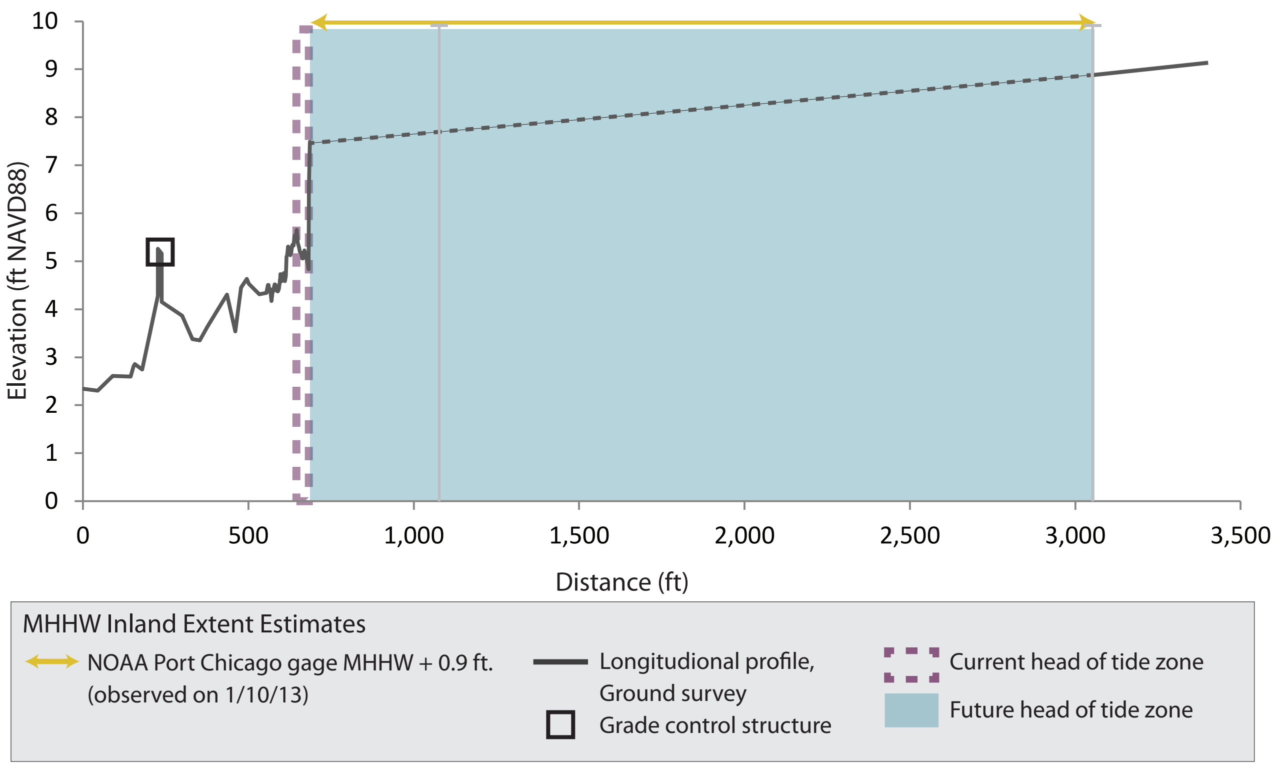


Figure 3.7C and D. Future Wildcat Creek HoT Zone. (A) The desktop estimate for the future (blue box) is between the result of the low confidence SLR viewer inland extent indicating MHHW +1 ft., and the downstream extent of the current desktop HoT. (B) The field estimate for the future HoT (blue box) is much wider due to the inconclusiveness of field investigations during the king tide of Jan 10, 2013.

Figure 3.8. Head of knick point in Wildcat Creek. Photo showing the knick point marking the limit of tidal influence in Wildcat Creek.

Port Chicago tide gage). Unfortunately, the incoming tide was assumed to be the source of the large volume of water in the channel during the field investigation, when in reality the source was high river flow from the watershed. Because of this assumption, the field procedure erroneously predicted the future HoT zone to be more than over 2,000 ft. upstream of the channel knickpoint. In this instance, the field investigation did not provide a more resolute indication of the future HoT zone than the desktop investigation.

General management implications A plan view perspective of the identified current and future HoT zone for Wildcat Creek is shown in Figure 3.9. It is likely that the future HoT zone will be controlled by the channel knickpoint and will remain at a similar location as the current HoT zone. Under this assumption, the HoT zone will begin to migrate upstream once MHHW reaches the top of the knickpoint, which is ~0.5 ft. above the future MHHW elevation used in this analysis. However, an increasing MHHW will also likely result in continued inland migration of the channel knickpoint because of increase erosive energy against the channel head, into the fine grained fluvial bed sediments that characterize lower Wildcat Creek. This may also increase bed scour through the current HoT zone, possibly compromising infrastructure such as buried sewer laterals that currently cross the creek. Over the next several decades while the HoT zone remains relatively stationary, increasing MHHW elevation will result in an increase in storm-induced flooding potential within and adjacent to the

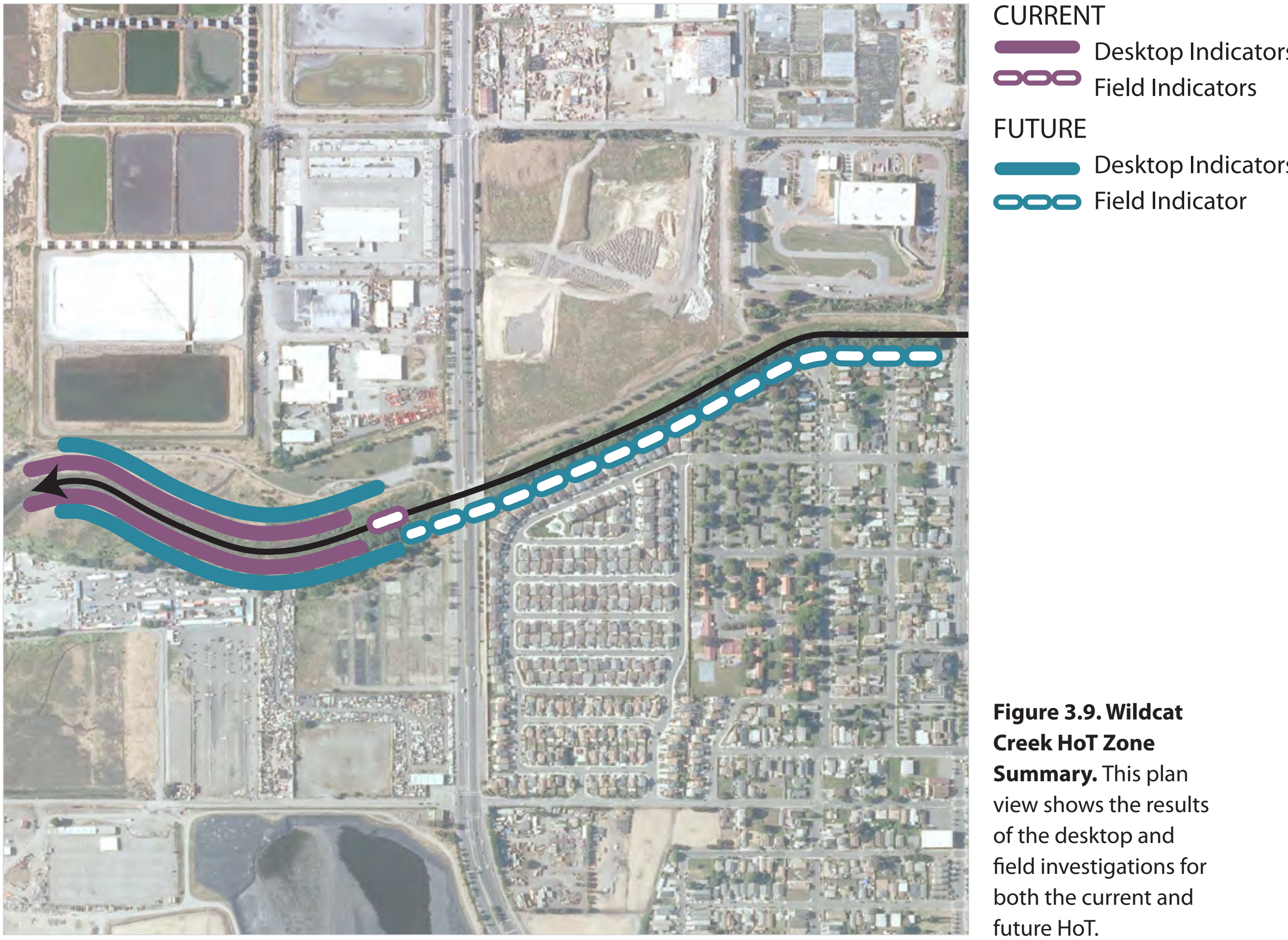
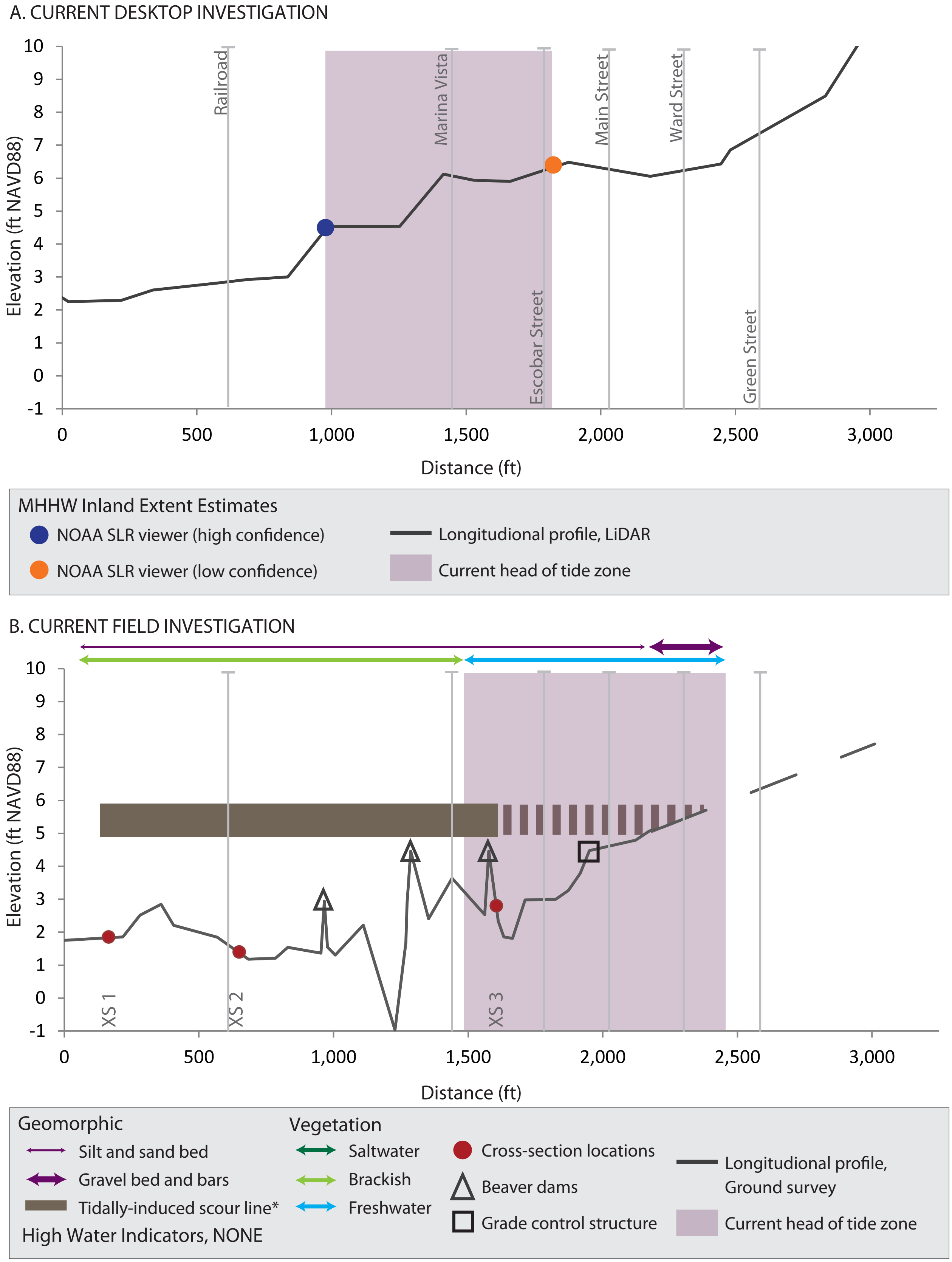


Figure 3.9. Wildcat Creek HoT Zone Summary. This plan view shows the results of the desktop and field investigations for both the current and future HoT.

zone, which includes the industrial and developed areas on the southern floodplain and the industrial and commercial areas on the northern floodplains. At the same time, an increasing MHHW will cause more frequent inundation of the marsh at the downstream end of the study site, which will result in decreased Wildcat Creek floodwater storage capacity and a compression of the marsh habitat and ecological value of the HoT zone against the Richmond Parkway. These issues will need to be considered when making decisions regarding management approaches for lower Wildcat Creek and options for maintaining a high level of flood and habitat protection.

3.3.4.3 Alhambra Creek

Current head of tide The results from the desktop investigation for estimating the current Alhambra Creek HoT zone are shown in Figure 3.10A. Combining the channel longitudinal profile from the 2010 LiDAR dataset with the NOAA SLR viewer output shows a relatively large range in MHHW elevations and consequently a long distance between where the lower and upper estimates cross the channel bed. The HoT zone is approximately 900 ft. long, varies in bed elevation by approximately 2 ft., and has a longitudinal slope that is much less than the LiDAR-derived channel slope (0.4%) through the entire study site.



*Scour line width driven by the upper and lower scour line elevation measurements

Figure 3.10A and B. Current Alhambra Creek HoT Zone. (A) The resulting current HoT from the desktop indicators (purple box) falls between the high and low confidence points of MHHW inland extent using the NOAA SLR viewer. (B) The current HoT from field indicators (purple box) overlaps with the desktop zone but extends upstream. This HoT is based on observations of the tidally influenced scour line, as well the transition from brackish to freshwater vegetation. The width of the scour line indicates the range of elevations where it was measured, and the dashed lined indicates its assumed extent.

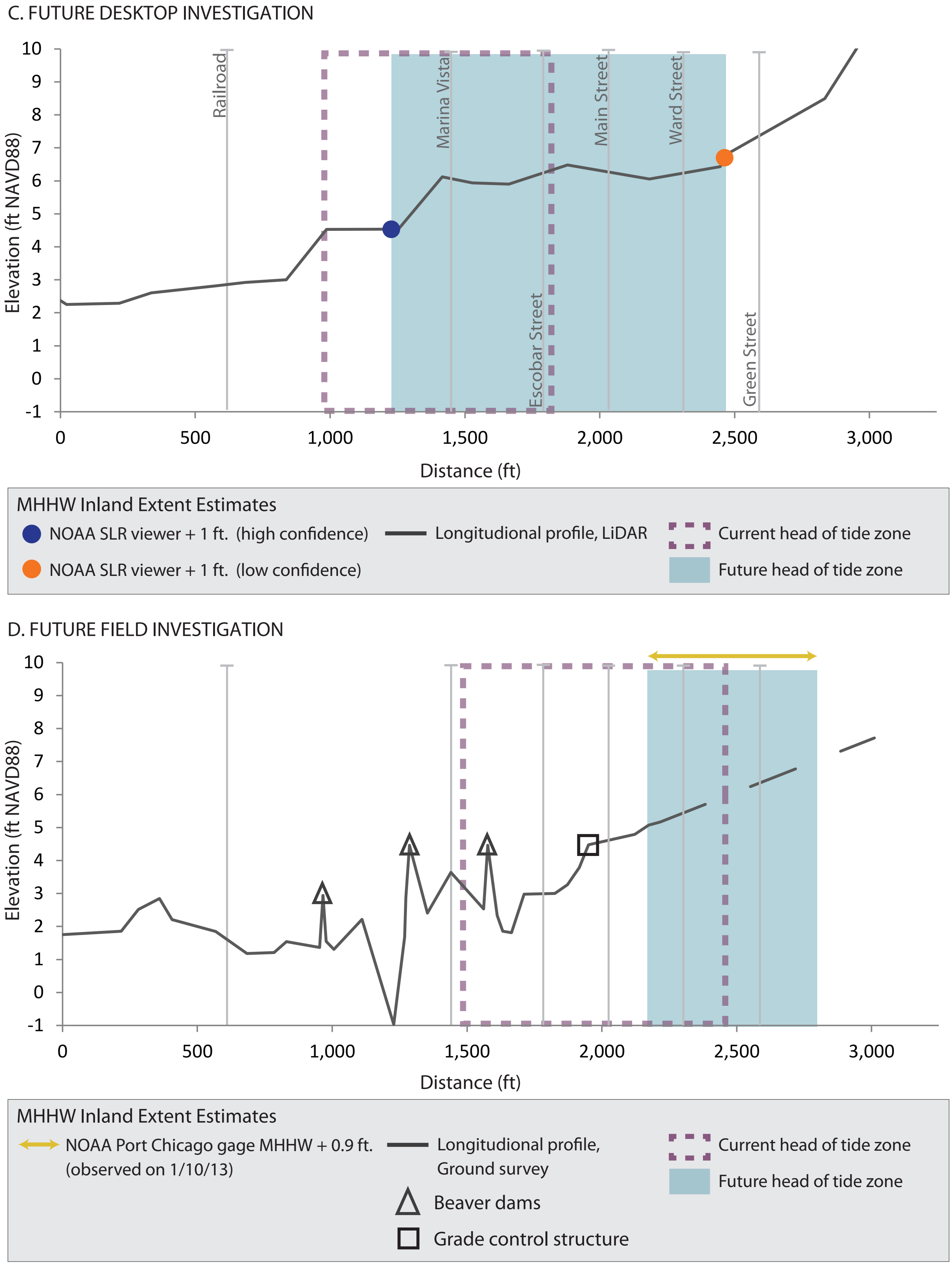


Figure 3.10C and D. Future Alhambra Creek HoT Zone. (A) The resulting future HoT from the desktop indicators (blue box) falls between the high and low confidence points of MHHW + 1 ft. using the NOAA SLR viewer and spans many city blocks. (B) The future HoT from field indicators (blue box) is upstream of the desktop estimate and is based on field observations at high tides.

Figure 3.11. Alhambra Creek field observed HoT Zone. Showing a fluvially-dominated vegetated bar feature with deposits of coarse sediment. Willows are pictured low to the channel in the background indicating freshwater dominance.

The results from the field investigation for estimating the current Alhambra Creek HoT zone are shown in Figure 3.10B. The field investigation included surveying a longitudinal profile from a location presumed to be below mean tide elevation upstream to a location presumed to be above regular tidal influence based on local vegetation; surveying channel cross-sections from the downstream end to the middle of the site, noting general bed texture and geomorphic characteristics; and vegetation mapping. It was apparent during the initial field effort that field geomorphic observations alone in such a relatively steep channel impacted by several grade control structures and considerable beaver activity may provide an incomplete or even inaccurate picture of the HoT zone and should be combined with other field indicators. Therefore, detailed vegetation mapping of the site was conducted during a follow-up field visit. The vegetation mapping shows a transition in plant community composition from brackish to freshwater species dominance approximately 800 ft. downstream of where both tidally-induced bank scour and fluvial depositional bar features disappeared (Figures 3.10B and 3.11). The current HoT zone estimated from the field investigation is therefore thought to be between the field-observed fluvial bar disappearance location and the shift in vegetation type occurring between Ward Street and Green Street. This zone overlaps with the desktop-derived current HoT zone extent and appears to provide a finer-scale estimate of the current HoT zone.

Similar to Wildcat Creek, the channel bed elevations within the Alhambra Creek study site differ considerably between the LiDAR and field-derived longitudinal profile data sets, with local differences ranging from approximately 0.5 ft. to over 5 ft. This difference, which is likely due to artificially high LiDAR elevations associated with water and/or vegetation interference, suggests that the current HoT zone estimated using the desktop procedure would likely be much further inland using the correct channel bed elevations. The difference in channel bed elevations also indicates that the LiDAR and field-derived channel gradients are different, with the LiDAR channel gradient through the entire study site (0.4%) being almost twice as high as the field-derived value (0.2%).

Future head of tide The results from the desktop and field investigations for estimating a future Alhambra Creek HoT zone are shown in Figures 3.10C and 3.10D. The NOAA SLR viewer predicts that a 1-foot increase in MHHW will cause the center of the HoT zone to migrate approximately 500 ft. For the field investigation, the future HoT zone was determined by observing the inland extent of high tide on January 10, 2013, when high tide was approximately 0.9 ft. above MHHW (as recorded at the nearby NOAA Port Chicago tide gage). The field investigation results suggest that the predicted future HoT zone center will be several hundred feet shorter and approximately 800 ft. further inland than the desktop-derived future HoT zone. These results suggest that the field investigation provided a more resolute indication of the future HoT zone than the desktop investigation.

General management implications A plan view perspective of the identified current and future HoT zones for Alhambra Creek is shown in Figure 3.12. This figure illustrates that the field-derived HoT zone in this relatively high gradient, engineered channel will migrate only a few hundred feet inland through the town of Martinez over the next several decades, with the extent of migration being controlled by the relatively steep gradient of the channel coming

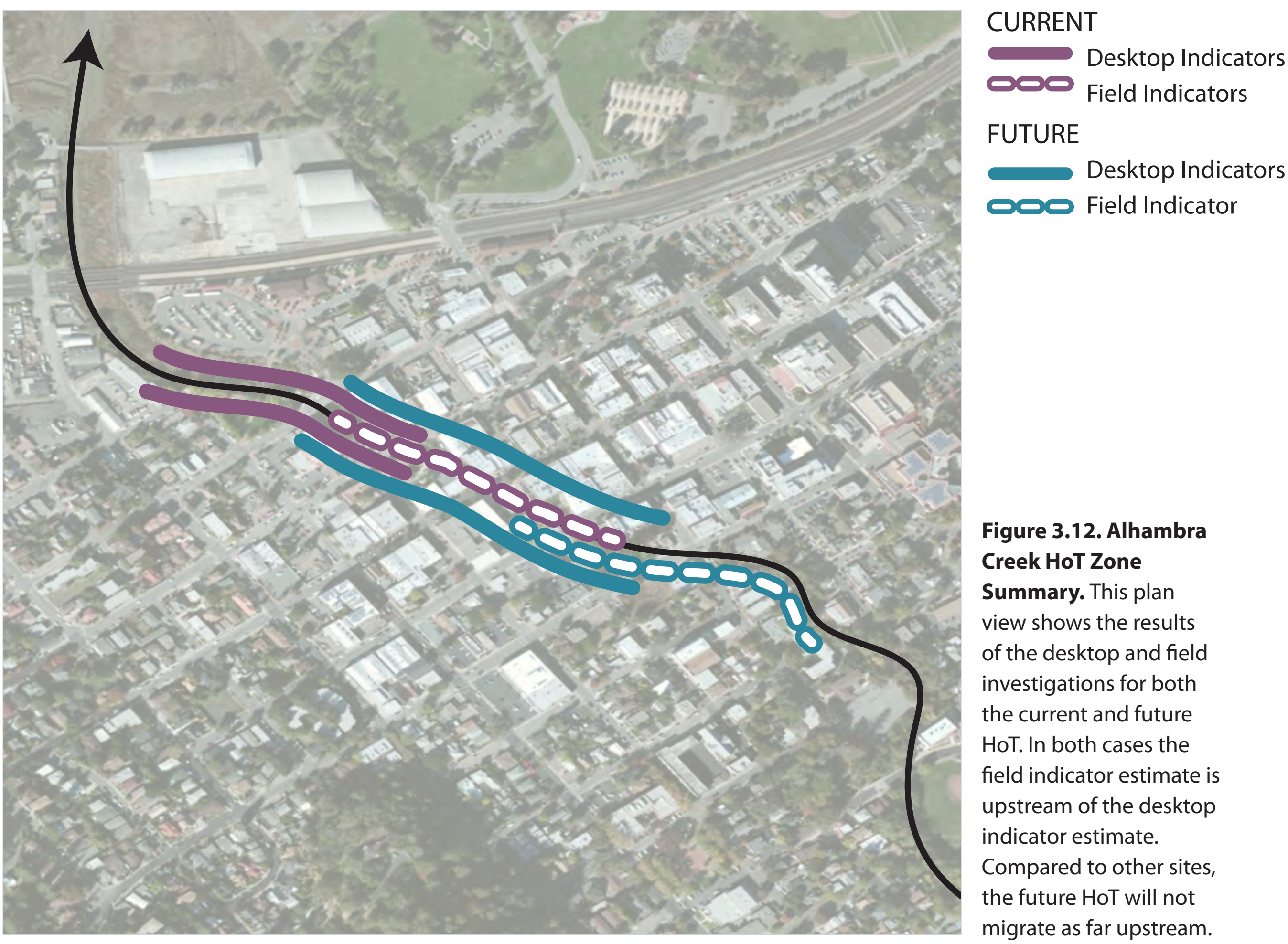


Figure 3.12. Alhambra Creek HoT Zone Summary. This plan view shows the results of the desktop and field investigations for both the current and future HoT. In both cases the field indicator estimate is upstream of the desktop indicator estimate. Compared to other sites, the future HoT will not migrate as far upstream.

out of the watershed and into the fluvial-tidal transition zone. As the HoT zone migrates upstream, there will be an associated increase in storm-induced flooding potential within and adjacent to the zone, which includes commercial areas on the northern and southern floodplains, as well as six road bridges and two foot bridges. A migrating HoT zone will have impacts on sediment deposition and bed scour dynamics, which could impact important in-channel habitat features (e.g., beaver dams, species diversity). A rising MHHW will also cause more frequent inundation of the restored marsh at the downstream end of the study site, which will result in decreased Alhambra Creek floodwater storage capacity. However, the relatively steep channel gradient upstream of the current HoT zone suggests that the increase in flooding will be mostly contained within and downstream of the HoT zone. Management decisions regarding flood protection and in-stream habitat in lower Alhambra Creek will have to be considered in order to best manage this HoT zone and protect against flooding, to provide protection for important infrastructure, and protect against the compression of this ecologically significant zone.

3.3.4.4 Novato Creek

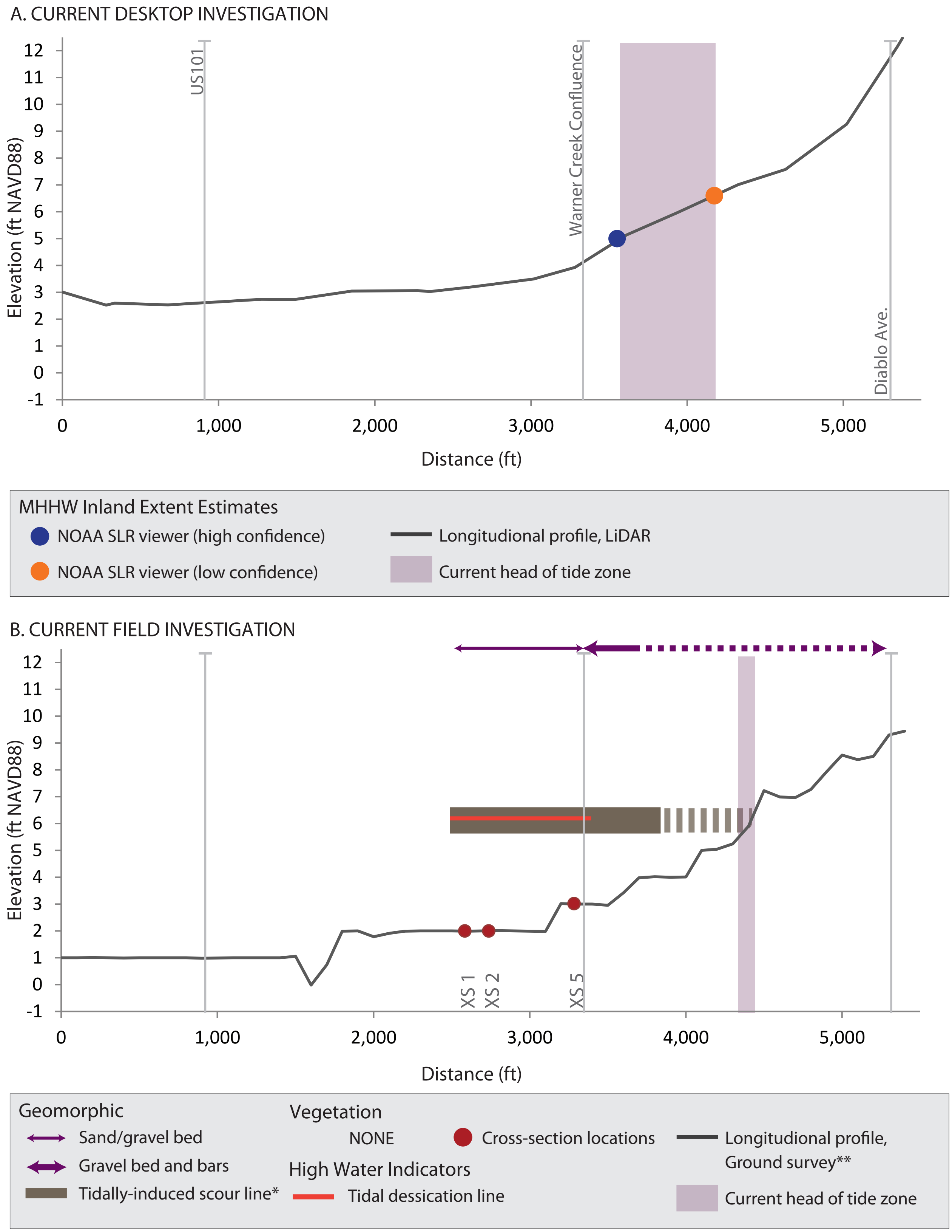
Current head of tide The results from the desktop investigation of the current Novato Creek HoT zone are shown in Figure 3.13A. Combining the channel longitudinal profile from the 2010 LiDAR dataset with the NOAA SLR viewer output shows a relatively narrow range in predicted MHHW elevations and consequently a relatively narrow distance between the positions where the lower and upper estimates cross the channel bed. The zone is approximately 600 ft. long, varies in bed elevation by approximately 2 ft., and has a longitudinal slope that is somewhat greater than the LiDAR-derived channel slope through the entire study site (0.2%).

The results from the field investigation for developing a fine-scale estimate of the current Novato Creek HoT zone are shown in Figure 3.13B. The field investigation, which occurred right after channel maintenance dredging to maintain flood capacity, included collecting channel cross-section data towards the downstream end of the study site and making observations of the channel and adjacent floodplain from a location presumed to be below mean tidal elevation to a location presumed to be well above regular tidal influence based on local vegetation. The field observations included noting high water indicators, general changes in bed texture, and channel morphologic characteristics. Observations indicated that fluvial features extend far into the tidal frame (likely due in part to a local influx of coarse sediment from Warner Creek) and that regular tidal inundation with salt water causes desiccation of overhanging bank vegetation that appeared to coincide with the upper limit of tidally-induced bank scour (Figure 3.14). The current HoT zone estimated from the field investigation is therefore estimated to be at the location where a desiccated vegetation line disappeared, which coincided with the disappearance of tidally-induced bank scour. The field-derived current HoT zone location is just upstream of the current HoT zone extent derived from the desktop analysis and is considered to be a more refined estimate.

Future head of tide The results from the desktop and field investigations for estimating the future Novato Creek HoT zone are shown in Figures 3.13C and 3.13D. The NOAA SLR viewer predicts that a 1-foot increase in MHHW will cause the center of the HoT zone to migrate inland approximately 300 ft. For the field investigation, the future HoT zone was determined by observing the inland extent of high tide on January 9, 2013 when high tide was approximately 0.9 ft. above MHHW (as recorded at the nearby NOAA Sonoma Creek tide gage). High river flows during the field investigation affected observations of flow indicators (e.g., flow direction of surface debris) and resulted in the future zone extending downstream of the current zone. It should be noted, however, that the center of the desktop-derived and field-derived future HoT zones are at a similar location. Therefore, in this instance, the field investigation did not provide a more refined estimate than the desktop investigation.

General management implications A plan view perspective of the identified current and future HoT zones for Novato Creek is shown in Figure 3.15. Focusing on the desktop-derived findings, this figure illustrates that the HoT zone in this relatively low gradient, engineered channel will migrate only a few hundred feet inland over the next several decades, which, similar to Alhambra Creek, will be controlled by the relatively steep gradient of the channel coming out of the watershed and into the fluvial-tidal transition zone. As the HoT zone migrates with a rising MHHW elevation, there may be an associated increase in storm-induced flooding within and adjacent to the zone, which includes the commercial areas on the eastern floodplain, residential areas on the western floodplain, and four road bridges in the study site (as well as a road bridge and railroad bridges downstream). This area currently floods frequently during high flow/high tide conditions, impacting the residences and businesses adjacent to the creek. Future flooding as MHHW rises is likely to be a continuing concern for management agencies.

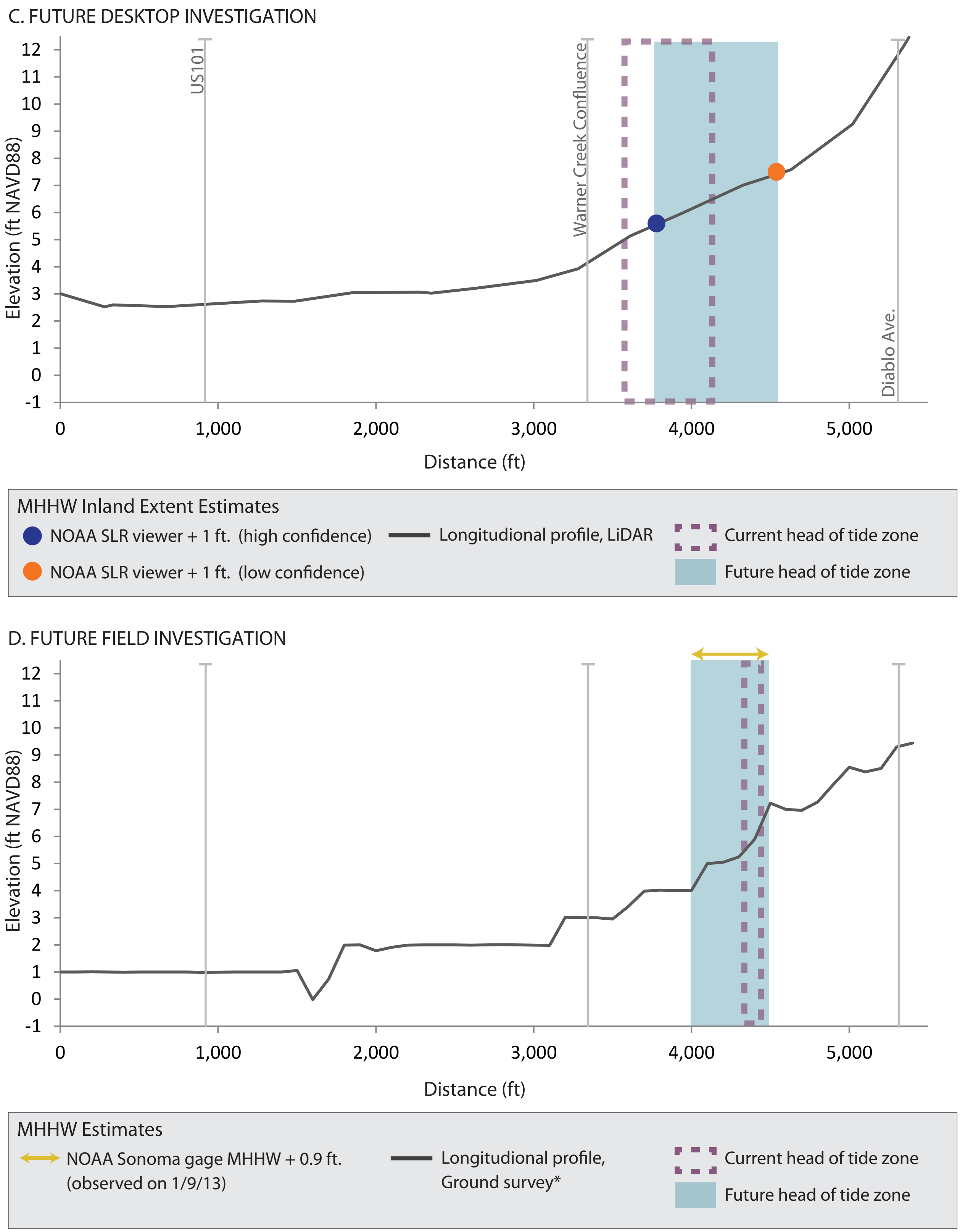
Marin County Flood Control and Water Conservation District (MCFC&WCD) is currently studying sediment dynamics and flow out of the watershed to plan for improved sediment management and flood protection approaches. The management of Novato Creek is complicated by the frequent sedimentation and dredging within the fluvial-tidal transition zone. Sedimentation within this zone will become exacerbated as sea level continues to rise, the channel gradient continues to decrease, and the channel sediment transport capacity continues to decline. In addition, an increasing MHHW will result in decreased flood water storage capacity in the managed basins at the downstream end of Novato Creek floodplain (although there are currently plans underway to restore much of the lower creek in the coming years). Like Alhambra Creek, the relatively steep channel gradient upstream of the current HoT zone suggests that the increase in flooding associated with a rising MHHW elevation will be relatively contained to the area within and downstream of the current HoT zone.



*Scour line width determined by the upper and lower scour line elevation field measurements

**Source: Kamman Hydrology & Engineering

Figure 3.13A and B. Current Novato Creek HoT Zone. (A) The resulting current HoT inland extent from the desktop indicators (purple box) falls between the high and low confidence points of the elevation of MHHW using the NOAA SLR viewer. (B) The current HoT from field indicators (purple box) is much shorter and is based on measurements of the desiccated vegetation and the tidally induced scour line (brown line) and its assumed extension upstream.



*Source: Kamman Hydrology & Engineering

Figure 3.13C and D. Future Novato Creek HoT Zone. (A) The resulting future HoT from the desktop indicators (blue box) falls between the high and low confidence points of MHHW + 1 ft. inland extent using the NOAA SLR viewer. (B) The future HoT from field indicators (blue box) is within the desktop result and is based on field observations at high tides.

Figure 3.14. Novato Creek desiccated vegetation line. Showing the line of desiccated vegetation caused by regular tidal inundation which matches the elevation of the scour line further upstream. The dissappearance of this line helps to indicate the current HoT.

CURRENT
- Desktop Indicators
- Field Indicators

FUTURE
- Desktop Indicators
- Field Indicator

Figure 3.15. Novato Creek HOT Summary. This plan view shows the results of the desktop and field investigations for both the current and future HoT zones. Compared to other sites, the future zone will not migrate far upstream, most likely because of the steep slope of the channel at the current HoT.

3.3.4.5 Sonoma Creek

Current head of tide The results from the desktop investigation for developing a coarse estimate of the current Sonoma Creek HoT zone are shown in Figure 3.16A. Unfortunately, the lower Sonoma Creek channel bed elevations within the 2010 NOAA LiDAR dataset are inaccurate (likely due to water and vegetation interference), resulting in excessively high LiDAR-derived longitudinal profile elevations well above MHHW elevations from the nearby NOAA Sonoma Creek tide gage approximately 6 miles downstream from the study site. The NOAA SLR viewer uses this same LiDAR dataset and therefore provided an estimate of the inland extent of MHHW that was too inaccurate for this study, as indicated by a comparison with the MHHW inland extent shown in other recent studies (e.g., ESA PWA 2012). Therefore, the desktop investigation was not possible.

The results from the field investigation for developing a finer-scale estimate of the current Sonoma Creek HoT zone are shown in Figure 3.16B. The field investigation included walking the channel from a location well above the presumed inland extent of MHHW downstream to a location within the tidal frame where tidal water was observed moving upstream during an average high tide. During the field investigation, it was apparent that channel geomorphic characteristics such as bed texture and depositional features were the best indicators of the current HoT zone in this relatively large, relatively steep channel system. Local channel bed sediment size distribution (e.g., sandy gravel) and the presence of fluvial point bars were observed (Figure 3.17). Based on field indicators, the current HoT zone is estimated to be at the location in the channel where the bed texture shifted from mostly gravel to mostly sand and silt, which coincided with the location where the predominance of fluvial point bars essentially ended. When these observations are combined with the best available field-based longitudinal profile for the study site (from ESA PWA 2012), it is clear that the geomorphic observations coincide with a considerable break in channel slope, which essentially marks the channel transition from fluvial to tidally-influenced condition, and the current HoT zone (see Figure 3.16B).

Future head of tide zone delineation The results of the Sonoma Creek future HoT zone field investigation are shown in Figure 3.22. As with the current HoT zone, the desktop investigation using the 2010 LiDAR dataset and the NOAA SLR viewer for the future HoT zone was not possible. For the field investigation, the future HoT zone was determined by observing the inland extent of high tide on January 9, 2013 when high tide was approximately 0.9 ft. above MHHW (as recorded at the nearby NOAA Sonoma Creek tide gage). Similar to Novato Creek, high river flow during the field investigation affected flow indicator observations and resulted in the future zone extending downstream of the current zone. However, the field investigation results suggest that the center of the HoT zone will migrate approximately 200 ft. inland. As there are no results from the desktop analysis, the field investigation provided the only estimate of the future HoT zone.

General management implications A plan view perspective of the identified current and future HoT zones for Sonoma Creek is shown in Figure 3.18. As explained above, there are only field-derived findings at this site. Overall, this figure illustrates that the HoT zone in this relatively high gradient, natural channel will migrate only a few hundred feet inland over the next several decades, which, similar to Alhambra Creek and Novato Creek, is controlled by the steep gradient of the entering the fluvial-tidal transition zone.

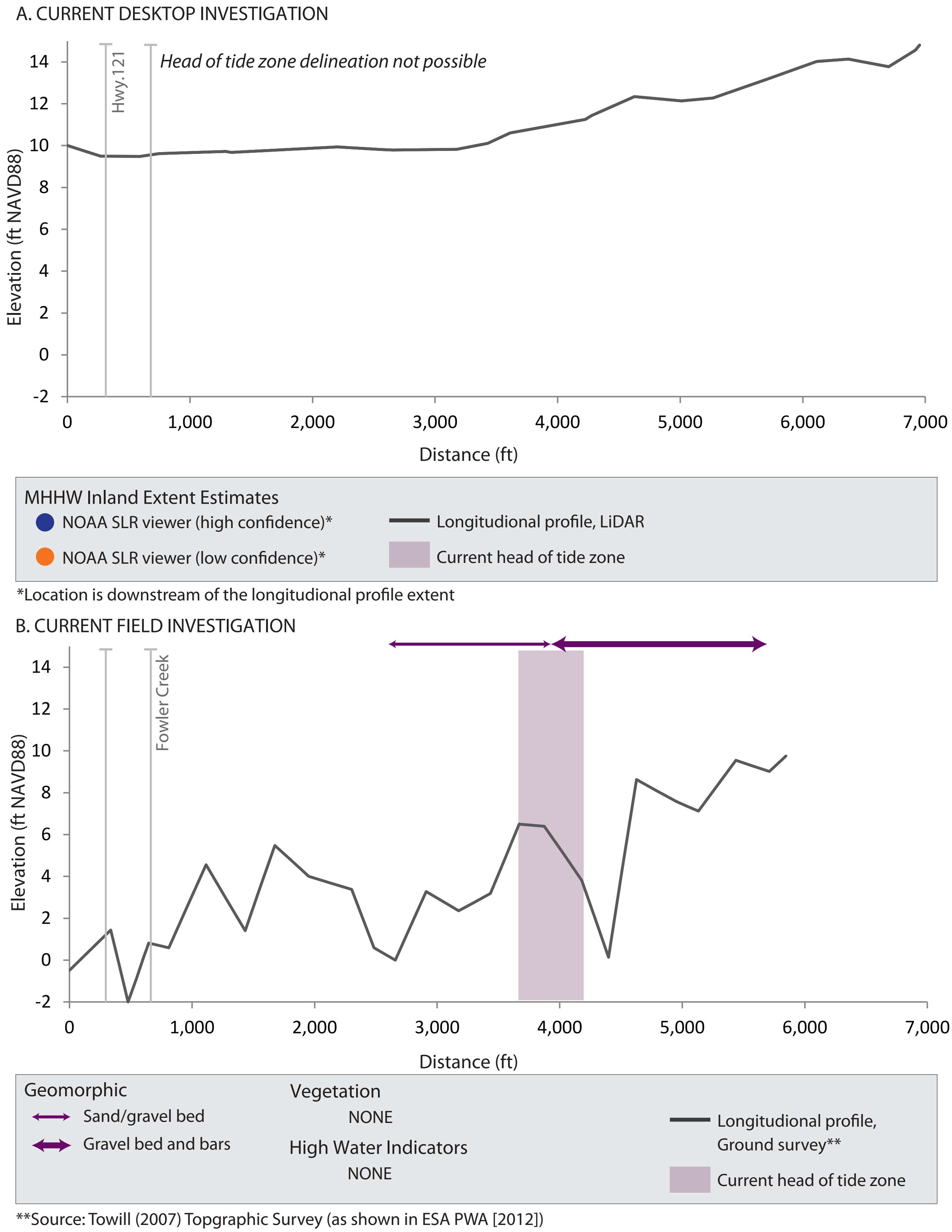
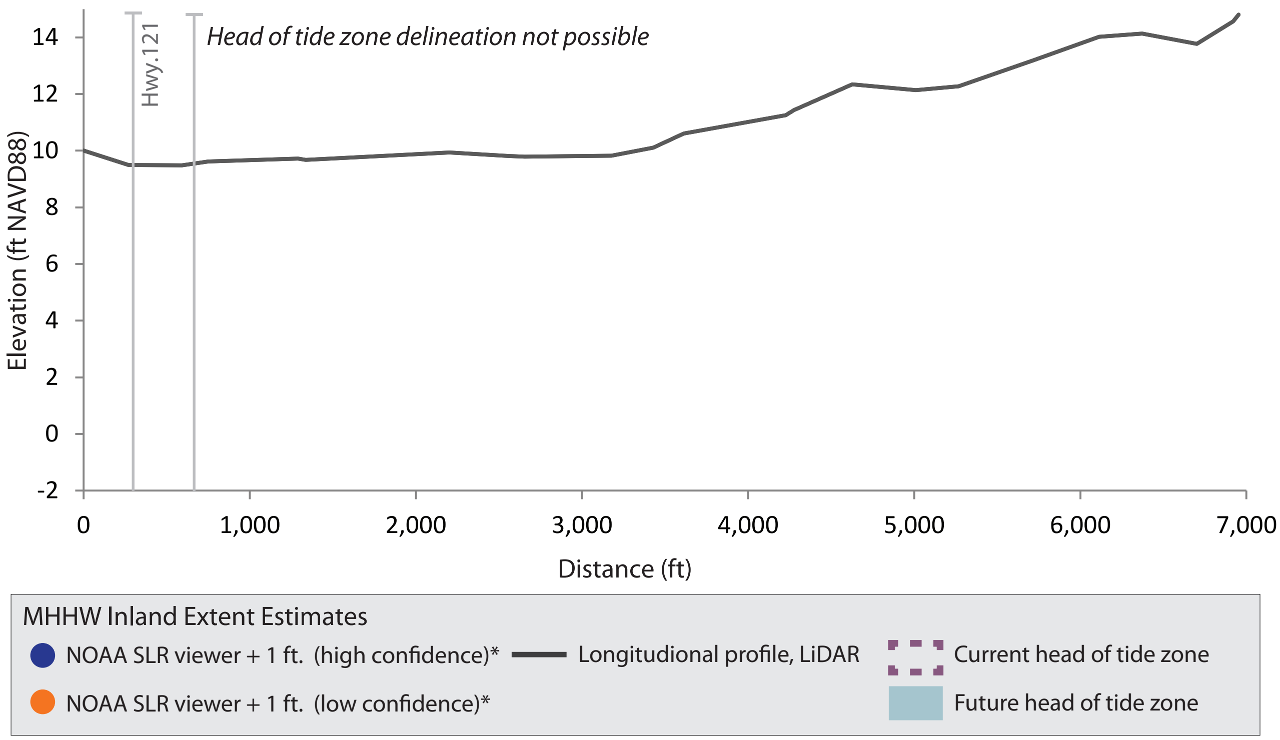


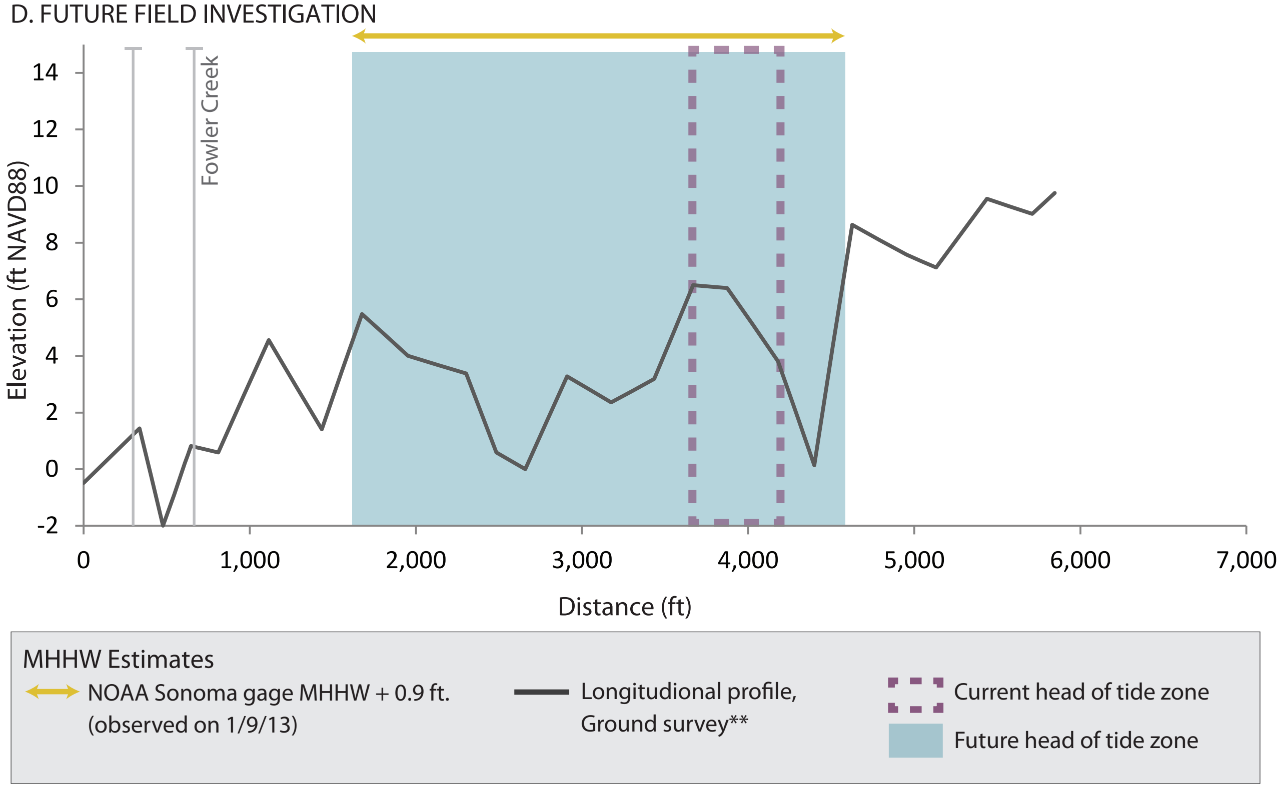
Figure 3.16A and B. Current Sonoma Creek HoT Zone. (A) The current HoT could not be delineated using desktop indicators because the inability of the LiDAR to measure through water over estimated the long profile. (B) The current HoT from field indicators (purple box) based on field observed geomorphic indicators, specifically the transition from gravel bed and bars to a sand/gravel dominated bed.

C. FUTURE DESKTOP INVESTIGATION



*Location is downstream of the longitudinal profile extent

D. FUTURE FIELD INVESTIGATION



**Source: Towill (2007) Topgraphic Survey (as shown in ESA PWA [2012])

Figure 3.16C and D. Future Sonoma Creek HoT Zone. (A) The future HoT could not be estimated using desktop indicators because the inability of the LiDAR to measure through water overestimated the long profile. (B) The future HoT from field indicators (blue box), based on field observations from the king tide of 1/9/13, is exceedingly long because of access limitations.

Figure 3.17. Sonoma Creek gravel bed and bar. Showing the field estimated upstream location of the HoT based on geomorphic indicators.

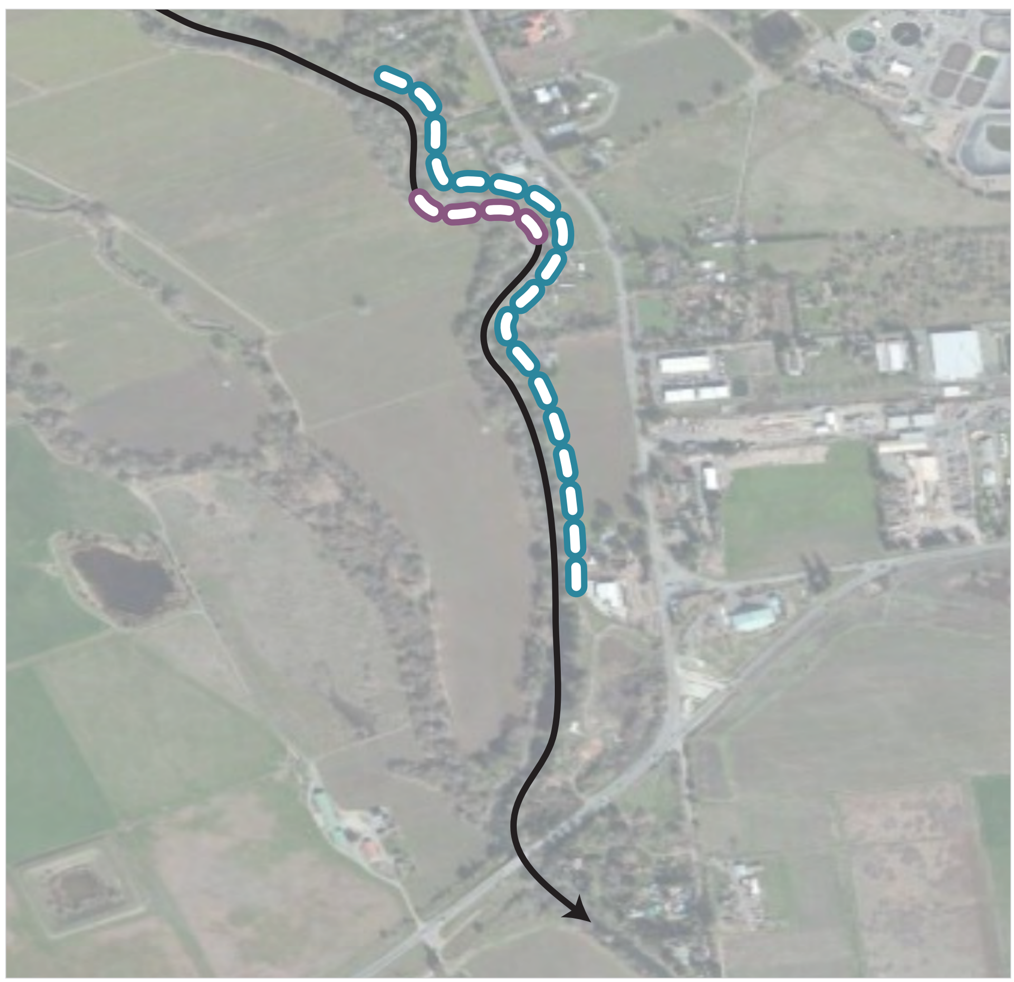


Figure 3.18. Sonoma Creek HoT Zone Summary. This plan view shows the results of the field investigations for both the current and future HoT Zones. The future HoT zone will not migrate far upstream, most likely because of the steep slope of the channel at the current HoT zone. The future HoT zone is much longer than the current HoT zone because of the limitations of field observations at high tide conditions.

CURRENT
Field Indicator

FUTURE
Field Indicator

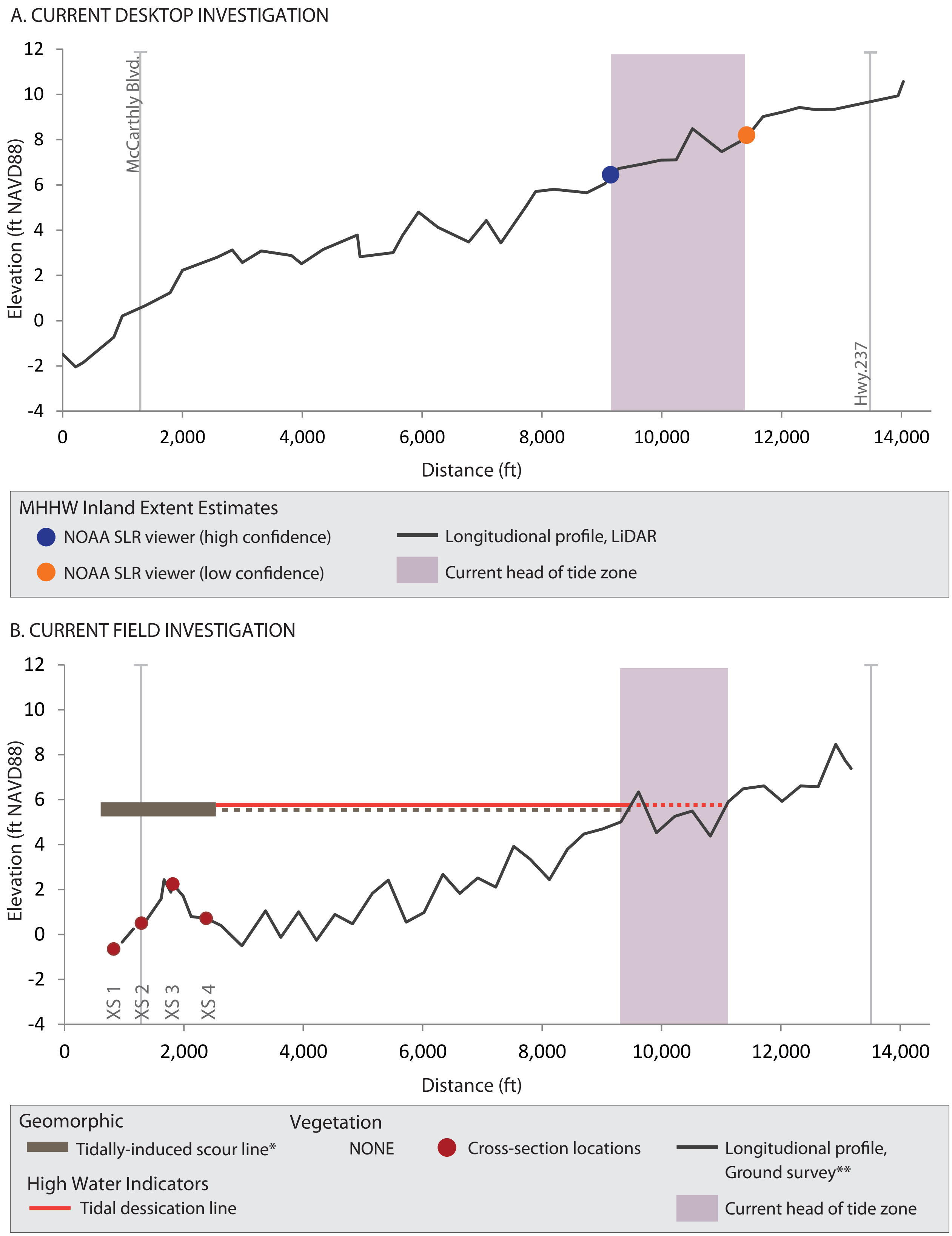
Like Novato Creek, Sonoma Creek currently floods frequently around the HoT zone. As the HoT zone migrates upstream with a rising MHHW, there will be an associated increase in storm-induced flooding potential within and adjacent to the HoT zone, which includes the leveed agricultural and residential areas on the eastern and western floodplains, as well as one road bridge (and two additional road bridges downstream). There will also be a compression of the HoT zone which will impact overall in-channel habitat quality and availability. Maintaining the levees as the MHHW elevation continues to rise will result in more flood water staying in the channel and will likely exacerbate future flooding problems for areas downstream and impact in-channel habitat conditions. Like Alhambra Creek and Novato Creek, the relatively steep channel gradient upstream of the current HoT zone suggests that the increase in flooding associated with a rising MHHW will be relatively contained to the area within and downstream of the HoT zone. One management option currently being explored is targeted levee removal to increase flood storage capacity (see ESA PWA 2012).

3.3.4.6 Coyote Creek

Current head of tide The results from the desktop investigation of the current Coyote Creek HoT zone are shown in Figure 3.19A. Combining the channel longitudinal profile from the 2010 LiDAR dataset with the NOAA SLR viewer output shows a relatively narrow range in predicted MHHW elevations but a relatively long distance between the position where the lower and upper estimates cross the channel bed. The HoT zone is approximately 2,000 ft. long, varies in elevation by approximately 2 ft., and has a longitudinal slope that is similar to the relatively low LiDAR-derived channel gradient through the study site (0.1%).

The results from the field investigation for estimating the current Coyote Creek HoT zone are shown in Figure 3.19B. The field investigation included collecting channel cross-section data towards the downstream end of the study site near the mean tide elevation, and making observations of the channel and adjacent floodplain from the downstream end of the study site upstream to a location presumed to be well above regular tidal influence based on local vegetation. Field observations indicated that the zone of transition from a fluvial channel to a tidally-influenced channel in this relatively low-gradient system is quite long, with coarse-grained fluvial riffles observed well into the tidal frame and in-channel vegetation affected by regular tidal inundation observed well inland. Focusing on a combination of tidally-induced bank scour and high water indicators (i.e., desiccated overhanging bank vegetation) proved to be the best approach for identifying the current HoT zone (Figure 3.20). The field-derived estimate of the current HoT zone is therefore where both the desiccated vegetation line and the bank scour disappeared (see Figure 3.19B). This location is essentially the same as the desktop-derived current HoT zone and therefore does not provide a more refined estimate.

It is important to note that although the desktop and field procedures provided similar HoT zone locations, the channel bed elevations from the LiDAR and field-derived longitudinal profile differ by approximately 1.5 to 3 ft. Like Alhambra Creek, this difference is likely due to LiDAR elevation error associated with water and/or vegetation interference and suggests that the current desktop-derived HoT zone would be much further inland using the correct channel bed elevations. The difference also indicates that the LiDAR-derived and field-derived

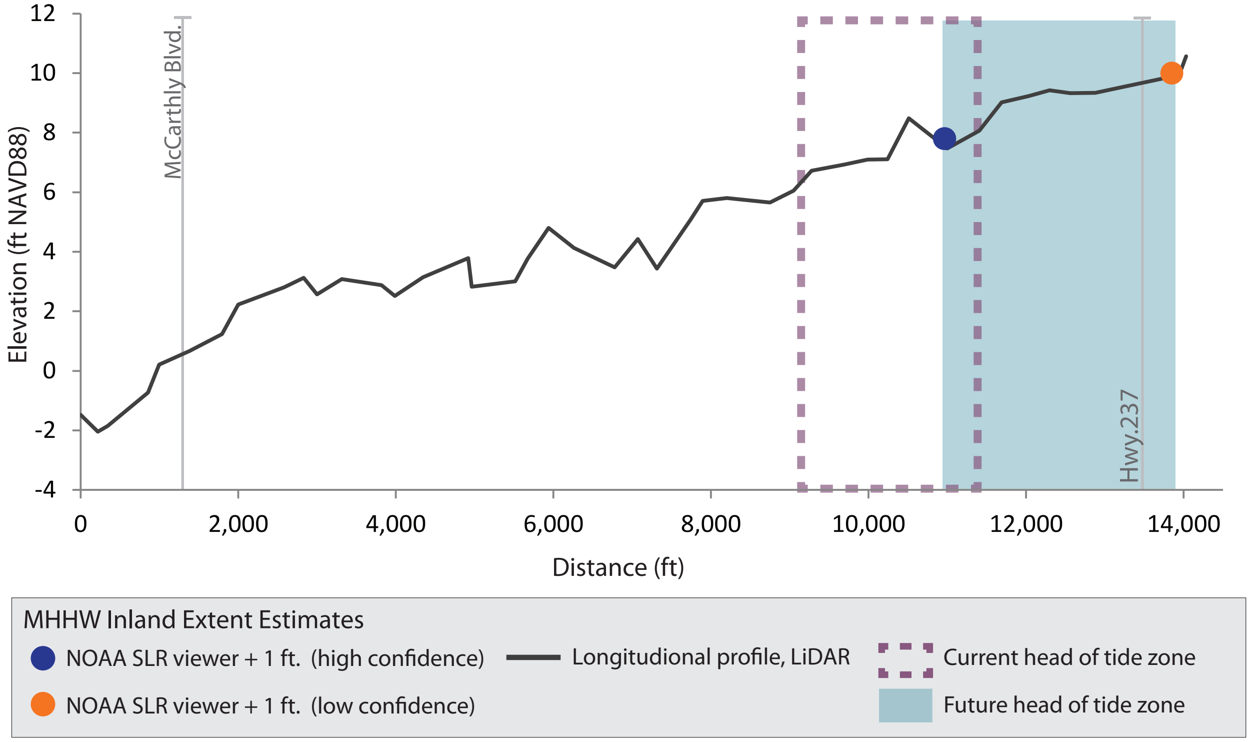


*Scour line width determined by the upper and lower scour line elevation field measurements

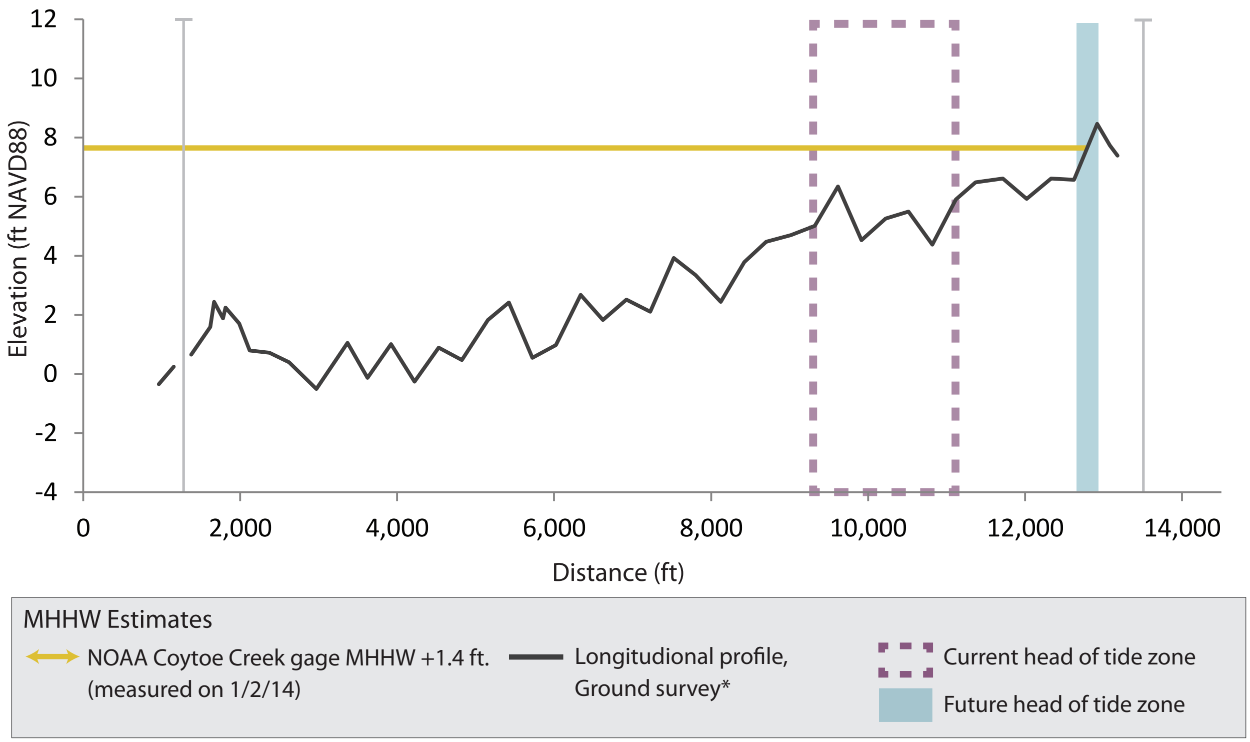
** Source: Santa Clara Valley Water District

Figure 3.19A and B. Current Coyote Creek HoT Zone. (A) The resulting current HoT from the desktop indicators (purple box) falls between the high and low confidence points of the inland extent of MHHW using the NOAA SLR viewer. (B) The field indicated current HoT (purple box) is delineated from where the tidally induced scour line is expected to intersect the bed (dashed brown line) to where the elevation of tidally induced desiccated vegetation is expected to intersect the bed (dashed red line).

C. FUTURE DESKTOP INVESTIGATION



D. FUTURE FIELD INVESTIGATION



*Source: Santa Clara Valley Water District

Figure 3.19C and D. Future Coyote Creek HoT Zone. (A) The resulting future HoT from desktop indicators (blue box) falls between the high and low confidence points of MHHW + 1 ft. using the NOAA SLR viewer. (B) The future HoT from field indicators (blue box) is within the desktop result and is based on field measurements at observed high tides (1/2/14).

Figure 3.20. Coyote Creek tidally desiccated vegetation line. This photo shows desiccated vegetation indicating that this reach is still under tidal influence.

channel gradients are different, with the LiDAR channel gradient through the entire study site (0.1%) being twice as high as the field-derived value (0.05%).

Future head of tide The results from the desktop and field procedures for estimating a future Coyote Creek HoT zone are shown in Figures 3.19C and 3.19D. The NOAA SLR viewer predicts that a 1-foot increase in MHHW will cause the center of the HoT zone to migrate inland approximately 2,500 ft. For the field investigation, the future HoT zone was determined by measuring the water surface elevation on January 2, 2014 when high tide was 1.4 ft. above MHHW (as recorded at the nearby NOAA Coyote Creek gage) and the elevation of the silt line created during the previous high tide. The field investigation results suggest that the predicted future HoT zone will be much shorter than the desktop-predicted zone, but that the center of the two zones will be in around the same location (approximately 2,500 ft. inland from the current HoT zone center). The field-derived HoT zone is therefore considered to be a more resolute estimate of the future HoT zone.

General management implications A plan view perspective of the identified current and future HoT zones for Coyote Creek is shown in Figure 3.21. Like Sulphur Creek, this figure illustrates that the HoT zone in this relatively low gradient, engineered channel will migrate over 1,000 ft. inland over the next several decades. As the HoT zone migrates with a rising MHHW, there will be an associated increase in storm-induced flooding potential within and adjacent to the zone, which includes leveed industrial and commercial areas on eastern and western floodplains, as well as a road bridge at the upstream and downstream ends of the site. An increasing MHHW will also cause more frequent inundation of the marsh at the downstream end of the study site, which will result in decreased Coyote Creek floodwater storage capacity. In addition, the relatively low channel gradient upstream of the HoT zone at this site suggests that the increase in flooding associated with a rising MHHW

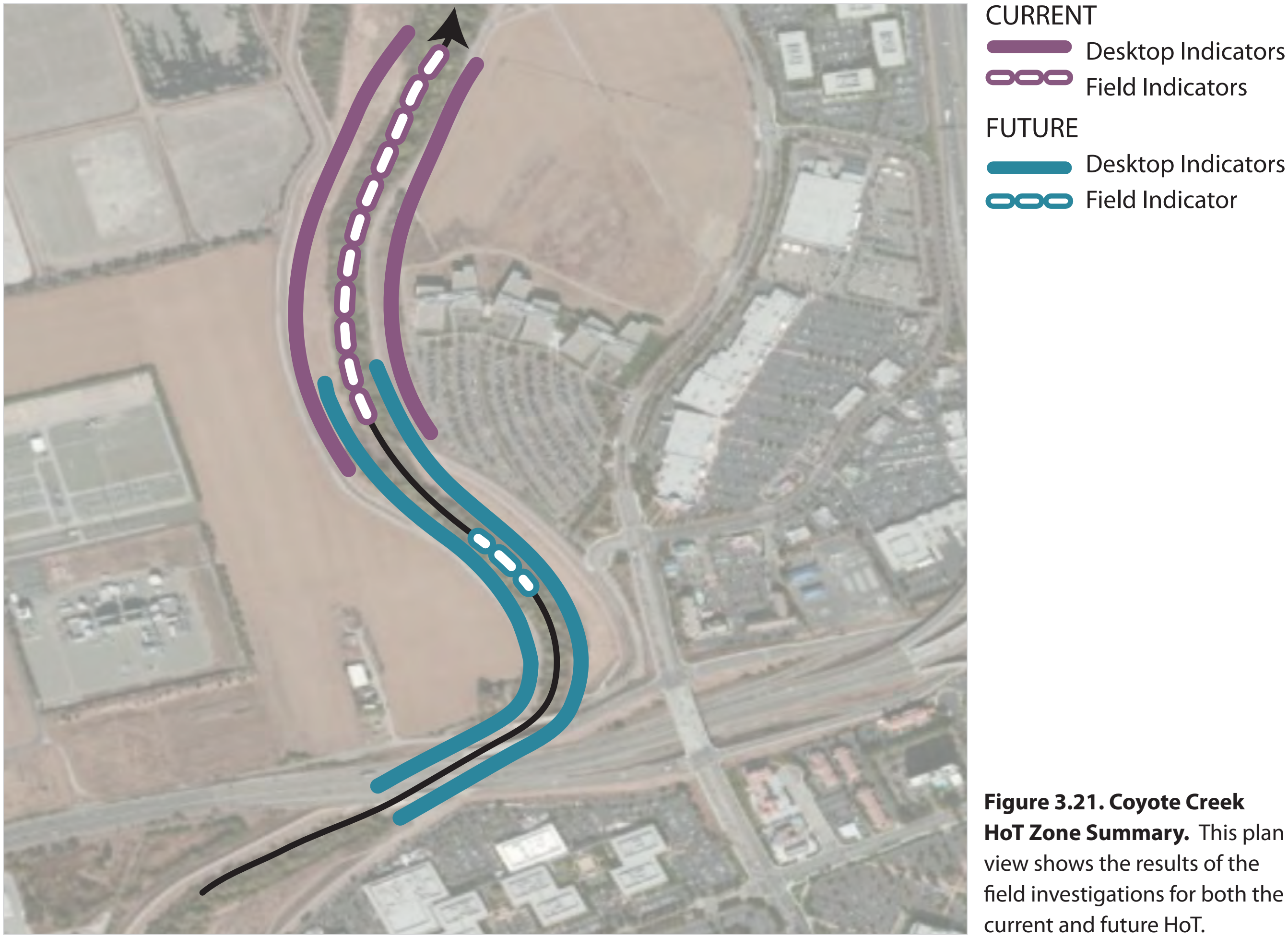


Figure 3.21. Coyote Creek HoT Zone Summary. This plan view shows the results of the field investigations for both the current and future HoT.

elevation will extend relatively far upstream. Removing or setting back the levees along Coyote Creek would result in a considerable increase in floodwater storage capacity and a decrease in overall flooding risk, as well as inland marsh expansion and habitat creation as MHHW continues to rise.

4. HEAD OF TIDE ZONE DELINEATION SYNTHESIS

4.1 Current Head of Tide Zone

The key findings from the desktop and field procedures for estimating the current HoT zone are as follows:

- **Limitations of using extracted channel profiles from LiDAR data.** This study showed that LiDAR data can misrepresent channel bed elevation data resulting in both an inability to develop a desktop-derived current HoT zone estimate at one site (Sonoma Creek) and poor agreement between desktop-derived and field-derived current HoT zone estimates at several sites (Wildcat Creek, Alhambra Creek, and Coyote Creek). The low accuracy of the LiDAR in these locations is likely due to the inability of LiDAR to measure the true ground surface through water or dense vegetation. Thus, in a large, deep channel such as Sonoma Creek, the water surface elevation is often erroneously extracted as representative of the channel thalweg. In addition, the bed elevation differences also caused LiDAR-derived local channel slope estimates to be twice as high as the field-derived values (e.g., Wildcat Creek, Alhambra Creek, and Coyote Creek), which can affect estimates of HoT zone inland migration. The findings from this study also suggest that these issues are somewhat localized due to differences in water depth and canopy cover at the time of the LiDAR flight. Even with the localized elevation accuracy issues, the LiDAR dataset helped provide a reasonable coarse estimate of the current HoT zone at most sites.

- **Agreement between field- and desktop-derived HoT zone estimates.** In general, the field procedure provided a more refined estimate of the current HoT zone than the desktop procedure. For most study sites, the field-derived current HoT zone was several hundred feet shorter than the desktop-derived current HoT zone. The main exception is Alhambra Creek, where the desktop-derived and field-derived HoT zones have a similar length. This is partly explained by the tidal salinity regime. At the Alhambra Creek site, the incoming tidewater is brackish, whereas it is saline at the other sites. The transition from salt-tolerant to brackish vegetation is therefore more indistinct at Alhambra Creek. The local breadth of this transition increased the uncertainty of the HoT zone estimate, and may have contributed to an over-estimate of the upstream and/or downstream limit of the HoT zone. The usefulness of vegetation as a HoT zone indicator may decrease under brackish and freshwater tidal regimes.

- **Correlation of MHHW elevation and field indicators at one site.** At the Wildcat Creek site, a local, site-specific MHHW elevation was estimated by comparing the measured water surface elevation during low river flow conditions with the tidal elevation at the nearby NOAA Port Chicago tide gage. This local MHHW elevation estimate was very close to the elevation of the tidally-induced scour line, providing additional confidence in our assessment that the location where the scour line disappears corresponds to the inland extent of MHHW and lies therefore within the current HoT zone.

- **When geomorphic indicators are useful.** The field investigations suggest that shifts in certain channel geomorphic characteristics can be strong indicators of the current HoT zone. However, the importance of these characteristics can vary among sites. As mentioned above, the results show that the location along a channel where a tidally-induced bank scour line disappears can be a good field indicator at most sites. Conversely, shifts in bed sediment texture and depositional bedforms are shown to be important field indicators at just two sites (Alhambra Creek and Sonoma Creek), which may be a function of relatively high yields of coarse sediment from the watersheds of these sites and/or localized hydraulic controls. However, bed texture and bedforms alone are not capable of indicating the HoT zone at sites such as Coyote Creek, where high stream power can push fluvial bed forms far downstream during wet years, as indicated by coarse depositional bars well within the tidal reach.

- **When vegetation indicators are useful.** The field investigations suggest that a shift in relative abundance of salt-tolerant plant species can be an important field indicator for the current HoT zone in channels draining smaller watersheds (<20 mi^2). This may be a result of smaller watersheds having relatively low daily average stream flow, which may promote higher water salinity within the fluvial-tidal transition zone during both wet and dry seasons, and a more defined transition between salt-tolerant and freshwater vegetation.

- **When high water marks are useful.** The field investigations suggest that high water indicators of tidal inundation can be useful for identifying the current HoT zone during the dry season, especially in larger watersheds (>20 mi^2) with very low dry season flows. At the Novato Creek and Coyote Creek sites, overhanging bank vegetation was desiccated by regular tidal inundation at an elevation similar to the tidally-induced bank scour line (i.e., the presumed MHHW elevation). The reason for the existence of this desiccated vegetation high water mark at just two of the study sites is currently not known. One possible explanation is that the observed desiccation is specific to the overhanging bank vegetation that exists at the Novato Creek and Coyote Creek sites.

4.2 Future Head of Tide Zone Delineation

The key findings from the desktop-based and field-based delineation of the future HoT zone at the study sites are as follows.

- **LiDAR elevation issues.** This study showed that the limitations of LiDAR data for channel bed elevations resulted in both an inability to develop a complete desktop-derived future HoT zone estimate at one site (Sonoma Creek) and contributed to poor agreement between desktop-derived and field-derived future HoT zone estimates at several sites (Wildcat Creek, Alhambra Creek, and Coyote Creek). Despite these accuracy issues, the LiDAR dataset helped provide a reasonable albeit coarse desktop-derived estimate of the future HoT zone for most sites.

- **Agreement between field- and desktop-derived HoT zone estimates.** The field procedures used in this study to delineate the future HoT zone generally provided a more robust zone than the desktop-derived estimate. For most study sites, the field-derived estimate of the future HoT zone was at least a few hundred feet shorter than the desktop-derived estimate. The major exception was Wildcat Creek, which highlights the considerable impact that high river flows can have on efforts to delineate the upstream limit of tidal inundation using flow indicators.

- **Future HoT zone inland migration.** The study results show a clear relationship between channel slope and the predicted extent of inland HoT zone migration. In general, for study sites with a field-derived channel gradient <0.2%, the predicted inland migration from field observations was >1,000 ft., whereas the predicted migration was much shorter for sites with a field-derived channel gradient >0.2%. This finding shows that channel slope dominates the other factors affecting the inland extent of tidal inundation (e.g., channel roughness).

4.3 Potential Management Applications

The findings from this study show that desktop and field investigations are both useful for delineating the current and future HoT zones for San Francisco Bay tributaries, but provide different levels of resolution and information regarding HoT zone characteristics. Recommendations for how these two types of analysis should be used by the management community for decision making are as follows:

- **Desktop investigations.** This study demonstrated that combining NOAA SLR viewer MHHW inland inundation extent with LiDAR-derived channel elevation data provided a reasonable "first cut" estimate of both the current and future HoT zones for most of the study sites. As such, the results suggest that a desktop investigation following the approach used in this study is appropriate as a preliminary tool for guiding high level flood control and habitat management planning at the fluvial-tidal interface. An example of an appropriate application would be the assessment of vulnerable infrastructure and key habitats that would potentially be affected as the HoT zone migrates inland with a rising sea level. If this type of assessment is done for channels throughout a management agency's jurisdiction or for jurisdictions throughout the region, the results could be used to highlight "problem areas" between current and future HoT zones, and help develop management priorities.
- **Field investigations.** This study demonstrated that field investigations aimed at delineating HoT zones using physical and biological indicators provided a refined estimate of zone length and location compared to a desktop investigation. Whereas the desktop investigation of the HoT zone depends on elevation data collected remotely and modeled water surface elevations, the field investigation uses on-the-ground observations of geomorphic features, vegetation, high water marks, and flow direction that reflect the impact of local channel topography and hydraulic controls (e.g., bridges, grade control structures, channel boundary roughness). Therefore, the results suggest that a field investigation following the approach used in this study could be used to hone the desktop-derived HoT zone location and extent, and to help elucidate the local factors controlling the rate or impact of HoT zone migration that may not be discernible from the desktop analysis. Knowing the location and associated impact of local factors is an essential step in developing appropriate short-term and long-term flood control and habitat management solutions.

5. HEAD OF TIDE ZONE DELINEATION PROTOCOL

The findings from this study suggest that desktop and field procedures provide reasonable delineations of both the current and future HoT zones for San Francisco Bay tributaries. Furthermore, the two procedures seem to provide levels of resolution appropriate for early and intermediate stages of HoT zone planning and management. The procedures used in this study were therefore converted into a set of steps that can be used in further trials of the protocol to guide its improvement. As the findings are from a pilot project focused on a limited number of field sites, this version of the protocol is intended to be viewed as a starting point leading to a comprehensive, robust, and thoroughly tested protocol for the Bay. Nonetheless, this first version of the protocol can generate appropriately accurate HoT zone delineations where and when the indicators thus far developed are applicable.

Part 1: Desktop Investigation

I. PRELIMINARY DATA COMPILATION AND ANALYSIS

Step 1: Locate the study area and delineate the site extent on a georeferenced aerial image in GIS.

- The study area should be at least 1,000 ft. long and should be centered on a best-guess of the location where MHHW crosses the bed.
- The best-guest should be based on a general knowledge of tidal inundation extent at the site, including the approximate location of mean tide level and where the channel is fluvial (i.e., upstream of extreme high tide elevations).

Step 2: Retrieve the best available LiDAR dataset for the site and extract a longitudinal profile of the channel thalweg (or line of lowest elevation) through the site.

- Transfer the extracted longitudinal profile (channel distance and elevation information) from GIS into a spreadsheet program.

Step 3: Using the NOAA SLR viewer, display current MHHW inland inundation extent and projected future MHHW inland inundation extent (e.g., current MHHW+1 foot) in plan view.

- Find both the "low confidence" and "high confidence" locations, which are defined by the inland extent of colored channel areas in the NOAA SLR viewer.
- Identify the coordinates of the high and low confidence extents in GIS.
- This step may necessitate updating the inland extent of the study site and extending the LiDAR-derived longitudinal profile upstream.

The protocol for estimating the current and future HoT zone positions in San Francisco Bay tributaries based on the results of this study is given below. The basic requirements for using the protocol are access to the internet, access to GIS software and basic GIS analysis skills, access to spreadsheet software and basic spreadsheet analysis and graphing skills, knowledge of geomorphic processes, and vegetation mapping skills. It is important to note that although guidance is given for the data needed to complete each protocol step, in many instances it is up to the user to locate the data discussed.

II. CURRENT HOT ZONE DELINEATION

Step 1: Combine the current MHHW inland inundation extent data from the NOAA SLR viewer with the extracted LiDAR-derived longitudinal profile to estimate where MHHW crosses the channel.

Step 2: Mark the current MHHW inland inundation extent locations (i.e., high confidence and low confidence estimates) onto the georeferenced aerial image in GIS.

- Translocate the positions of the high and low confidence estimates to the longitudinal profile using linear referencing or another method in GIS in order to estimate elevation and position.

Step 3: Delineate the desktop-based current HoT zone on the georeferenced aerial image in GIS based on the most upstream and downstream estimates of where MHHW crosses the channel.

STEP III. FUTURE HOT ZONE DELINEATION

Step 1: Develop an estimate of the location where the future MHHW inland inundation extent (e.g., current MHHW+1 foot) from the NOAA SLR viewer intercepts the bank of the channel at its mouth, downstream of the site.

Step 2: Combine the future MHHW elevation estimate (from inland inundation extent) with the extracted LiDAR-derived longitudinal profile to estimate the future inland locations where MHHW crosses the channel bed.

Step 3: Mark the predicted future MHHW inland inundation extent locations from the NOAA SLR viewer (i.e., high confidence and low confidence estimates) onto the georeferenced aerial image in GIS.

Step 3d: Delineate the future HoT zone on the georeferenced aerial image in GIS.

Part 2: Field Investigation

STEP I: PRELIMINARY DATA COMPILATION AND ANALYSIS

Step 1: Determine the contributing watershed area upstream of the site.

- o Exclude the watershed area upstream of any large dams.

Step 2: Calculate the average channel slope through site the using the LiDAR-derived longitudinal profile.

Step II: Current HoT zone delineation

Step 1: Use the contributing watershed area and channel gradient data with Table 5.1 to identify the channel "class" and associated appropriate HoT zone field indicators.

- o Table 4.1 was developed from limited field data and should be viewed as a first approximation of the relationship among drainage area, channel gradient, and HoT zone field indicators. Table 4.1 does not provide guidance for HoT zone delineation in small drainages with a high local channel gradient because no study site has those characteristics.

Step 2: Visit the site at low tide in the dry season (April-September) and delineate the current HoT zone using the appropriate HoT zone field indicators and focusing on the area within and adjacent to the desktop-derived estimate of the current HoT zone.

- o If time and budget allow, start by surveying a detailed channel longitudinal profile through the desktop-derived current HoT zone. If this is not possible, the LiDAR longitudinal profile can be used, noting its limitations.
- o Geomorphic characteristics and high water marks should be identified through a rapid visual assessment.
- o Vegetation mapping should be done at sites where vegetation characteristics comprise one or more field indicators (following an accepted protocol like the CRAM protocol).
- o The current HoT zone boundaries determined from field indicators should be marked with handheld GPS waypoints and photo-documented.

Step III: Delineate the field-based HoT zone on the georeferenced aerial image in GIS using the best estimates of the upstream and downstream HoT zone boundaries.

- o The handheld GPS waypoints identifying field indicator derived boundaries need to be brought into GIS.
- o For sites requiring vegetation mapping, the vegetation zone polygons will be digitized and attributed in GIS and the shift from salt tolerant to freshwater vegetation will be noted.

Step IV: Future HoT zone delineation

Step 1: Visit the site during low runoff conditions (ideally in the dry season), when the tide is predicted to be ~1 foot above current MHHW (e.g. spring tides in summer months), and estimate the inland location of MHHW, focusing on the area within and adjacent to the desktop-derived future HoT zone.

- o The date and time of day when tidal elevation is predicted to be ~1 foot above MHHW should come from the closest NOAA tide gage.
- o The inland landward extent of tidal inundation should be identified by observing flow direction indicated by floating debris, looking for slack water or flow reversals, and looking for the silt lines from the previous high tide.
- o The locations of indicators marking the inland boundary of tidal inundation should be noted with handheld GPS waypoints and photo-documented.

Step 2: Delineate the field-based future HoT zone on the georeferenced aerial image in GIS based on the best estimates of the most upstream and downstream HoT zone boundaries.

- o The GPS waypoints identifying the boundaries need to be brought into GIS.
- o If a detailed longitudinal profile was surveyed, combine the profile with the GPS waypoints and field observations to delineate the HoT zone.

Table 5.1. Targeted field indicators by drainage area and channel gradient class

Drainage Area Class	Local Channel Gradient Class	Targeted Field Indicators				Representative Study Site
		Geomorphic characteristics		Vegetation characteristics	High water marks	
		Extent of tidally-induced bank scour	Shift in bed texture/ Extent of bar features	Shift from brackish to freshwater vegetation	Extent of tidally-desiccated bank vegetation	
Small (<10 mi²)	Low (<0.2%)	✓		✓		Sulphur Creek
	High (>0.2%)	No data				None
Medium (10-100 mi²)	Low (<0.2%)	✓			✓	Novato Creek
	High (>0.2%)	✓	✓	✓		Wildcat Creek Alhambra Creek
Large (>100 mi²)	Low (<0.2%)	✓			✓	Coyote Creek
	High (>0.2%)		✓			Sonoma Creek

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary of Findings

This study explored the ability of desktop-based and field-based procedures to delineate the current and future HoT zones in six representative San Francisco Bay tributaries. The major findings from this study are as follows:

- A desktop investigation using high-resolution LiDAR data with estimates of the local MHHW elevations (estimated from the NOAA SLR viewer) provided a reliable albeit coarse estimate of the current and future HoT zones at most study sites. The usefulness of the desktop procedure depends on accurate LiDAR elevation data. Overestimated elevations in the longitudinal profile extracted from the LiDAR prevented delineation of the current and future HoT zones at one site. For the other sites, the desktop delineations ranged in length from several hundred to several thousand feet, as did the predictions of HoT zone inland migration distance. The predicted migration distances mainly reflected the LiDAR-derived channel slope, with steeper slopes resulting in shorter migration distances.

- At the start of this study, it was not known if a set of field indicators could be used to delineate the upstream and downstream boundaries of the current HoT zone in San Francisco Bay tributaries. This study showed that key field indicators can be used to delineate the HoT zone at the study sites. The key indicators shown to be the most useful are shifts in bed texture, the presence of depositional bar features, inland extent of tidally-induced bank scour, shifts from brackish to freshwater vegetation, and the inland extent of tidally-induced plant desiccation. The indicators were shown to vary in usefulness depending on site-specific conditions. For example, the suite of useful indicators varied with watershed size and salinity regime. It is important to note, however, that the inland extent of tidally-induced bank scour was a useful indicator of the upstream boundary of the current HoT zone at almost all study sites.

- Overall, the field procedure based on the indicators provided a more refined estimate of the current HoT zone than the desktop procedure. The HoT zone delineations provided by the field procedure fit within the delineations provided by the desktop procedure. At one site, inaccurate LiDAR data caused the desktop and field procedures to result in very different delineations of the current HoT zone. It appears that the two procedures would otherwise have yielded comparable results. The field procedure generally produced higher HoT zone migration distances, which were controlled primarily by local channel slope.

- The study findings are encouraging but not conclusive. The two complimentary HoT zone delineation procedures developed within this study comprise a useful first delineation protocol for San Francisco Bay tributaries. However, the procedures are based on only six study sites that neither represents the full range of factors affecting the HoT zone nor the full range of conditions for any one key factor. In order for this protocol to be widely applicable around the region, further development is needed.

6.2 Data Gaps and Recommended Analyses

Although the findings from this study were capable of building the framework for a HoT zone delineation protocol for San Francisco Bay tributaries, additional data collection efforts and quantitative analyses are necessary. Specifically, more information is needed for improving the overall understanding of appropriate field indicators for a range of geomorphic settings, thereby improving the ability of the protocol to delineate the HoT zone for any type of tributary around the Bay. Recommended data collection efforts and quantitative analyses needed for continuing the HoT zone delineation protocol development include the following:

- **More data from more sites.** Future data collection efforts need to include a large number of field sites in San Francisco Bay tributaries that together represent a larger range of contributing watershed area, local channel gradient through the HoT zone, and salinity regime, and perhaps watershed sediment yield.
- **Assessing additional current HoT zone field indicators.** The utility of other field indicators of the current HoT zone, such as water salinity and benthic macroinvertebrate species composition, should be explored at selected sites.
- **Validation of the estimated current HoT zone.** Future data collection should include a rigorous validation of the field-derived estimate of the current HoT zone. This could include monitoring water surface elevation at representative sites to: 1) compare predicted and actual local MHHW elevation; and 2) compare actual local MHHW elevation and the HoT zone bed elevation relative to MHHW as estimated from field indicators. The results could be used to develop numerical corrections for predicted MHHW elevations for different classes of tributaries.
- **Validation of the estimated future HoT zone.** The utility of multiple field observations of tidal inundation extent at a high tide elevation of MHHW + 1 foot (spring tides, or king tides) for validating or refining the future HoT zone location estimates should be explored.
- **Uncertainty analysis of current and future HoT zone estimates.** A method should be developed to assess error estimates associated with the HoT zone delineations.
- **Investigation of the vulnerability of infrastructure in the HoT zone.** In most of the study sites, major infrastructure intersected either the current or future HoT zones. This infrastructure, which includes bridges and pipelines, often controls the local channel gradient and therefore impacts the rate of HoT zone migration and constrains HoT zone planning and management. This infrastructure will most likely be impacted with sea level rise and should be evaluated for overall vulnerability and risk of failure.

6.3 Next Steps

The HoT zone is an area of concern for many management agencies at all levels of government. The concern will grow as sea level rise accelerates and the inland migration of the HoT zone results in flooding in urban centers and impacts to aquatic habitat. The preparation and response of managers and planners will require knowing where the HoT zone is now, where it is likely to be in the future, what resources are threatened by its migration, and how these threats might be mitigated. This information will need to be organized in a way that can be easily shared and added to by local and regional interests, such as an online interactive map and database. The most fundamental need at this time is therefore a method for delineating the current and future HoT zones for the San Francisco Bay region. Once validated, the protocol can be used around the region to develop an interactive Bay-wide map of current and future HoT zone locations along with appropriate physical and biological attributes, and known resources at risk.

This study provides the first version of a protocol to delineate the current and future HoT zones for San Francisco Bay tributaries. As discussed above, the protocol can be used now but needs further development to be broadly applicable around the region and have associated levels of certainty.

Given the growing interest in the HoT zone management across many agencies, it seems appropriate to ask them to help guide further development of the HoT zone protocol and information system. One possible way to garner their input would be to form a HoT zone steering group from a consortium of regional agencies most responsible for or affected by HoT zone conditions. Such a group could include representatives of the Bay Conservation and Development Commission (BCDC), Bay Area Flood Protection Agencies (BAFPA), Association of Bay Area Governments (ABAG), and the Regional Water Quality Control Board (Regional Board). The group would ensure adequate technical support for HoT zone planning and management by utilizing to the fullest degree appropriate all existing technical tools, services and public forums. An early charge of the group might be to champion the integration of HoT zone information into existing online information delivery systems, such as the NOAA SLR viewer and EcoAtlas. Other charges for the group might be to identify sources of funding to further develop the HoT zone delineation protocol and interactive map, develop a plan for implementing the tools through the existing planning and management programs of state and local agencies, deciding what additional HoT zone data are needed, and disseminating information to the regional community of environmental scientists.

Recommendations for continuing the development of a HoT zone toolset in coordination with a steering committee include the following:

- Initiate discussion with NOAA about the feasibility of intensifying the content of the SLR viewer for San Francisco Bay with high resolution local elevation data, Bay Area Aquatic Resource Inventory (BAARI) data, ABAG land use data, forthcoming flood infrastructure maps for the region, and HoT zone delineations.

- Initiate discussion with the regional hydrologic and hydraulic modeling community about the data needs to integrate fluvial and tidal hydrologic and hydraulic models to improve predictions of the future HoT zone location and extent.

- Continue or initiate discussions with natural resource economists, sociologists, and local historians about the economic and cultural consequences of HoT zone migration.

- Generate collaborative proposals to build and implement the HoT zone protocol and information system as part of the larger effort recommended by The Goals Project to coordinate planning and management of the tidal-terrestrial transition zone around San Francisco Bay.

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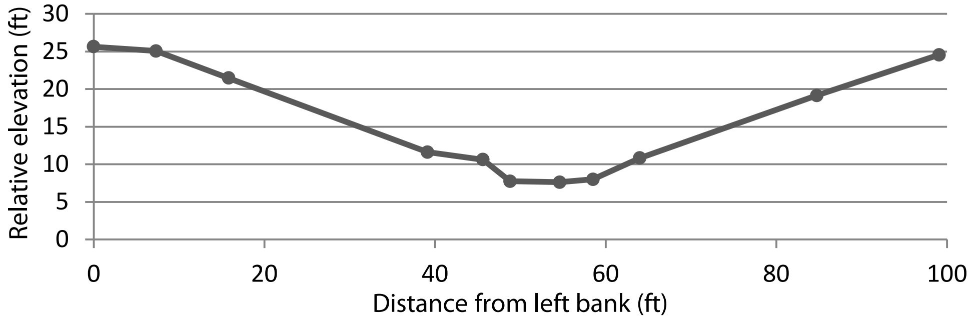
Appendix A. HoT Zone Field Indicators

Priority	Indicators	Description	Field Method	Temporal Variability
	Physical			
High	Bed slope	Changes in slope	Topographic survey	low
High	Channel morphology	Sinuousity, channel geometry	Topographic survey	low
High	Streambank morphology	Degree of undercutting, bank stratigraphy, vegetation on banks	Topographic survey	low
High	Sediments	Silt-clay-sand-gravel, organic content	Visual (surface), or bulk samples (subsurface)	low
High	Tides	Variations of upstream extent of tides	Visual survey	high
Low	Salinity	FW: Annual average below 0.5 ppt to SW: above 20 ppt	Salinometer, YSI	high
Low	Dissolved sulfur	FW: trace (1ppm) to SW: very high (2500 ppm)	Sondes or YSI	high
Low	Dissolved oxygen	DO dips around the head of tide	Sondes or YSI	high
Low	Turbidity	Turbidity Maxima at head of estuary because of net non-tidal circulation at the null zone	Hawke meter	high
Low	Freshwater inflows	Variations of fluvial discharge determines location	Pressure transducers, Velocimeter	high
	Vegetation			
High	Species diversity	High species diversity, low dominance by single species	Visual survey, mapping	low
High	Salt tolerant species presence	Dominant freshwater species to dominant salt water species	Visual survey, mapping	low
Low	Life history strategies	FW: reproduction both sexual and asexual SW: reproduction principally asexual, through dispersal of rhizomes	Visual survey, mapping	low
	Wildlife			
Low	Fishes	FW and oligohaline species to SW and estuarine species	Fish sampling	high
Low	Invertebrates	FW: lower species diversity, mostly freshwater species SW: higher species diversity, estuarine and marine	BMI sampling	high

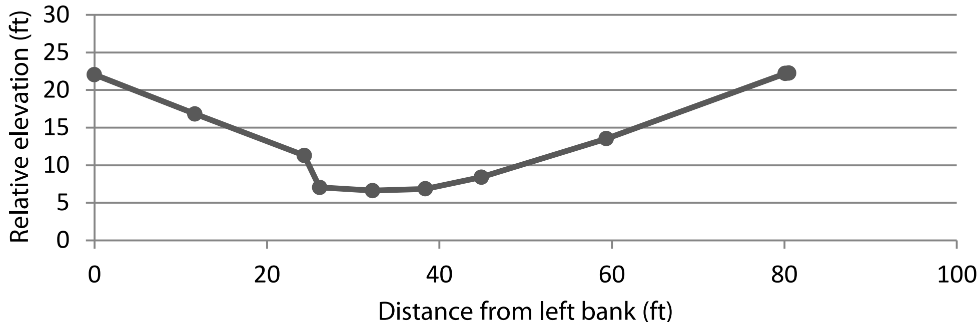
Table A1. List of field indicators considered for field investigation. The indicators listed above were considered for use in the HoT zone protocol development. They were assessed for inclusion in the study based on their temporal variability, accessibility of methods, and TAC input. Indicators listed as high priority were employed during the field investigation.

Appendix B. Cross Sections

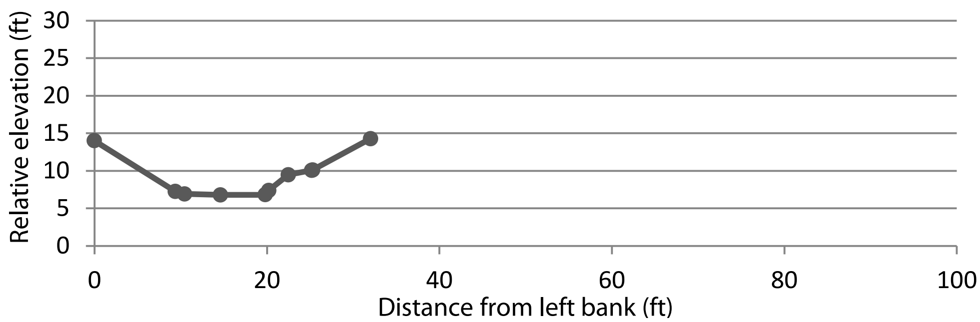
Cross Section 1



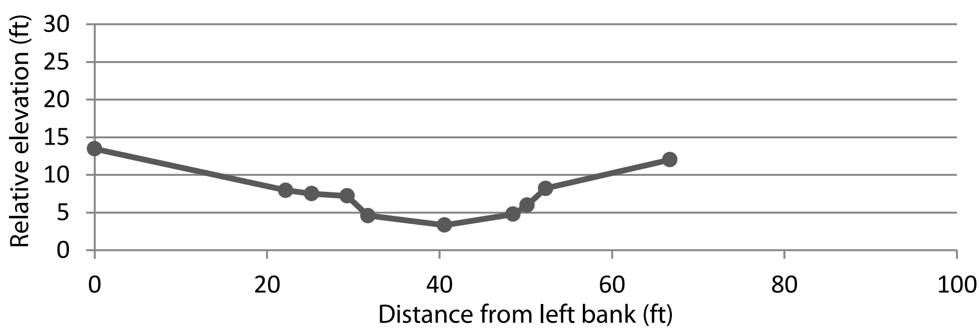
Cross Section 2



Cross Section 3



Cross Section 4



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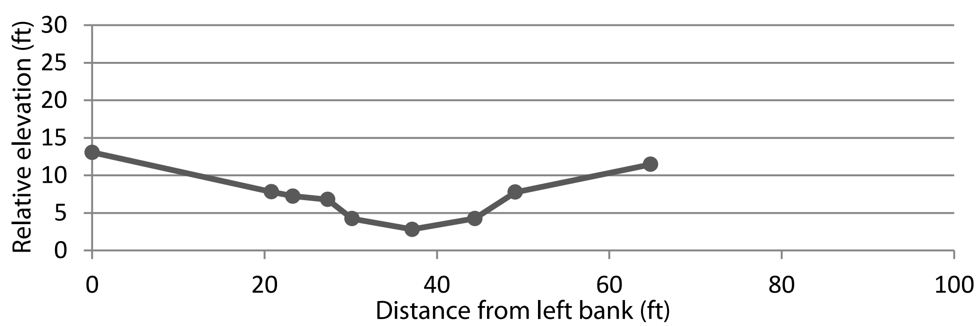
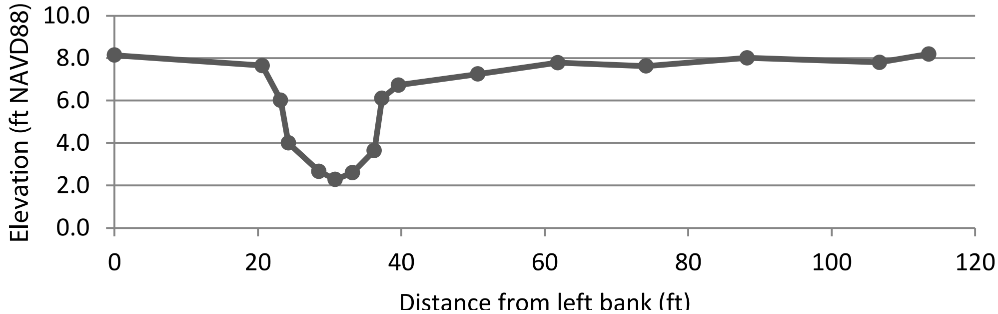


Figure B1. Sulphur Creek Cross Sections. Cross sections completed on 5/21/13, from downstream to upstream.

Cross Section 1



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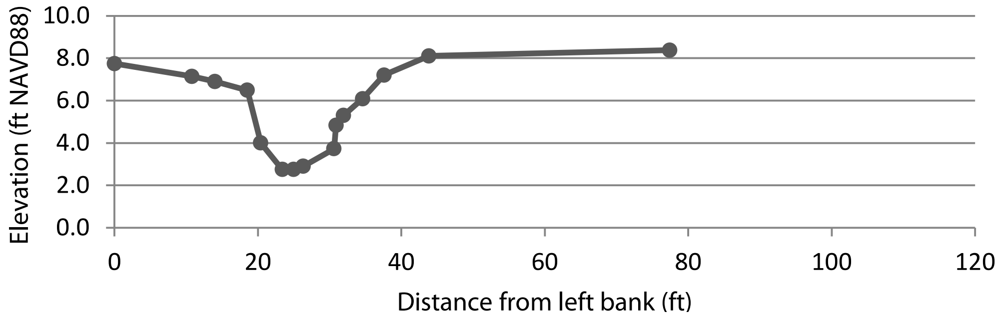
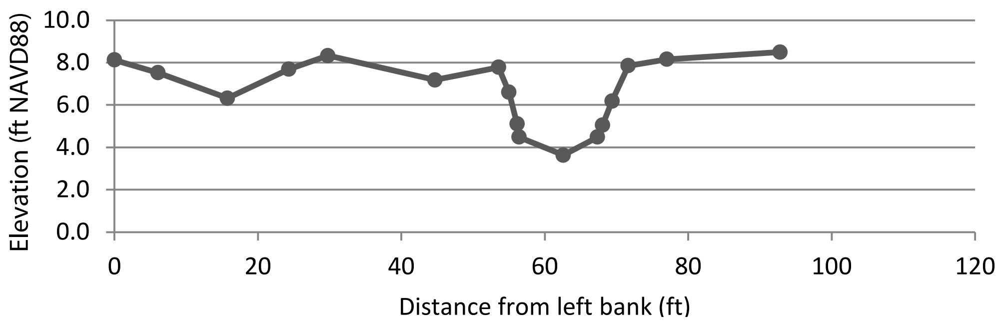


Cross Section 3



Cross Section 4

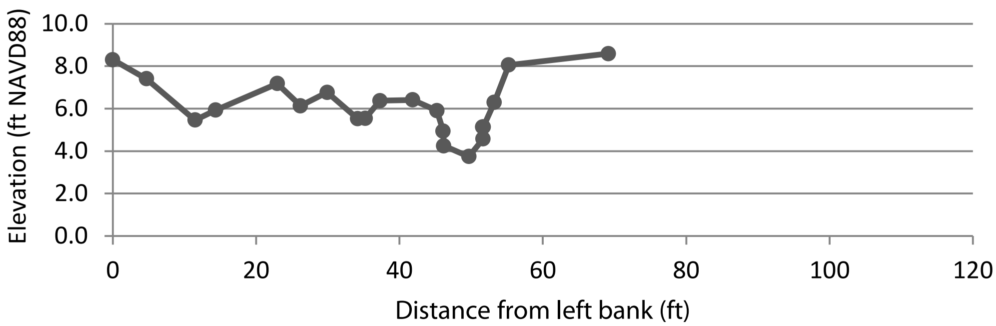
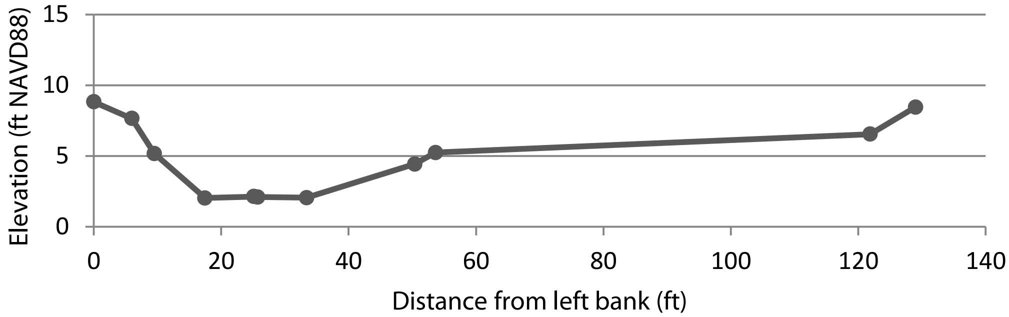
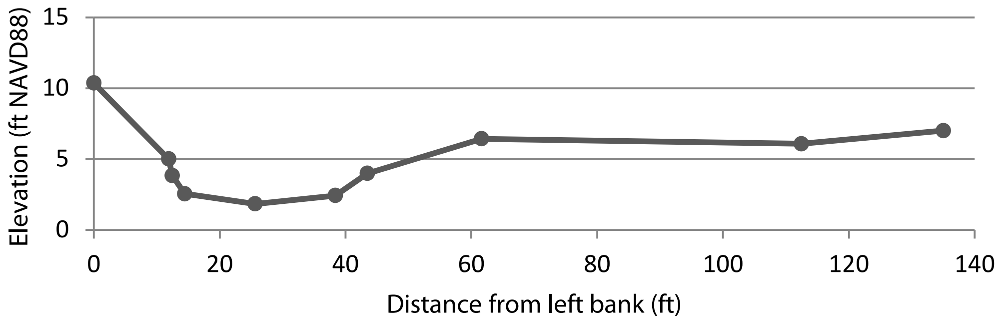


Figure B2. Wildcat Creek Cross Sections. Cross sections completed on 6/24/13, from downstream to upstream.

Cross Section 1



Cross Section 2



Cross Section 3

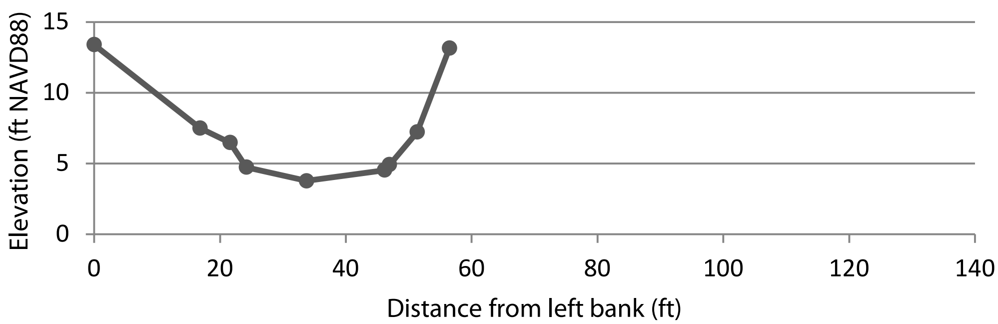
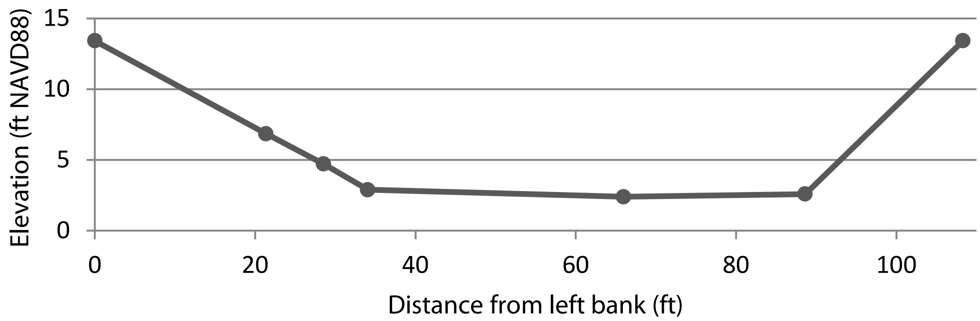
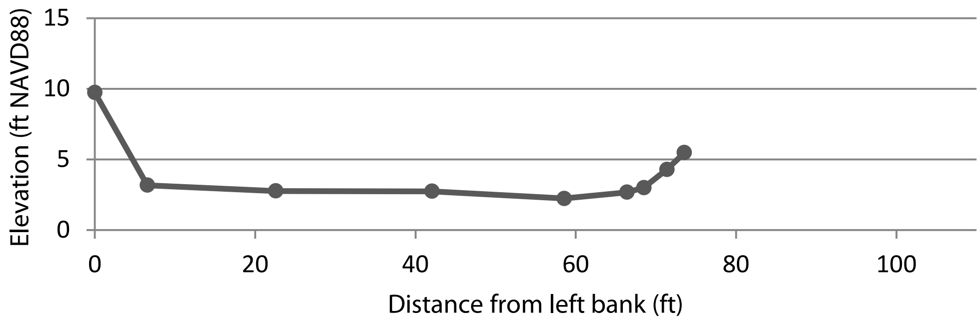


Figure B3. Alhambra Creek Cross Sections. Cross sections completed on 6/25/13, from downstream to upstream.

Cross Section 1



Cross Section 2



Cross Section 5

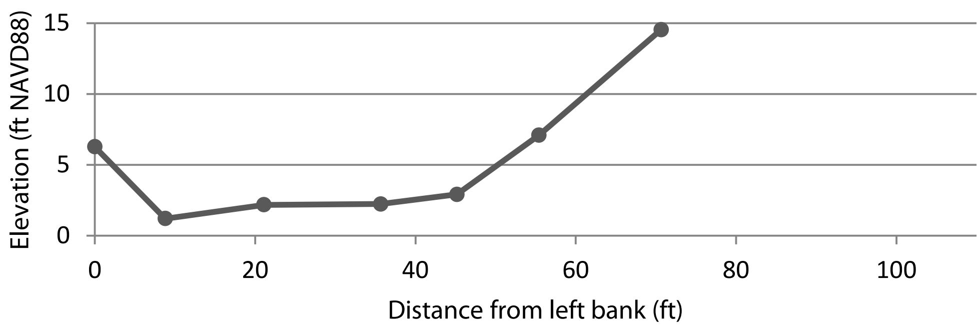
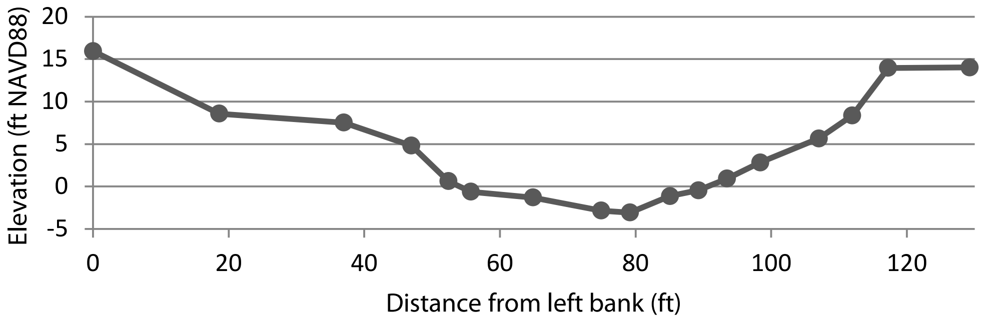
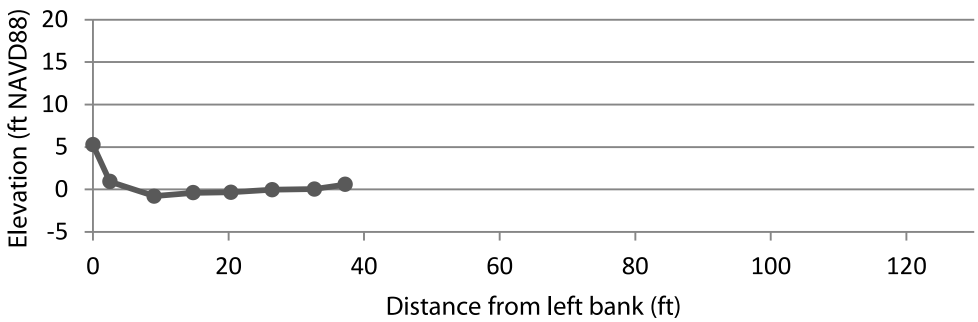


Figure B4. Novato Creek Cross Sections. Cross sections completed on 6/26/13, from downstream to upstream.

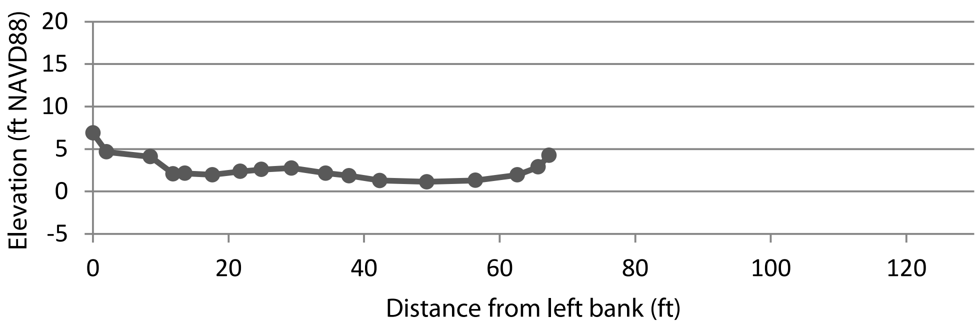
Cross Section 1



Cross Section 2



Cross Section 3



Cross Section 4

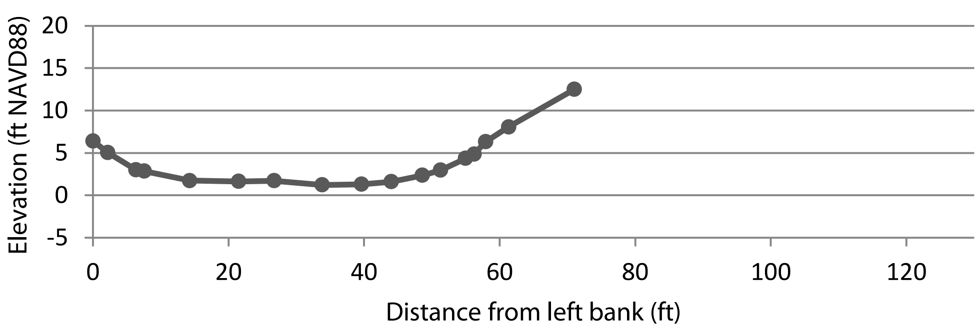


Figure B5. Coyote Creek Cross Sections. Cross sections completed on 6/27/13, from downstream to upstream.

Appendix C. Vegetation Mapping

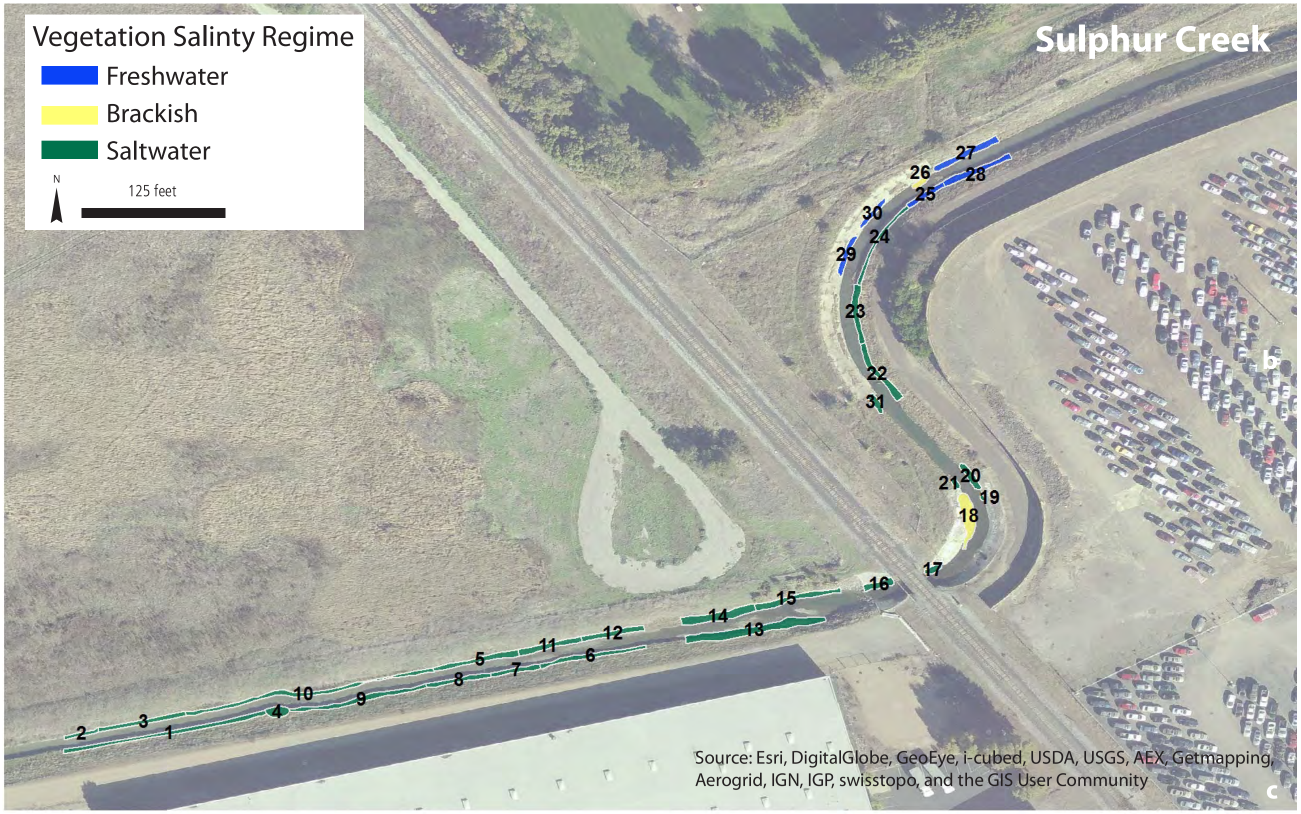


Figure C1. Sulphur Creek Vegetation Map. Numbered polygons explained in Table C1.

ID	Species 1	% Cover	Species 2	% Cover	Species 3	% Cover	Species 4	% Cover	Species 5	% Cover	Species 6	% Cover	Species 7	% Cover
1	*Distichlis spicata*	20	*Atriplex triangularis*	20	*Jaumea carnosa*	20	*Grindelia stricta*	20	*Salicornia pacifica*	15	*Frankenia salina*	5		
2	*Distichlis spicata*	30	*Atriplex triangularis*	30	*Salsola soda*	30	*Grindelia stricta*	5	*Scirpus maritimus*	5				
3	*Distichlis spicata*	50	*Atriplex triangularis*	20	*Salsola soda*	30								
4	*Atriplex triagularis*	60	*Aster sp.*	20	*Cynodon dactylon*	20								
5	*Atriplex triagularis*	50	*Distichlis spicata*	40	*Salicornia pacifica*	5	*Salsola soda*	5						
6	*Distichlis spicata*	40	*Salsola soda*	30	*Atriplex triangularis*	20	*Aster sp.*	10						
7	*Distichlis spicata*	70	*Atriplex triangularis*	10	*Salsola soda*	10	*Grindelia stricta*	5	*Salicornia pacifica*	10				
8	*Distichlis spicata*	55	*Atriplex triangularis*	10	*Grindelia stricta*	10	*Frankenia salina*	10	*Salicornia pacifica*	5	*Salsola soda*	5	*Jaumea carnosa*	5
9	*Distichlis spicata*	40	*Salicornia pacifica*	25	*Jaumea carnosa*	20	*Atriplex triagularis*	10	*Grindelia stricta*	5				
10	*Distichlis spicata*	35	*Atriplex triangularis*	30	*Scirpus maritimus*	10	*Grindelia stricta*	10	*Salsola soda*	10	*Aster sp.*	5		
11	*Distichlis spicata*	90	*Atriplex triangularis*	10	*Salicornia pacifica*	m								
12	*Distichlis spicata*	40	*Atriplex triangularis*	35	*Scirpus maritimus*	10	*Salicornia pacifica*	10	*Grindelia stricta*	5				
13	*Distichlis spicata*	40	*Jaumea carnosa*	30	*Atriplex triangularis*	15	*Salicornia pacifica*	10	*Frankenia salina*	5				
14	*Distichlis spicata*	30	*Salicornia pacifica*	25	*Grindelia stricta*	25	*Jaumea carnosa*	10	*Atriplex triagularis*	10				
15	*Salicornia pacifica*	40	*Distichlis spicata*	30	*Atriplex triangularis*	20	*Scirpus maritimus*	5	Unknown	5				
16	*Salicornia pacifica*	40	*Distichlis spicata*	30	*Atriplex triangularis*	20	*Scirpus maritimus*	5	Unknown	5				
17	*Distichlis spicata*	60	*Salicornia pacifica*	30	*Salsola soda*	10								
18	*Atriplex triangularis*	40	*Bromus diandrus*	30	*Grindelia stricta*	20	*Lotus corniculatus*	10	*Salsola soda*					
19	*Distichlis spicata*	80	*Atriplex triangularis*	15	*Grindelia stricta*	5								
20	*Distichlis spicata*	80	*Atriplex triangularis*	15	*Grindelia stricta*	5								
21	*Jaumea carnosa*	65	*Distichlis spicata*	15	*Atriplex triangularis*	15	*Salicornia pacifica*	5						
22	*Distichlis spicata*	70	*Atriplex triangularis*	30	*Grindelia stricta*									
23	*Atriplex triangularis*	85	*Distichlis spicata*	10	*Aster sp.*	5								
24	*Atriplex triangularis*	80	*Distichlis spicata*	10	*Aster sp.*	10								
25	*Atriplex triangularis*	75	*Aster sp.*	10	*Paspalum sp.*	10	Upland grass	5						
26	*Paspalum sp.*	50	*Aster sp.*	15	*Atriplex triangularis*	10	*Salicornia pacifica*	10	*Grindelia stricta*	5	*Salsola soda*	5	*Cotula coronopifolia*	5
27	*Cynodon dactylon*	80	*Atriplex triangularis*	15	*Aster sp.*	5								
28	*Atriplex triangularis*	50	Upland grass	50										
29	*Atriplex triangularis*	100												
30	*Atriplex triangularis*	100												
31	*Distichlis spicata*	100												

m= minimal observance, less than 5% of total area

Table C1. Sulphur Creek Vegetation Mapping Results. ID numbers are associated with Figure C1.

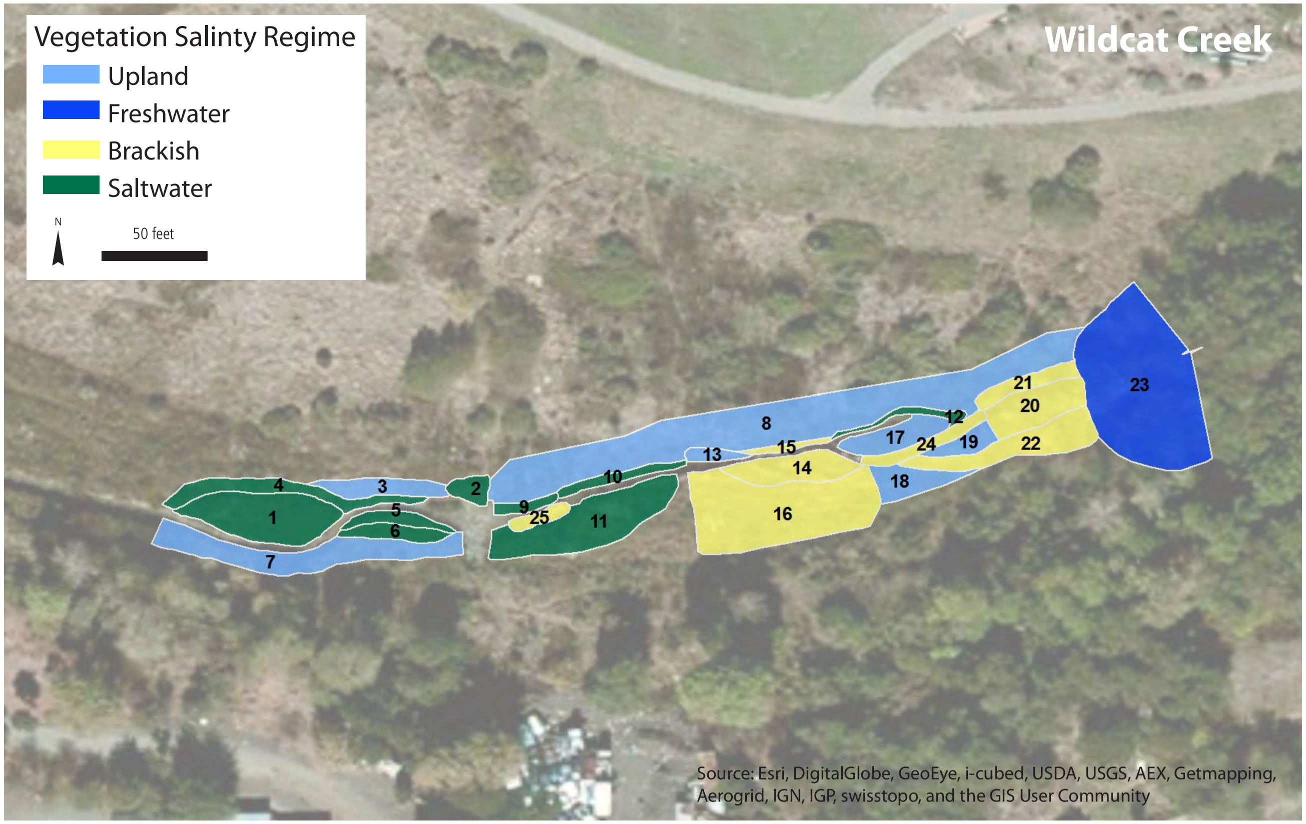


Figure C2. Wildcat Creek Vegetation Map. Numbered polygons explained in Table C2.

ID	Species 1	% Cover	Species 2	% Cover	Species 3	% Cover	Species 4	% Cover	Species 5	% Cover	Species 6	% Cover	Species 7	% Cover	Species 8	% Cover
1	*Grindelia stricta*	45	*Salicornia pacifica*	40	*Distichlis spicata*	10	*Scirpus maritimus*	5	*Atriplex triagularis*	m	*Dipsacus fullonum*	m				
2	*Salicornia pacifica*	75	*Grindelia stricta*	10	*Dipsacus fullonum*	10	*Baccharis glutinosa*	5								
3	*Eleymus glaucus*	95	*Salicornia pacifica*	5												
4	*Salicornia pacifica*	60	*Grindelia stricta*	30	*Eleymus glaucus*	10										
5	*Salicornia pacifica*	40	*Schoenoplectus acutus*	40	*Grindelia stricta*	10	*Baccharis glutinosa*	10								
6	*Salicornia pacifica*	70	*Baccharis glutinosa*	25	*Atriplex triagularis*	5										
7	*Eleymus glaucus*	75	*Dipsacus fullonum*	15	*Baccharis pilularis*	5	*Baccharis glutinosa*	5								
8	*Dipsacus fullonum*	40	*Baccharis pilularis*	25	*Salicornia pacifica*	25	*Avena fatua*	10								
9	*Grindelia stricta*	50	*Salicornia pacifica*	45	*Scirpus maritimus*	5										
10	*Salicornia pacifica*	75	*Grindelia stricta*	15	*Baccharis glutinosa*	10	*Phalaris aquatica*	m								
11	*Salicornia pacifica*	50	*Grindelia stricta*	15	*Baccharis glutinosa*	15	*Dipsacus fullonum*	10	*Baccharis pilularis*	5	*Typha angustifolia*	5				
12	*Salicornia pacifica*	50	*Grindelia stricta*	15	*Baccharis glutinosa*	15	*Dipsacus fullonum*	10	*Baccharis pilularis*	5	*Typha angustifolia*	5				
13	*Eleymus glaucus*	25	*Bromus diandrus*	25	*Baccharis glutinosa*	10	*Bromus hordeaceus*	10	*Avena fatua*	10	*Lolium multiflorum*	10	Unknown grass	10		
14	*Typha angustifolia*	60	*Salicornia pacifica*	30	*Baccharis glutinosa*	10	*Atriplex triagularis*	m								
15	*Typha angustifolia*	60	*Salicornia pacifica*	30	*Baccharis glutinosa*	10	*Atriplex triagularis*	m								
16	*Typha angustifolia*	50	*Baccharis glutinosa*	30	*Salicornia pacifica*	10	*Atriplex triagularis*	10	*Rumex crispus*	m	*Picris echioides*	m	*Dipsacus fullonum*	m		
17	*Baccharis glutinosa*	70	*Atriplex triagularis*	10	*Dipsacus fullonum*	10	*Typha angustifolia*	10								
18	*Eleymus glaucus*	50	*Baccharis pilularis*	40	*Foeniculum vulgare*	10										
19	*Eleymus glaucus*	50	*Baccharis pilularis*	40	*Foeniculum vulgare*	10										
20	*Schoenoplectus acutus*	25	*Rubus ursinus*	20	*Salix lasiolepis*	15	*Baccharis glutinosa*	10	Unknown grass	10	*Eleymus glaucus*	10	*Dipsacus fullonum*	5	*Arrundo donax*	5
21	Unknown grass	50	*Salicornia pacifica*	30	*Dipsacus fullonum*	20	*Atriplex triagularis*	m								
22	*Typha angustifolia*	70	*Baccharis glutinosa*	30												
23	*Salix lasiolepis*	40	*Alnus rhombifolia*	15	Unknown grass	15	*Rubus armeniacus*	15	*Baccharis glutinosa*	15	*Eleymus glaucus*	m	*Arrundo donax*	m	*Schoenoplectus acutus*	m
24	*Schoenoplectus acutus*	100														
25	*Typha angustifolia*	70	*Schoenoplectus acutus*	30												

m= minimal observance, less than 5% of total area

Table C2. Wildcat Creek Vegetation Mapping Results. ID numbers are associated with Figure C2.

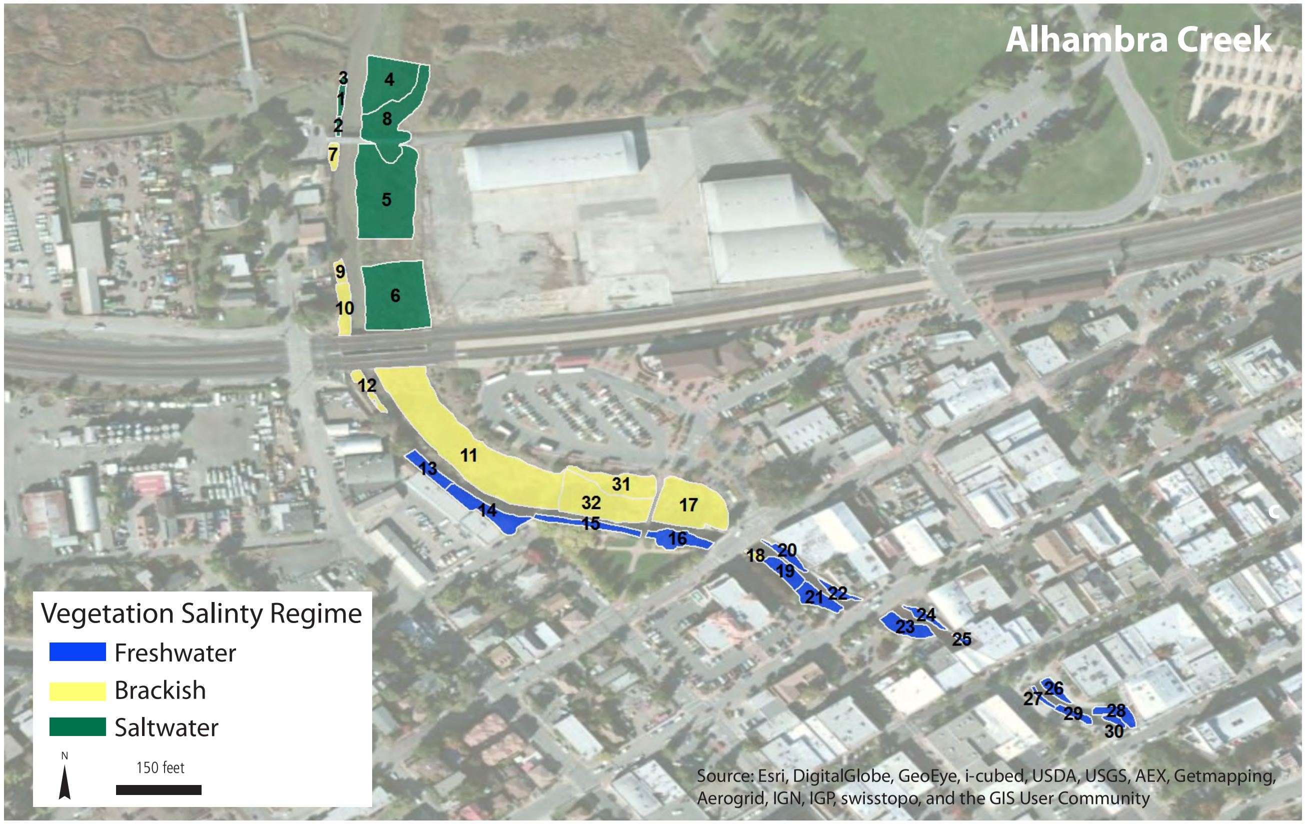


Figure C3. Alhambra Creek Vegetation Map. Numbered polygons explained in Table C3.

ID	Species 1	% Cover	Species 2	% Cover	Species 3	% Cover	Species 4	% Cover	Species 5	% Cover	Species 6	% Cover	Species 7	% Cover	Species 8	% Cover	Species 9	% Cover
1	*Grindelia stricta*	45	*Typha angustifolia*	30	*Lepidium latifolium*	10	*Distichlis spicata*	10	*Atriplex triagularis*	5								
2	*Typha angustifolia*	50	*Distichlis spicata*	40	*Atriplex triagularis*	10	*Lepidium latifolium*	m										
3	*Phragmites australis*	40	*Salicornia pacifica*	20	*Schoenoplectus sp.*	10	*Grindelia stricta*	10	*Distichlis spicata*	10	*Lepidium latifolium*	10						
4	*Phragmites australis*	75	*Spartina sp.*	20	*Grindelia stricta*	5												
5	*Phragmites australis*	75	*Spartina sp.*	20	*Grindelia stricta*	5												
6	*Phragmites australis*	75	*Spartina sp.*	20	*Grindelia stricta*	5												
7	*Distichlis spicata*	50	*Typha angustifolia*	30	*Lepidium latifolium*	10	*Grindelia stricta*	10										
8	*Scirpus maritimus*	80	*Typha angustifolia*	10	*Schoenoplectus sp.*	5	*Phragmites australis*	5										
9	*Distichlis spicata*	25	*Typha angustifolia*	15	*Scirpus maritimus*	15	*Grindelia stricta*	15	*Schoenoplectus sp.*	10	*Spartina sp.*	10	*Lepidium latifolium*	5	*Atriplex triangularis*	5		
10	*Distichlis spicata*	40	*Typha angustifolia*	25	*Phragmites australis*	25	*Atriplex triangularis*	10	*Grindelia stricta*	m								
11	*Phragmites australis*	45	*Scirpus maritimus*	30	*Distichlis spicata*	10	*Atriplex triangularis*	5	*Grindelia stricta*	5	*Typha angustifolia*	5	*Salicornia pacifica*	m	*Schoenoplectus sp.*	m		
12	*Distichlis spicata*	50	*Lepidium latifolium*	30	*Typha angustifolia*	15	*Avena fatua*	5										
13	*Piptatherum miliaceum*	50	*Salix laevigata*	40	*Fraxinus latifolia*	5	*Atriplex triangularis*	5										
14	*Salix laevigata*	40	*Piptatherum miliaceum*	20	*Hedera helix*	15	*Rubus ursinus*	15	*Quercus agrifolia*	5	Unknown blackberry	5						
15	*Piptatherummiliaceum*	50	*Populus fremontii*	20	Unknown blackberry	15	*Quercus agrifolia*	10	*Foeniculum vulgare*	5	*Typha angustifolia*	m	*Phragmites australis*	m				
16	Unknown blackberry	40	*Piptatherum miliaceum*	35	*Populus fremontii*	20	*Foeniculum vulgare*	5	*Typha angustifolia*	m	*Schoenoplectus sp.*	m	*Distichlis spicata*	m				
17	*Phragmites australis*	25	*Piptatherum miliaceum*	20	*Typha angustifolia*	15	*Atriplex triangularis*	15	*Cynodon dactylon*	15	*Rubus armeniacus*	10	*Scirpus maritimus*	m	*Salicornia pacifica*	m		
18	*Piptatherum miliaceum*	60	*Schoenoplectus acutus*	15	*Phragmites australis*	10	*Typha angustifolia*	5	*Atriplex triangularis*	5	Unknown blackberry	5						
19	*Salix laevigata*	40	*Piptatherum miliaceum*	30	*Equisetum arvense*	10	*Arrundo donax*	5	*Rubus ursinus*	5	*Vinca*	m	Sedge	m	*Lemonbaum*	m		
20	Unknown blackberry	50	*Piptatherum miliaceum*	30	*Atriplex triangularis*	5	*Schoenoplectus sp.*	5	*Salix laevigata*	5	*Fraxinus latifolia*	5						
21	*Salix laevigata*	45	*Rubus ursinus*	45	*Cynodon dactylon*	5	*Vitis californica*	5										
22	*Piptatherum miliaceum*	35	*Salix laevigata*	30	Unknown blackberry	15	*Cynodon dactylon*	10	*Atriplex triangularis*	5	*Arrundo donax*	5						
23	*Piptatherum miliaceum*	45	*Salix laevigata*	15	*Cynodon dactylon*	10	*Atriplex triangularis*	10	*Schoenoplectus sp.*	10	Unknown blackberry	5	*Vitis californica*	5	*Juncus effusis*	m		
24	*Salix laevigata*	40	*Cynodon dactylon*	35	*Piptatherum miliaceum*	25	*Grindelia stricta*	m	*Trifolium repens*	m								
25	*Piptatherum miliaceum*	30	*Cynodon dactylon*	25	*Melilotus alba*	20	*Plantago major*	10	*Xanthium strumarium*	5	*Cyperus eragrostis*	5	*Atriplex triangularis*	5	*Schoenoplectus sp.*	m		
26	*Cynodon dactylon*	40	*Atriplex triangularis*	25	*Plantago major*	10	*Typha angustifolia*	5	*Lepidium latifolium*	5	*Trifolium repens*	5	*Melilotus alba*	5	*Solanum sp.*	5		
27	Unknown garden vine	75	*Rubus armeniacus*	20	*Urtica diotica*	5												
28	*Salix laevigata*	75	*Rubus armeniacus*	10	*Piptatherum miliaceum*	10	*Equisetum arvense*	5	*Urtica diotica*	m								
29	*Salix laevigata*	75	*Rubus armeniacus*	10	*Piptatherum miliaceum*	10	*Equisetum arvense*	5	*Urtica diotica*	m								
30	*Salix laevigata*	90	*Urtica diotica*	5	*Cynodon dactylon*	5												
31	*Cynodon dactylon*	60	*Salix laevigata*	20	*Piptatherum miliaceum*	10	*Baccharis pilularis*	10										
32	*Phragmites australis*	25	*Grindelia stricta*	15	*Salicornia pacifica*	15	*Atriplex triangularis*	10	*Distichlis spicata*	10	Unknown	10	*Scirpus maritimus*	5	*Typha angustifolia*	5	*Piptatherum miliaceum*	5

m= minimal observance, less than 5% of total area

Table C3. Alhambra Creek Vegetation Mapping Results. ID numbers are associated with Figure C3.

Appendix D. Water Surface Elevations

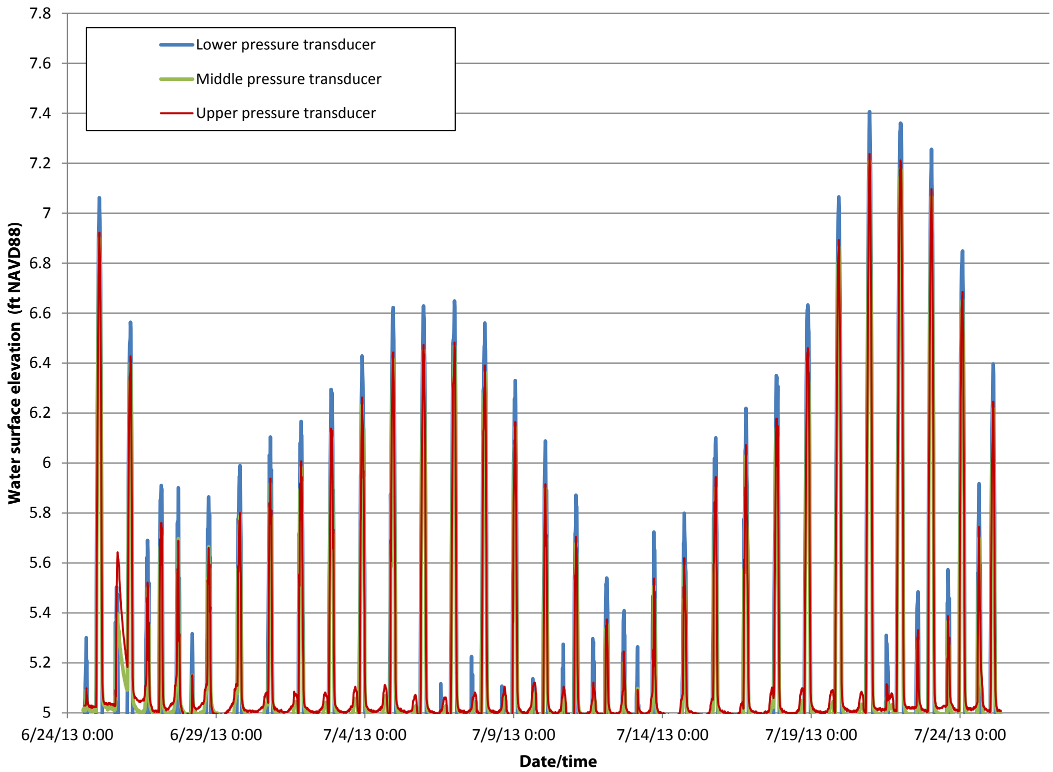


Figure D1. Wildcat Creek monitored water surface elevations.

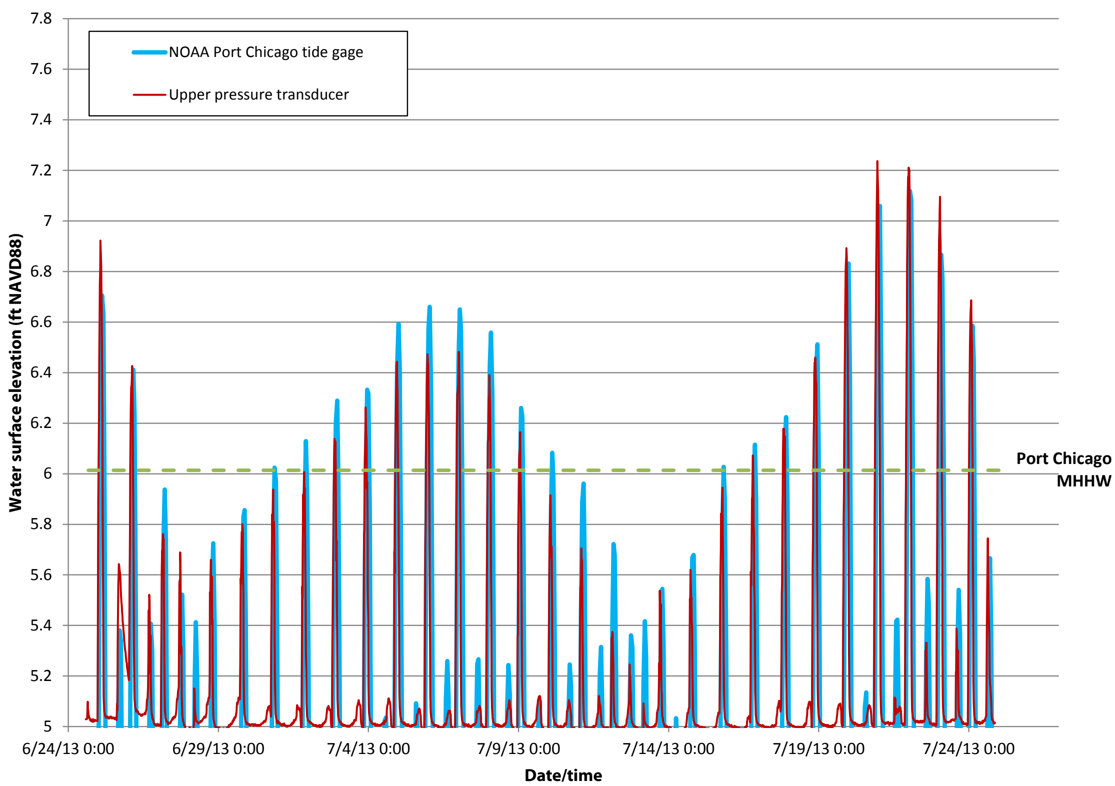


Figure D2. Comparison of local tidal elevation and Wildcat Creek water surface elevation.