Lower Salmon Creek Delta
Salmonid Habitat Enhancement Project
Phase 2

FINAL

Design Report

January 15, 2010

Prepared for:

Pacific Coast Fish, Wildlife & Wetlands Association

US Fish and Wildlife Service

California Department of Fish and Game
(CDFG Grant Agreement No. P0710550)

Prepared by:

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1. Project Background and Goals

1.1. Report Overview

The purpose of the this report is to present the overall goals and objectives of the Lower Salmon Creek Delta Salmonid Habitat Enhancement Planning Project and detail the site investigations and methods used for developing the engineering designs for Phase 2 of the project. The report is structured as follows:

Chapter 1 presents the project background, project goals and objectives, and components of project Phases 1 and 2.

Chapter 2 provides a detailed summary of the proposed Phase 2 project elements.

Chapter 3 presents the methodology and results of monitoring conducted after Phase 1 implementation. The monitoring of tidal fluctuation, geomorphic response, and water quality within the project reach were used to guide development of the Phase 2 design.

Chapter 4 presents mapped topography and project design hydrology and tidal boundary conditions necessary to develop the Phase 2 design.

Chapter 5 presents the Phase 2 design methods and results, including tidal channel design, unsteady HEC-RAS hydraulic model development, and the use of modeling results to design specific project elements.

Chapter 6 presents permitting and construction issues, including earthwork volumes, sequence of construction, water management, areas of disturbance, and an engineer's estimate of implementation costs.

1.2. Project Background

In 2001, California Department of Fish and Game (CDFG) funded Pacific Coast Fish Wildlife and Wetlands Restoration Association (PCFWWRA) to evaluate existing conditions and develop an overall plan to improve fish access to Salmon Creek and fisheries habitat within the Humboldt Bay National Wildlife Refuge (Refuge). Michael Love & Associates (MLA) and Graham Matthews & Associates prepared the report for PCFWWRA, entitled *Lower Salmon Creek Delta Salmonid Habitat Enhancement Opportunities* (PCFWWRA, 2003). The report characterized current conditions and limiting factors on the Refuge for salmonid production and developed three alternative restoration approaches. The goals of the study were to identify methods to create a self-sustaining estuarine system while working within the current physical constraints imposed by the land use objectives of the Refuge, upstream landowners, and transportation infrastructure. This would be achieved by increasing the tidal prism within the levees on the Refuge, which would provide fish access, improve flood flow conveyance and sediment transport capacity, and increase the amount of estuarine in-channel and off-channel habitats on the Refuge.

The Refuge selected Alternative B (near-term alternative) and chose to design and implement the project in two phases. The preferred alternative included the following project components, shown in Figure 1-1.

1.2.1. Phase 1 Components

This section summarizes the components of Phase 1. Implementation of Phase 1, funded by U.S. Fish and Wildlife Service (USFWS) and CDFG, is complete. The Environmental Assessment

(Laird, 2005) and Biological Assessment (Laird, 2006) provides detailed descriptions for Phase 1 of the project.

Install Two Tidegates with Adjustable Muted Tidal Openings. The existing Salmon Creek tidegate was replaced in summer/fall 2008 and a new tidegate further towards the west, referred to as the Overflow Gate, was constructed in fall/winter 2007-2008. The new tidegates triple outflow capacity and include adjustable incoming flow openings that permit aquatic organism passage and seawater to flow into lower Salmon Creek. The incoming flow openings enlarge the muted tidal prism within the Salmon Creek estuary from 35 acre-feet to approximately 130 acre-feet (AF), as measured between mean lower low water (MLLW) and mean higher high water (MHHW). The incoming flow openings in the tidegates were designed to increase MHHW in the Salmon Creek estuary inside the levees from approximately 3.0 feet (as measured in 2002) to an elevation of approximately 4.8 feet.

The increased tidal prism enlarges the estuary of Salmon Creek and serves to alleviate in-channel sedimentation and remove existing accumulated sediment through daily tidal flushing and channel enlargement. The increased outflow capacity drains stored floodwaters more rapidly, increasing stream power and reducing channel sedimentation within the Refuge. The new tidegates also provide unimpeded fish passage.

Removal of High Point in Channel. A high point in the lower channel, identified in the 2003 report and referred to as the knick-point, coincided with where the downstream end of a channel constructed by the Refuge in 1994 tied into the existing Salmon Creek channel. The knick-point functioned as a hydraulic control that limited upstream tidal influence. The channel knick-point, composed of material resistant to erosion, was excavated in 2006 to increase upstream tidal influence and promote channel downcutting and enlargement. Removal of the knick point allows the tidal action to extend farther upstream into the Refuge and has removed a fish passage blockage at lower tides.

Connect Existing Off-Channel Ponds to Salmon Creek. The 2003 report identified opportunities to increase connectivity between the Salmon Creek channel and existing off-channel ponds. The pond connections were intended to allow juvenile salmonids access to suitable off-channel rearing habitat during winter flows, when the salinity within the ponds are low, and provide aquatic and marine species access during summer low flows. Small connection channels were excavated by the Refuge between 2006 and 2008.

Replace Two Tidegates on Tidal Channels in Hookton Slough. Two existing tidegates on small drainage channels to Hookton Slough were replaced in 2006. The new tidegates allow a muted tide inside of the levees to create estuarine habitat and promote sediment flushing. The new gates also allow fish access and eliminate stranding potential for adult and juvenile salmonids that arises during larger over-bank flow events in Salmon Creek.

1.2.2. Phase 2 Components

This section presents Phase 2 project components. Chapter 5 presents the proposed project in more detail. Project components for Phase 2 are shown schematically in Figure 1-2. Appendix A presents the draft engineering design plans.

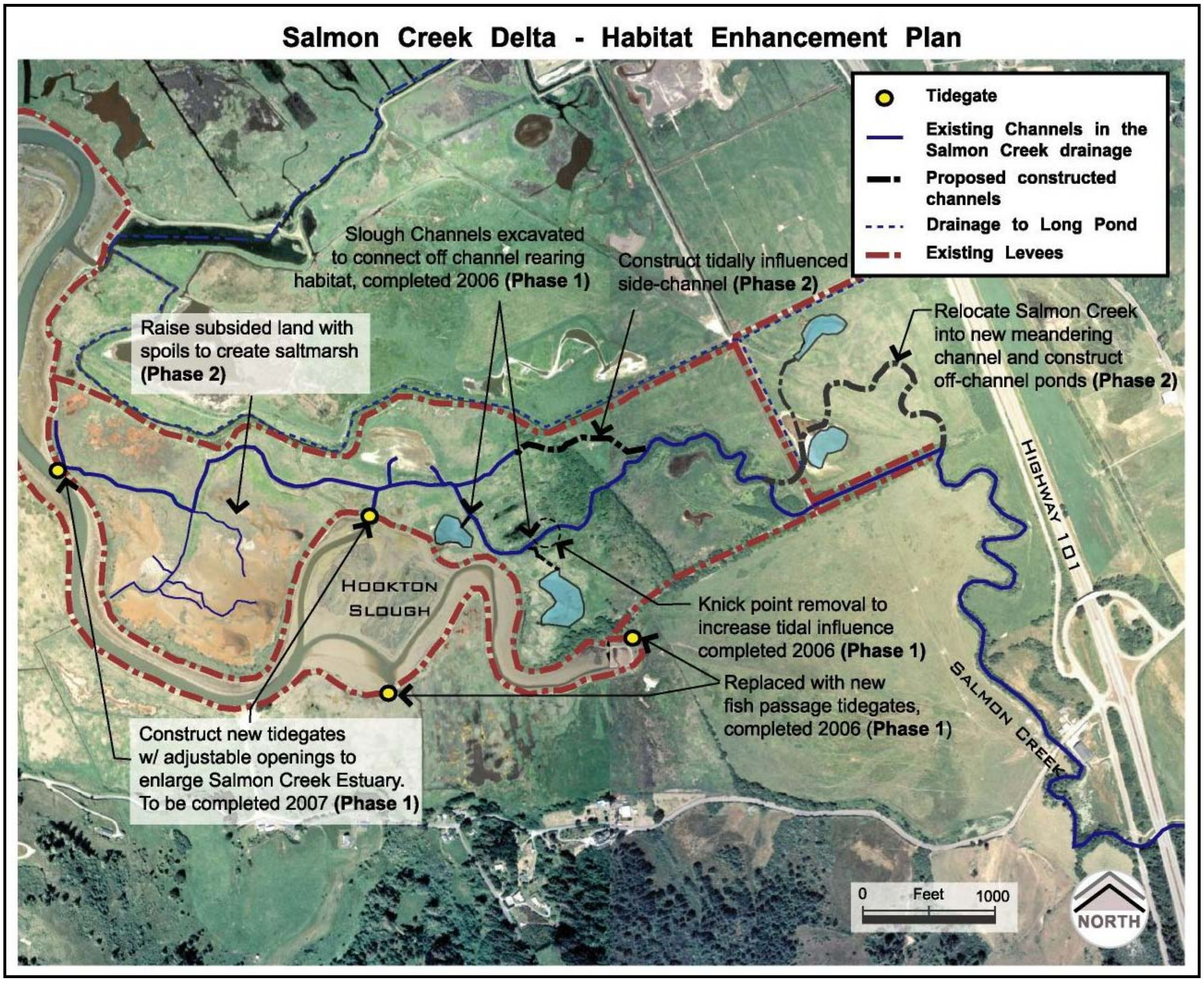


Figure 1-1. Schematic of Phase 1 and Phase 2 Improvements to Salmon Creek (adapted from the Salmon Creek Delta, Phase 2 Planning Project grant submittal to CDFG). Proposed channel alignments and location and number of new ponds have been modified and refined with development of Phase 2.

Engineering design and environmental permitting of Phase 2 has been funded by USFWS and the CDFG Fisheries Grants Program. Preliminary design for Phase 2 began in early 2008. The conceptual design and brief overview of the project background, goals and objectives, followed by a description of the preliminary Phase 2 conceptual design were presented in a Technical Memorandum (Appendix B) prepared by Michael Love & Associates in July 2008 (MLA, 2008). The Phase 2 conceptual design was reviewed and approved in August 2008 by the Technical Advisory Committee comprised of staff from the U.S. Fish & Wildlife Service, California Department of Fish & Game, and National Marine Fisheries Service.

Relocate Salmon Creek Tidal Channel within the Upper Refuge

The upper reach of Salmon Creek on the Refuge will be realigned out of the existing ditch to improve geomorphic function and habitat diversity. The reconstructed channel is designed to function as part of the upper estuarine ecotone. Dimensions of the new channel allow for conveyance of the daily tidal flux and frequently occurring high flow events and associated sediment load.

The realigned channel will be constructed at a substantially lower elevation than the existing channel, allowing tidal influence to extend into the Upper Refuge. During low streamflows this influences will extend to the Refuge property boundary. The existing ditch will continue to function as a tidal backwater and provide flood flow relief. The new channel design will improve connectivity with the floodplain and off-channel ponds while reducing the risk of fish stranding.

Construct Tidal Side-Channel within the Middle Refuge

A side-channel in the middle portion of the Refuge will be constructed to increase conveyance of the tidal prism to the Upper Refuge, and will also improve routing of floodwaters and sediment. The new side channel will serve as the primary tidal channel.

Construction of the new side channel will result in the conversion of the existing channel in this reach to a tidal backwater channel that provides flood flow relief.

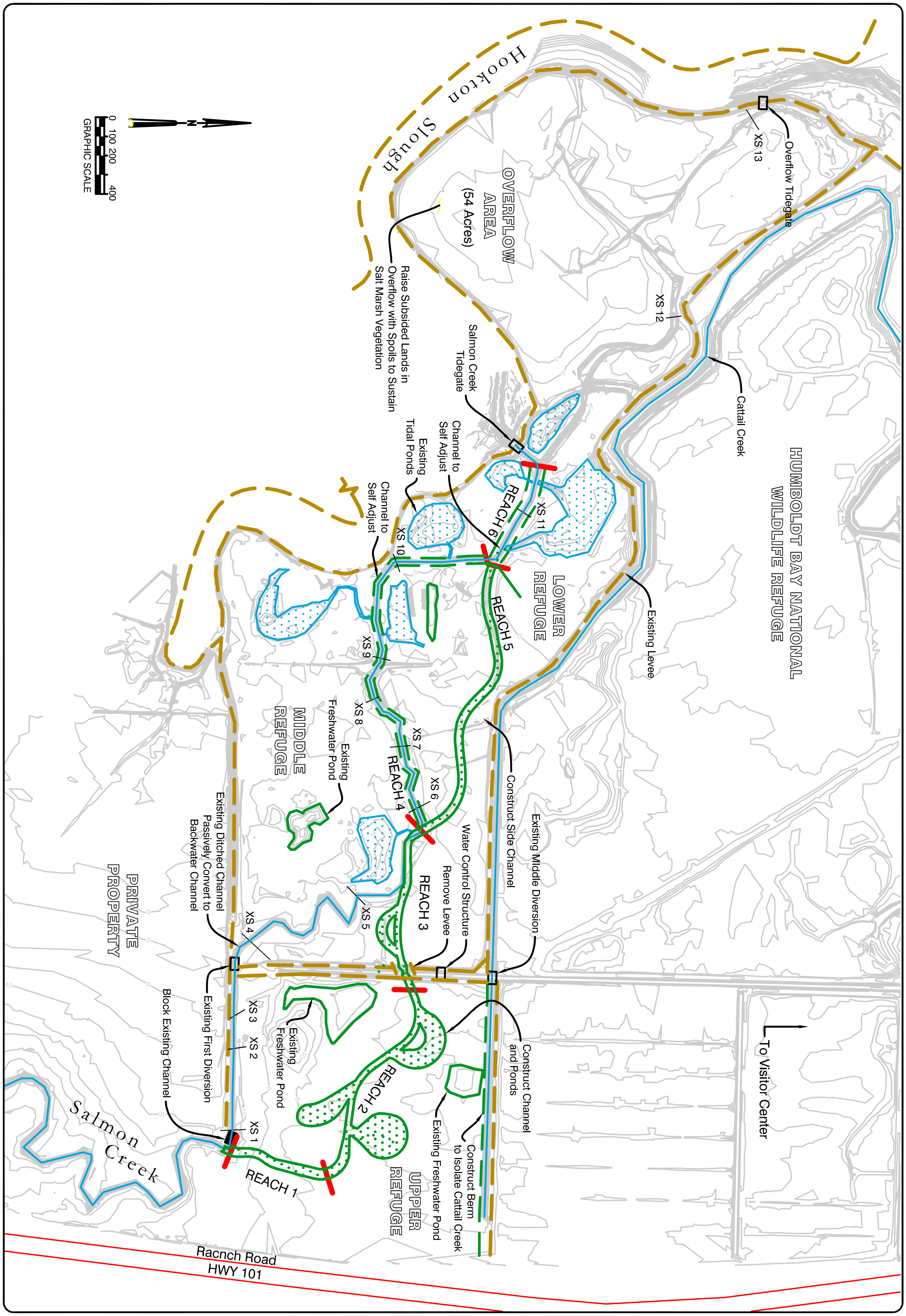
Construct Tidally Influenced Off-Channel Habitat within the Upper Refuge

Creation of four new, tidally influenced off-channel ponds in the Upper and Middle Refuge will provide winter freshwater rearing habitat for salmonids, specifically coho salmonids (*Oncorhynchus kisutch*), during the wet season and become brackish during the dry season. The ponds will be constructed to mimic the form and function of naturally occurring ponds and overflow channels typically found in low-gradient fluvial systems.

Minimize Cattail Creek Fish Stranding & Construct New Water Diversion Structure

The Refuge relies in part on the overbank storm flows from Salmon Creek flowing into Cattail Creek, which are then diverted to other parts of the Refuge to maintain freshwater wetlands and ponds used by waterfowl. However, the overtopping storm flows potentially strand fish in other part of the Refuge. A low berm will be constructed between Salmon Creek and the south bank of the Cattail Creek diversion ditch to greatly reduce the frequency of Salmon Creek waters flowing into Cattail Creek. The berm will also increase water depth and decrease water velocities across the Salmon Creek floodplain, making it more suitable habitat for rearing salmonids during flood events. The berm will be set back from Cattail Creek and have some sinuosity, in plan view. This will provide needed space between the creek and the berm to allow for future realignment and restoration of Cattail Creek.

Streamflow from Salmon Creek is also passively diverted to Cattail Creek and the northern Refuge when the stream's stage is elevated sufficiently to overtop stoplogs (which are maintained at their highest setting) at the existing First Diversion structure. The First Diversion structure will no longer be functional with realignment of the Salmon Creek Channel, requiring construction of a new water control structure to ensure the continued delivery of freshwater to the northern wetlands. Since commencement of the Phase 2 design, the USFWS has reviewed alternatives for screening diverted flows to prevent salmonids from being stranded in the northern portions of the Refuge. They have concluded that screening is impractical and have developed an alternative approach. USFWS plan to create a return route for juvenile salmonids and other aquatic species from the northern Refuge to Salmon Creek by including a fish passage facility as part of a new water control structure. This will provide salmonids the opportunity to rear during the wet season in the large ponds, wetlands, and channels located in the northern Refuge, while being able to return to Salmon Creek or out-migrate to Humboldt Bay as salinity increases and water quality conditions deteriorate during the late spring and summer. The water control structure and fish passage facility are being developed under a separate contract and are not discussed in detail in this design report.



DATE 28 JULY 08 DESIGN Love/Shea DRAWN Llanos SHEET 1 of 1	FIGURE 1-2. SCHEMATIC DESIGN	Humboldt Bay National Wildlife Refuge Salmon Creek Enhancement Plan PHASE 2

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Raise Subsided Lands in Overflow (Overflow Area) to Create High Marsh

The Overflow has experienced several feet of subsidence since it was diked and drained. As a result, much of the area is too low to sustain salt marsh vegetation with the increased muted tide created in Phase 1. A portion of the spoils generated from excavation of the new channels and ponds will be used to raise the ground within parts of the Overflow to elevations suitable for sustaining native salt marsh vegetation, specifically the *Sarcocornia virginica* vegetation complex.

1.3. Phase 2 Project Objectives and Constraints

Design development for Phase 2 was guided by specific project objectives established during earlier project phases. Specific Phase 2 project objectives are to:

- Extend tidal influence and estuarine conditions into the Upper Refuge
- Create geomorphically stable channels that convey the enlarged tidal prism and transport supplied sediment
- Restore floodplain function and connectivity
- Improve fish access and fish passage on the Refuge
- Reduce fish stranding on the Refuge
- Create off-channel seasonally freshwater ponds suitable as salmonid winter rearing habitat
- Restore native salt marsh habitat, specifically the *Sarcocornia virginica* vegetation complex, in subsided mudflats in the Overflow area
- Maintain existing wetlands and improve wetland function
- Limit project impacts to within the Refuge boundaries

Selection of implementation approach, location of project elements, and project design were constrained by numerous factors. This report presents how project site constraints were considered during the design process. Project constraints included, but were not limited to the following:

- Predefined project area
- Project area location and elevation near a tidal interface
- Existing infrastructure
- Off-Refuge channel conditions
- Refuge management goals
- Existing habitat features
- Tidal prism provided by Phase 1 tidegates
- Incoming sediment from upstream
- Channel elevation at upstream project boundary
- Incoming flows from upstream
- Construction/maintenance accessibility
- Maintenance needs
- Properties of underlying soils

2. Phased 2 Project Description

Phase 2 of the Salmon Creek enhancement project consists of enhancing 5,700 feet of existing tidal channel and constructing 3,500 feet of new channel on the Refuge. The new channel will be constructed to convey the design tidal prism at equilibrium conditions. Appendix A presents design plans and specifications.

Construction of the new channel will serve to move the existing channel out of a ditched reach in the Upper Refuge and create a new side channel in the Middle Refuge. Rock grade control structures constructed at the upstream limits of the realigned reach will ensure that improvements on the Refuge do not affect the privately owned property upstream of the Refuge.

The existing 2,200-foot ditched channel and 2,100-foot side channel will function as tidal backwater channels, increasing the estuarine habitat area on the Refuge. These channels are expected to self-adjust in response to the small tidal prism they will convey.

Where channel improvements are constructed, riparian vegetation will be planted and large wood structures will be added to improve channel complexity and cover.

The project also includes creation of four off-channel ponds in the Upper and Middle Refuge. These ponds have a total surface area at MHHW of approximately 2 acres and a contributing tidal prism (MLLW to MHHW) of approximately 4 acre-feet.

Excavated material from construction of the channel and ponds will be placed in the Overflow area to convert up to 14 acres of existing mudflats to marsh plain at elevations suitable for establishing and supporting a *Sarcocornia virginica* vegetation complex.

The following sections summarize the proposed Phase 2 design. Chapter 5 presents the design of each project element in detail.

Note that all elevations given in this report are in the North American Vertical Datum 1998 (NAVD88)

2.1. Reach 1

Reach 1 is a transition reach between the riverine dominated channel upstream of the Refuge and tidally dominated channel in Reach 2. The upstream end of the Reach 1 channel meets the existing channel at an elevation of 3.9 feet at the Refuge property boundary. Reach 1 has a channel slope of approximately 1% for 440 feet, ending at a channel elevation of -0.2 feet. The lower 365 feet of the reach slopes at 0.07%. The channel will be constructed with a 5-foot bottom width and 3H:1V side slopes.

The more steeply sloped sections of the Reach 1 channel follow the historical alignment of Salmon Creek, as seen in the 1870 mapping and clearly visible in the 1948 and subsequent aerial photographs (Laird, 2008). Placing Reach 1 in the historical channel location is intended to restore the historical channel planform where site constraints allow, and to provide maximum flexibility for any future restoration actions that may be taken in the channel reach upstream of the Refuge.

A geologic investigation, conducted by Pacific Watershed Associates (2009) as part of this project, found that below approximately elevation 4.5 feet, the historical channel in Reach 1 is filled with uncohesive sands and gravels that were saturated in January during the exploratory trenching (see Section 3.4). Outside the limits of the historical channel, the subsurface was characterized by dense highly cohesive clay overlaid by silt. The geologic report makes several recommendations regarding channel bank stabilization, rock weir construction and dewatering of the channel in Reach 1 during construction. The recommendations of the geologic report were incorporated into the design where appropriate.

The over-steepened section of Reach 1 will be constructed with permanent rock grade controls to maintain the design elevation and slope of the channel and to maintain the current channel grade within the privately owned property upstream of the Refuge. The grade control will consist of 10 rock structures with sloping faces. At high tide, all of the grade control structures will be backwatered, allowing fish to swim upstream unimpaired. During lower tides and low flows, the upper grade controls will not be backwatered by the tide and fish will have to swim or leap across the water surface drop created by each grade control structure. Drop between grade controls is set at 0.4 feet, which is less than the 0.5-foot criterion for upstream passage of juvenile salmonids (NMFS, 2001). This will reduce the risk of creating an excessive drop for fish passage if minor differential settlement between grade controls occurs. Due to the subsurface soil conditions identified as part of the geologic investigation, the rock grade control structures will be wrapped in a geofabric to distribute the load of the structures and minimize differential settlement.

If future restoration activities within the channel immediately upstream of the Refuge include reintroduction of tidal influence, grade controls could be removed in phases or all at once, and Reach 1 and areas upstream could be allowed to widen and incise within the historical channel configuration.

Near the downstream end of Reach 1, the new channel diverges from the historical channel location, turning west to meet the existing channel in Reach 3. The geologic investigation recommended that where the proposed channel diverges from the historical channel, the erodible channel banks be reinforced to maintain bank stability and to allow unimpeded flow of groundwater. In this location two log vanes will be installed on the outside bank of the meander bend to turn flow away from the streambank. To provide streambank coverage and quickly establish a dense root mat, a willow brush mattress will be installed between the log vanes and the top of the streambank.

To further stabilize the potentially unstable non-cohesive streambanks that may be encountered within the historical channel limits, coir soil stabilization matting will be installed from the toe of the streambank to the top of bank. A rapidly germinating seed mix will be used to obtain root strength within the bank material, and the area will be planting with live willow cuttings at 2-foot spacing. The willow cuttings are expected to rapidly develop a dense root mat for bank stabilization as well as provide riparian cover.

The geologic investigation also cautioned that this area of new channel may be susceptible to liquefaction and slumping during earthquakes and some maintenance may be necessary after an earthquake. The Refuge has committed to preparing a monitoring and maintenance plan prior to construction that will address specific issues identified in the geologic investigation.

2.2. Reach 2 and Cattail Creek

Reach 2 is a 950-foot long tidally influenced section of new channel that contains new Pond 1 through 3. Reach 2 will be constructed in the open fields within the Upper portion of the Refuge. The constructed channel slope will range from 0.07% to 0.1%, with an average channel bottom elevation of -1.0 feet. The channel will be constructed with a 6.5-foot bottom width and 1.5H:1V side slopes. The banks will be planted with live willow cuttings at 2-foot spacing above MHHW (approximately elevation 4.8 feet, NAVD 88).

To reduce Salmon Creek flow loss into Cattail Creek, a low earthen berm is proposed in the Upper Refuge between Salmon Creek and the south bank of Cattail Creek. The berm will be sinuous to allow for future restoration of Cattail Creek. The new berm is designed to prevent Salmon Creek floodplain flows in Reach 2 from being captured by Cattail Creek up to the 2-year peak design flow. Containing frequently occurring floodplain flows with the berm will create low velocity refuge and foraging habitat across the floodplain for juvenile salmonids during these events. The top elevation of the berm is within the elevation range of seasonally flooded herbaceous and riparian wetland vegetation mapped by USFWS within the Upper Refuge, thus is expected to provide the same wetland function after implementation. Salvaged topsoil will be placed on the top and side slopes of the Cattail Creek Berm to provide a seed bank of native plants. Additionally, the Refuge may plant additional trees, shrubs and other woody species.

2.3. Water Control and Fish Passage Structures

The realignment of Salmon Creek out of the existing ditched channel moves the active stream channel away from the First Diversion water control structure. Currently, flows in Salmon Creek that overtop the stop logs at the First Diversion are conveyed northward in ditch that connects to the Middle Diversion water control structure and Cattail Creek. Water from the First Diversion, as well as overbank flow from Salmon Creek that enters Cattail Creek near Ranch Road, supplies freshwater to the large wetland system in the northern portions the Refuge from late fall into the spring. During summer low-flows, no freshwater is supplied to the northern portion of the Refuge from Salmon Creek and the northern wetlands either dry-out or become brackish.

Fish entrained within the flood waters that flow into the northern part of the Refuge have the potential to become stranded as floodwaters recede and water quality decreases. Currently, the only means of fish egress from the northern part of the Refuge is through the Long Pond and White Slough tidegates that drain into the saline waters of South Bay.

To avoid a reduction in freshwater supply to the northern wetlands, a new water control structure is proposed, which will allow for a portion of Salmon Creek waters to flow into Cattail Creek during high-flow events. The structure would be placed in the existing ditch between the First and Middle Diversions, adjacent to the new Reach 3 channel.

The Refuge also plans to construct a fish passage structure that allows fish to return to Salmon Creek from the northern part of the Refuge as spring flows recede. The following are the design and operational goals presented by USFWS:

1. Channel shall be designed to allow fish to return on recession limb of stormflow events and during high baseflow. It is expected that (a) return will not be possible during stormflow peaks; and (b) passage may be temporally intermittent when baseflow decreases as spring advances.

2. Design should attempt to provide passage from first rainfalls capable of flushing juvenile salmonids into Cattail Creek to the end of juvenile out-migration.

3. Channel should operate passively.

4. Design should prevent discharge of saline water into Cattail Creek.

5. Design should provide controls for USFWS staff to adjust structure in accordance with adaptive management plan and observed fish passage conditions.

6. Design should provide means for USFWS to close connection for Refuge maintenance needs.

USFWS is currently coordinating with NMFS to agree on design and operational parameters for the water control and fish passage structure. It is the intent of USFWS to incorporate the water control and fish passage structure into the Salmon Creek Phase 2 project, although it may be constructed at a latter date.

2.4. Existing Ditched Channel

The existing ditched channel is 2,200 feet in length and parallels the new channel in Reaches 1 and 2. At the Refuge boundary, the existing ditched channel will be blocked to prevent baseflow and frequent flow events from entering the top end of the existing ditched channel, converting it into a backwater channel. During higher flows, water will flow over the channel block, allowing the channel to act as a flood overflow channel, reducing the frequency and duration of out-of-bank flows in Reaches 1 and 2.

The proposed channel block will be constructed using a combination of log step pools and an engineered log jam (ELJ). The step pools are designed to have one foot of drop between steps to allow adult salmonid fish passage when the channel is active. The ELJ is intended to control the tailwater elevation of the last step pool, as well as to create channel bottom diversity and habitat.

The channel will act as a side channel conveying a fraction of the tidal prism (1.4 AF), while the new channel in Reaches 1 and 2 convey the bulk of the design tidal prism within the Upper Refuge (7.1 AF). The existing ditched channel will be left to self-adjust to equilibrium conditions. The existing ditched channel is expected to widen only slightly. It could deepen up to 2.5 feet but tree roots and the presence of a heavy clay layer are expected to slow the erosion rate.

2.5. Reach 3

Reach 3 is a tidal reach that is 925 feet in length and contains New Pond #4. Reach 3 begins just upstream of the levees and ditch that runs between the First and Middle Diversion. The lower 300-foot portion of the reach is located along the existing alignment of the Salmon Creek channel, which was constructed by the Refuge in 1994. The reach of channel that follows the existing Salmon Creek alignment has a dense riparian forest composed primarily of alder trees along both banks.

Reach 3 conveys the tidal prism from the Upper and Middle portions of the Refuge to the Lower Refuge (9.6 AF as measured at the downstream end of Reach 3). Allowing the channel reach within the existing alignment of Salmon Creek to self-adjust presents excessive uncertainty and risk. Because Reach 3 is the conduit for all tidal flow into the Upper Refuge, relying on this reach to self-adjust could create a long-term hydraulic constriction. It is likely that the heavy clay found in the Upper Refuge and the knick point removed in Phase 1 in the Middle Refuge may be present in this Reach. Similar to the knick point, it is likely that the clay will inhibit the channel incision necessary to reach tidal equilibrium conditions. A constriction would inhibit tidal inflow into Reach 2 and conveyance of higher stream flows and associated sediment loads from upstream to downstream.

Reach 3 will be excavated to the design tidal equilibrium width and depth to maintain a continuous profile between Reaches 2 and 5. The channel in Reach 3 will be enlarged to form a tidal channel at a slope of 0.07%, a bottom width of 11 feet and 1.5H:1V side slopes. The average elevation of the new channel bottom is -1.6 feet. Excavation within the 300 feet of existing channel will require dewatering during construction. To minimize disturbance to the adjacent riparian areas, the southern streambank and riparian area will be preserved during excavation. The excavated streambanks will be stabilized above MHHW with live willow cuttings planted at 2-foot spacing.

Where the new channel crosses the levees and drainage ditch between the First and Middle Diversion, approximately 200 feet of the existing levees will be removed to the south of the new channel to restore floodplain topography. The intent of the levee removal is to restore continuity of floodplain flows between the Upper and Middle portions of the Refuge. The existing ditch between the First and Middle Diversion will be retained so that it can continue to provide wetland habitat for amphibians during lower flows, and will function as a low velocity backwater habitat during larger flow events. To provide access to the new water control and fish passage structure, as proposed by USFWS, the road-topped levee north of the new channel would not be removed.

2.6. Reaches 4 and 5

Reach 4 is a 2,100-foot reach of channel that was constructed by the Refuge in 1994. This channel will act as side channel while the new channel in Reach 5 will convey the bulk of the tidal prism. Construction access into Reach 4 would be difficult due to the number of tidal ponds and an existing mature alder forest along the reach. Therefore, Reach 4 will be left to self-adjust to tidal equilibrium conditions. Most of Reach 4 is currently close to its equilibrium depth, but expected to widen approximately 7 feet to an equilibrium top width of 22 feet. Root strength from riparian trees is expected to slow the erosion rate.

Reach 5 will be a newly constructed 1,525-foot long channel adjacent to Reach 4. The downstream portion of Reach 5 is located in an existing channel, which was originally constructed as a drainage channel, as evident in the 1958 aerial photograph (Laird, 2008). Reach 5 crosses through an open field before rejoining the existing channel at the downstream end of Reach 3. Reach 5 will be constructed with a slope ranging from 0.04 to 0.08%, a 14-foot bottom width, and 1.5H:1V side slopes. The average channel bottom elevation within the reach is -2.4 feet (NAVD88).

The excavated banks of Reach 5 will not be planted with live willow cuttings because of saline conditions. It is expected that the banks will rapidly colonize with *Sarcocornia virginica* and other salt marsh plants, similar to the observed rapid recolonization of other disturbed tidal marsh areas within the Refuge.

Reach 5 conveys the bulk of the tidal prism to and from the Upper Refuge (14.1 AF as measured at the downstream end of Reach 5), while Reach 4 conveys approximately 3.3 AF.

2.7. Reach 6

Reach 6 is 700 feet long and is located along the existing Salmon Creek channel alignment downstream of the confluence of Reaches 4 and 5. No channel improvements are proposed in Reach 6. The existing channel invert in Reach 6 is already near the equilibrium depth. Since completion of the Overflow tidegate and the associated increase in the tidal prism, more than five feet of channel bank erosion has been measured at monitoring cross sections within this reach. This indicates that the channel width along this reach is responding rapidly to the increased tidal prism resulting from Phase 1 of the project. Over time, Reach 6 is expected to widen through self-adjustment from approximately 28 feet to 52 feet wide.

Reach 6 is the conduit for all tidal flows into Salmon Creek in the Middle and Upper Refuge, conveying the tidal prism of 21.1 AF from Salmon Creek. Though there is a degree of uncertainty in the rate that channel widening will occur, based on observations it is expected that this reach will widen fairly rapidly, allowing conveyance of the design equilibrium tidal prism. If excavated, the amount of earthwork would be substantial. Low, wet ground and the presence of two existing tidal ponds adjacent to the channel would make construction access extremely difficult. Additionally, excavation in this reach would require dewatering the channel, which would be difficult due to the size and depth of the channel, softness of the channel materials, and potential impacts to aquatic organisms.

2.8. Overflow Area

A portion of the excavated material from the project will be used to raise subsided lands in the Overflow area to an elevation suitable for sustaining salt marsh vegetation, specifically the *Sarcocornia virginica* vegetation complex. The volume of material placed in the Overflow Area may range from approximately 15 AF to 25 AF, depending on the volume of excavated material used by the Refuge for other purposes, such as maintaining levees. Placing excavated material in the Overflow will balance earthwork for the project. Tidal volume created in the new tidal channels in the Upper Refuge will compensate for the storage decrease in the Overflow, moving the estuarine ecotone farther upstream. Tidal prism stored in the Overflow area will range from 84 AF to 90 AF after material is placed.

Material will be placed in areas of the Overflow where current elevations are between 2 feet and 3 feet. These areas area currently mudflat and can be converted to salt marsh with establishment of a suitable marsh plain elevation. The proposed marsh plain created from placed materials will slope gently upwards towards the levees from an elevation of 3.0 feet to an elevation of 5.0 feet. The material placement will create a substantial area for *Sarcocornia virginica* establishment and small tidal channel formation. An eco-levee with a 10H:1V side slopes will transition between the created marsh plain and the existing levee between elevations 5.0 and 7.0 feet. The eco-levee will be located around the perimeter of the Overflow Area where material is placed. The low slope on the eco-levee will allow vegetation establishment and will dissipate wave run-up that may occur from wind-generated waves. The elevation of the eco-levee is within the elevation range of tidal herbaceous wetland vegetation mapped by USFWS within the Overflow Area, thus is expected to provide the same wetland function after implementation.

The actual acreage of marsh creation depends on the volume and location of material placement. There is approximately 33 acres below elevation 3.0 feet that is currently mudflat and suitable for placement of material. If nearly all materials excavated for the tidal channels and ponds are placed in the Overflow, up to 14 acres of new marsh plain could be created. It is the intent of USFWS to obtain a permit to place material within the available 33 acres of mudflat to allow flexibility in the location of material placement to avoid impacts to pockets of existing native salt marsh vegetation and to maintain open water features.

2.9. Off-Channel Ponds

Four new ponds connected to Salmon Creek are proposed in Reaches 2 and 3. The proposed ponds will be seasonally freshwater during winter months, when winter baseflow will place the saltwater/freshwater interface downstream of the ponds. It is expected that coho salmon will use these ponds as rearing areas during the winter months. During the dry summer months, when freshwater flows in Salmon Creek are extremely low (less than 0.5 cfs), the lower three ponds are expected to be brackish or saline. However, Pond 1 may continue to contain predominately freshwater.

The proposed ponds are designed to simulate the form and function of natural meander cutoffs and oxbow ponds, typical off channel habitat found in low gradient systems. Circulation through the ponds will occur through changing streamflows, tidal flux, and from overbank flows from upstream.

The off-line nature of the ponds, outlet orientations, and elevation of outfall sills or "weirs" are intended to minimize entry of bedload sediments from the main channel into the ponds. Some fine material deposition may occur from smaller grained sediments suspended within the water column during flood events. However, a large volume of the water in the ponds is flushed twice daily by tidal action, reducing the amount of time for settlement of smaller particles.

Pond geometry includes gentle side slopes for shallow littoral vegetation and riparian vegetation establishment. Residual pools a minimum of 3 feet deep, as controlled by the outfall weirs, will provide refuge and thermal regulation for fish. Wood habitat structures will be installed in all ponds to create complex overhangs and cover. Salvaged topsoil will be placed on pond shoreline and banks to provide a seed bank of wetland plants. Occasional willow thickets will be planted on the steeper pond banks, and the more gentle side slope will be naturally colonized by native vegetation or vegetation planted by USFWS.

Earthen weirs at the pond inlets/outlets will limit winter saltwater intrusion into the ponds but allow open exchange with the Salmon Creek channel at all but the lowest tides. Outfall elevations vary between ponds to promote a diversity of water quality and habitat conditions and were established based in part on existing condition salinity measurements as well as two methods to predict the extents of saltwater intrusion.

2.10. Potential Future Improvements on the Upstream Property

Salmon Creek flows through private property upstream of the Refuge. Though the upstream channel primarily occupies its historical channel alignment, it has become filled with sediment and is confined by berms. Frequent breaches of the berms during storm events have resulted in flooding and potential fish stranding on the fields to the west of Salmon Creek. During larger over-bank flow events in Salmon Creek the two tidegates on Hookton Slough, replaced in 2006 as part of Phase 1, drain waters that flow across the fields, reducing stranding potential for adult and juvenile salmonids.

A geologic investigation of the channel upstream of the Refuge was conducted by Pacific Watershed Associates (2009) to identify the various geologic, geomorphic and hydraulic constraints the channel may have on the project area. The geologic report described the existing channel as highly erodible and susceptible to rapid headcutting. If initiated, these processes may create undesirable channel erosion upstream and large sediment inputs into the channel reaches on the Refuge.

Berm breaches on the property upstream of the Refuge still occur frequently. There is a concern, as discussed in the project's geologic report, that Salmon Creek could be captured and drain directly to Hookton Slough through the field to the west of Salmon Creek. Capture of Salmon Creek flows upstream of the Refuge is undesirable because it would disconnect Salmon Creek from the large area of tidal habitat on the Refuge. It will also cut off a valuable freshwater supply to the Refuge used to maintain seasonal wetlands for wildlife. Coordination with the landowner is currently underway to eliminate the berm breaching and potential capture of Salmon Creek.

The proposed enhancements on the Refuge were designed to maintain the stability of the channel in its present form upstream of the Refuge, but also provide flexibility in the design of improvements upstream of the Refuge, if they occur. Specifically, design of the channel planform and profile, channel capacity and flow competence was designed to function for both existing upstream conditions and future conditions arising from upstream channel improvements.

Reach 1 in the Refuge will be located within the historical channel alignment to provide a gradual planform transition with the upstream channel onto the Refuge. The construction of the channel in the historical alignment will also avoid cohesive soils (i.e. clays) that could impede any vertical channel adjustments that may be proposed as part of a later project phase upstream. A steeply sloped (1%) transition channel reach from the Refuge boundary was designed with permanent grade control structures to maintain the design grade and prevent upstream channel incision. The proposed grade control structures could be easily modified or removed in a future project phase to create a uniform profile from upstream of the Refuge to Reach 2. Section 5.4.3 provides additional information on the grade control design.

The proposed channel on the Refuge was designed assuming that all flows from the watershed will be conveyed to the project area and that the channel on the upstream private property will be improved in the future to contain higher flows. Even if flows continue to leave the channel upstream of the Refuge, the new project channel will have sufficient tidal flushing to transport deposited sediment. A flow competency analysis based on Shields critical shear stress indicates that the proposed channel will have the ability to move up to a 2 mm particle (coarse sand) during daily tidal flushing and a 15 mm particle during frequently occurring flow events (Section 5.4.2).

2.11. Project Longevity and Element for Adaptive Management

The longevity of the proposed Phase 2 project is dependent on the long-term functionality of the tidegates and the Refuge's response to regional influences such as incoming sediment loads, seismic events, and sea level rise. The proposed design includes elements that facilitate adaptive management of the system throughout the life of the project.

The Salmon Creek and Overflow tidegates are expected to function as designed for approximately 50 years. Openings within the tidegates are adjustable to allow for adaptive management of tidal flows within the Salmon Creek estuary. These openings can be closed to shut off tidal influence, if necessary, for Refuge maintenance or construction activities. They can also be opened wider to allow additional tidal prism to enter the project area, or partially shut to increase the muting of the tidal prism.

The adjustability of the tidegate openings provides a means to compensate for projected sea level rise over the next 50 years. The California Climate Change Center presents sea level rise projections of between 1.2 and 1.7 feet by the year 2060 (interpolated from Figure 19 in CEC, 2009). The opening area of the Salmon Creek and Overflow tidegates can be reduced to maintain the design muted tidal prism inside the levees over this range of sea level rise.

Over time, the volumes of the constructed ponds may slightly decrease from sediment accretion. If the ponds experience sedimentation, the Refuge possesses the equipment and staff to perform occasional maintenance dredging. The Refuge's experience with off-line ponds that were constructed on the Refuge over 15 years ago is that they self-maintain and dredging has not been required. If the ponds are not dredged, they will eventually evolve into a marsh plain that is close to the elevation of MHHW. Reduction in volume of the constructed ponds would have a small reduction in the tidal prism in the Upper Refuge.

The longevity of the proposed tidal channels in Phase 2 of the project is a function of the regulated tidal prism. The tidal channels were designed based on stable channel geometry for the design muted tidal prism. If the tidal prism changes, the channels are expected to adjust.

The proposed rock grade controls located immediately downstream of the Refuge boundary are designed to remain stable during large flood events. However, given the subsurface soil properties, there is a risk that they will subside over time. Monitoring of the grade control will be necessary to identify and respond to changes in the elevation of the grade control due to subsidence. Riparian planting in the area should be installed to ensure heavy equipment will be able to access the grade control structures to allow rock to be added to the top of the structures to maintain design grade.

As part of this project, the channel and ponds are sited in areas that will remain accessible by heavy equipment, allowing the Refuge to dredge ponds, if adaptive management objectives deem it necessary. USFWS is committed to monitoring and maintaining the constructed project. The proposed channel may be subject to occasional bank failures and high sediment loads from upstream, and is located in an area of high seismic activity that can cause rapid subsidence. The Refuge maintains sufficient staff, equipment and funding to monitor and maintain the project as designed. It is the intent of USFWS to develop a detailed maintenance and monitoring program for this project.

3. Post Phase 1 Monitoring and Geologic Characterization

Monitoring was conducted before and after implementation of Phase 1 to improve our understanding of the system's response to changes in tidal conditions. Information gained through this ongoing monitoring was used to characterize the physical processes occurring in Salmon Creek, compare measured hydraulic conditions against model predictions, inform the design of Phase 2, and inform future adaptive management decisions. For reference, Figure 1-2 shows locations of monumented cross sections (XS) used for monitoring geomorphic changes. These locations were also used for measuring water surface elevations and water quality parameters.

3.1. Water Surface Monitoring

3.1.1. Methods

USFWS installed four Solinst Level Logger Gold pressure-transducer continuous water level and temperature recorders. Recorders were located at the channel bank toe immediately inside and outside the Overflow tidegate and at Monitoring XS 1 and XS 6. The stage recorders were installed in October 2007, prior to construction of the Overflow tidegate, and monitoring continued through July 2008.

3.1.2. Results and Discussion

Following installation of the Overflow Tidegate with its 2.5 x 8-foot inflow opening, the Refuge removed a 4.5-foot by 7-foot flap gate from the old Salmon Creek tidegate (not yet replaced at the time of monitoring) to further increase tidal inflow. The water level data indicates this degree of tidal opening resulted in the water surface inside the levees reaching approximately 4.8 feet when the tide at Hookton Slough reached MHHW (6.24 feet). The observed water surface elevations with the completed Overflow Gate and removed flap gate on the old Salmon Creek tidegate are similar to those predicted for the combined new Salmon Creek and Overflow tidegates. Monitoring XS 6 experiences substantial tidal influence. Tidal influence was not observed at Monitoring XS 1.

Results from the recorded water surface elevations were used in the development of the proposed tidal channel design (Section 5.1) and for calibration of the HEC-RAS hydraulic modeling of the project area (Section 5.3). Data from the monitored water surface elevations are available from USFWS (Shea, C., 2009 pers. Comm.).

3.2. Monitoring of Salinity, Temperature, and Dissolved Oxygen

3.2.1. Methods

Salinity, water temperature and dissolved oxygen were measured on several occasions in July and December 2008. Measurements were conducted in-situ using a handheld HACH meter and were taken at the surface and 2 feet below the surface at several locations between the Salmon Creek tidegate and the First Diversion.

3.2.2. Results and Discussion

<u>Summer Salinity Measurements</u>

Prior to Phase 1 implementation, fully saline conditions extended slightly upstream of the knick point (shown on Figure 1-1), between Monitoring XS's 6 and 7. These measurements were taken on September 9, 2002 when Hookton Slough was at MHHW of 7.02 feet (NAVD88). On July 15, 2008, during a mean lower high water tide (MLHW), brackish conditions extended to over 400 feet upstream of Monitoring XS 5, suggesting that during higher tides brackish conditions extend to near Monitoring XS 4 and the First Diversion.

On July 10, 2008, measurements were taken on an incoming tide that reached approximately 6.5 feet in Hookton Slough. When these measurements were obtained, only the Overflow tidegate was operational, and 4.5-foot by 7-foot flap gate was removed from the old Salmon Creek tidegate. Salinity measurements found stratification between salt and freshwater occurring throughout much of the channel, including at Monitoring XS 11 near the Salmon Creek Gate. Temperature of the slightly brackish and freshwater on the surface water was considerably lower (16.9^0 C to 17.4^0 C) than the highly saline water (19.1^0 C to 23.2 ^{0} C) measured two feet below the surface. Dissolved oxygen (DO) of the saline water was relatively high near the Salmon Creek tidegate, likely due to good circulation and mixing. However, DO in saline water measured 2 feet below the surface at Monitoring XS 10, XS 7, and XS 6 was only between 2.2 mg/l and 3.4 mg/l. These low DO levels are likely due to poor circulation and lack of mixing in the deeper pools. The freshwater contained DO levels above 7 mg/l. Both temperature and dissolved oxygen within the freshwater and brackish surface water were within suitable ranges for supporting salmonids.

Winter Salinity Measurements

On December 12, 2008, detailed salinity measurements near Monitoring XS 4 were obtained during an infrequent extreme high tide in Hookton Slough (8.4 feet in Hookton Slough). When these measurements were recorded, both the Salmon Creek and Overflow tidegates had been constructed and were operational. Streamflow in Salmon Creek was at a low winter baseflow. For reference, daily average flow in the Little River near Trinidad was approximately 40% higher than during the July 10 measurements (USGS Station No. 11481200 provisional daily data).

The December 12 measurements indicated a fully saline body of water (31.5 ppm) advancing upstream during the rising tide, with little to no freshwater floating on top of the saline water. The farthest extent of saline water (20.5 ppm) was approximately 200 feet downstream of Monitoring XS 4. Stratification was observed over approximately a 150-foot length of channel. Upstream, fully fresh water (less than 1 ppm) was measured through the entire water column.

Discussion

Post-Phase 1 salinity measurements indicate that saline conditions are extending farther upstream in Salmon Creek than prior to Phase 1. This increase in extent of saline conditions is likely a result of the removed knick point and the increased volume and elevation of the tidal prism associated with the new tidegates with muted tide openings.

The pattern of salinity measurements cannot be fully explained with the limited data collected. However, the measurements of saline water on the surface during the winter in the upper estuarine ecotone suggest that a tidal intrusion front is progressing upstream in Salmon Creek during a rising tide. A tidal intrusion front forms where a strong incoming tide of saltwater meets a downstream flow of freshwater, forming a nearly vertical or steeply sloped front between freshwater and saltwater, with little mixing at the interface (Uncles & Stephens, 1993; Largier, 1992). Higher freshwater flows cause the location of the tidal intrusion front to form farther downstream from the freshwater source than when freshwater flows are lower. On the ebb tide, stratification between salt and freshwater is typically observed as the front dissipates.

The presence of a saltwater intrusion front versus stratification may affect the location of saltwater in Salmon Creek, which in turn influences the design of the off-channel rearing ponds. Section 5.4.8

presents a detailed discussion of the design for the coho rearing ponds and prediction of salinity extents under design conditions.

3.3. Channel Adjustments after Phase 1 Implementation

3.3.1. Methods

In 2006, prior to implementation of Phase 1, 14 channel cross sections located on Salmon Creek throughout the Refuge were surveyed to establish baseline channel conditions (locations shown in Figure 1-2). Ends of the sections were monumented with capped steel pipe embedded in concrete. In July 2008, the cross sections were resurveyed using an auto-level and fiberglass tape stretched between monumented cross section pins. Un-monumented cross sections surveyed in 2002 were used to evaluate changes in channel thalweg elevations. Figure 3-1 illustrates the channel thalweg profile created from the 2002 cross section survey, with the 2006 and 2008 surveyed channel inverts shown. Cross Section survey results are presented in Appendix C.

3.3.2. Results and Discussion

Surveyed channel changes within Salmon Creek less than one year after construction of the Overflow tidegate were not expected to show substantial channel changes. Research has indicated that once a marsh is exposed to an increased tidal prism, channel enlargement occurs over a period ranging from 2 to more than 30 years (Williams et al. 2002, Williams & Orr 2002). The rate of channel enlargement is influenced by a variety of factors, including tidal prism, ground elevation, soils, and vegetation. Channel enlargement in a marsh exposed to an increased tidal prism typically occurs first by deepening, then widening (Williams et al. 2002). Channel widening observed by Williams et al (2002) consisted primarily of slump block mass failures.

The cross section monitoring was used to understand the general rates and patterns of channel enlargement in Salmon Creek and to identify any controlling factors that could impact channel design or future channel evolution. Findings from the cross section monitoring were used in the channel design process, as presented in the following sections.

Overflow Area

The most dramatic changes in the monitoring cross sections occurred close to the new Overflow tidegate. Both XS 12 and 13 have widened and deepened considerably, following the patterns observed by Williams et al. (2002) in a marsh exposed to an increased tidal prism. The new Overflow tidegate with a permanent incoming flow opening has established through-flow in the channel where Monitoring XS 12 and 13 are located, substantially increasing the tidal prism in the channel. Before construction of the Overflow tidegate, water stored in the Overflow was a result of leakage through the Salmon Creek tidegate, and there was no direct through-flow in the Overflow.

Middle Refuge

Cross sections in the Middle Refuge (Monitoring XS 4 through XS 11) showed little vertical adjustment and a small amount of widening, with numerous tension cracks and slump blocks along both banks held in place by existing roots from riparian trees. The amount of widening generally decreases in upstream cross sections. XS 11 shows the most widening, with a 5-foot wide slump block that has collapsed into the channel. It is expected that additional slump blocks will fail in the near-term, causing the channel to further widen at most cross sections.

Materials excavated for the channel bed during removal of knick point, located between Monitoring

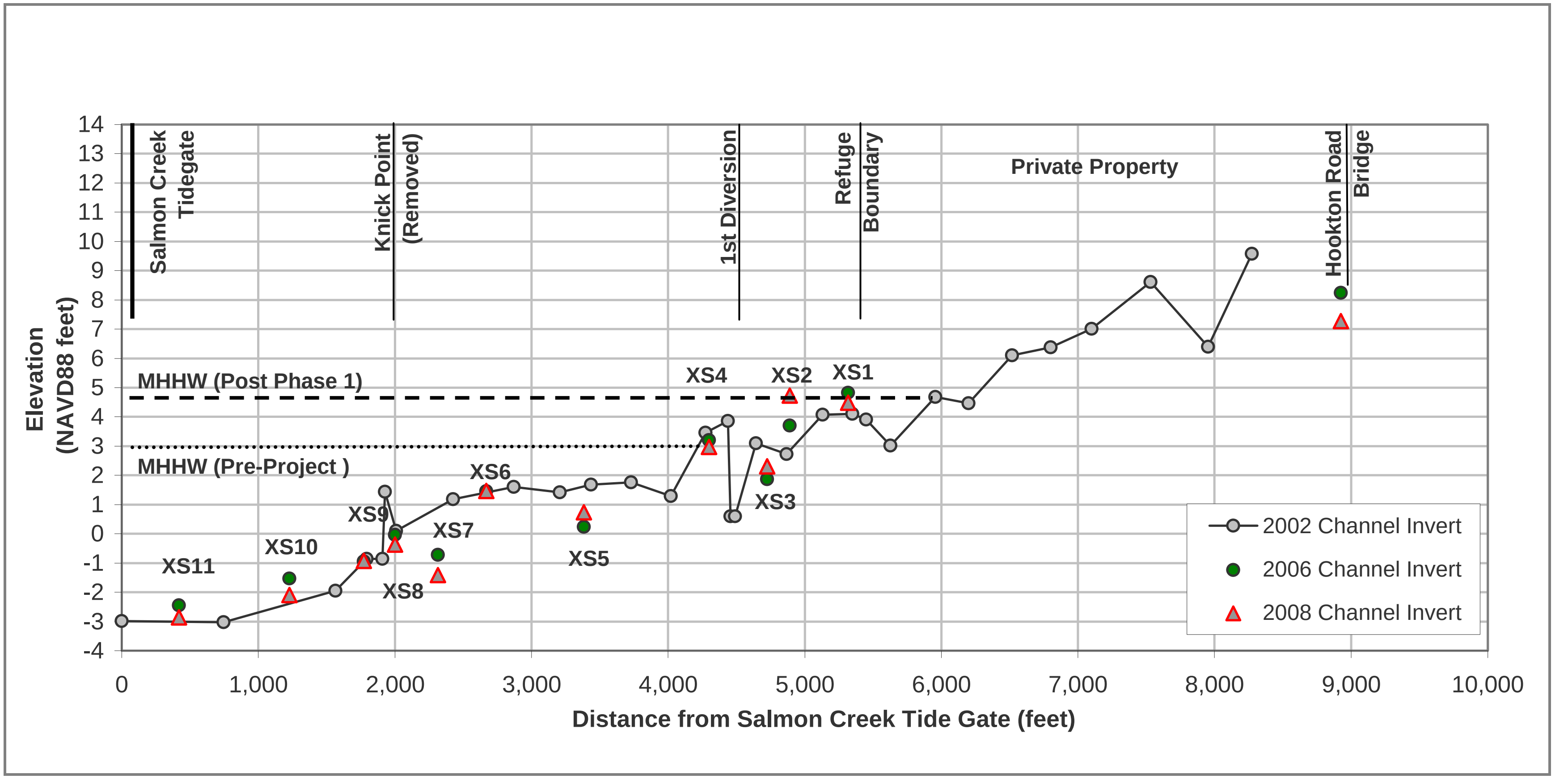

Figure 3-1. Salmon Creek channel thalweg profile generated from the 2002, 2006 and 2008 monitoring cross section surveys.

XS 8 and XS 9, was characterized as heavy clay-silt. This material appears highly resistant to erosion. The extents of this clay within the Salmon Creek Project area are unknown, but the geologic investigation conducted as part of the Phase 2 project identified a similar clay in a trench excavated in the Upper Refuge and associated these clays with the historical marsh plain (See Section 3.4). That the cross section monitoring found the channel upstream of the historic knick point is widening but not deepening suggests that the channel bed throughout this reach may be composed of similar erosion-resistant clay as observed in the knick point.

The observed pattern of channel change attributed to the presence of heavy clay layer has implications for the project design and implementation. The heavy clay is expected to limit channel incision, increasing the time it would take for a channel to reach equilibrium conditions and convey the design tidal prism. Therefore, in channel reaches where tidal prism conveyance is critical for the project success, channels will be excavated to their equilibrium dimensions (Section 5.1.2).

Upper Refuge

Observed trends in Monitoring XS 1 through XS 3 are different from downstream trends. These cross sections are located in a heavily wooded area, are minimally impacted by tidal exchange and were not expected to change as a result of Phase 1 activities.

3.4. Project Area Geologic Characterization

3.4.1. Channel Upstream of Refuge

Pacific Watershed Associates, Inc. performed a characterization of the channel reach upstream of the Refuge (Pacific Watershed Associates, 2009). The objective of the characterization was to identify the various geologic, geomorphic and hydraulic constraints imposed by the existing channel near the upstream property boundary. The characterization included collecting a core within the stream channel just upstream of the Refuge boundary and a subsurface characterization of the material properties in the Upper Refuge. Results of the geologic investigation are presented in Appendix D.

The geologic investigation in the channel upstream of the Refuge indicated that the existing channel is highly erodible and susceptible to rapid headcutting. If initiated, these processes may create potentially undesirable channel erosion upstream and large sediment inputs into the Refuge channel reaches. Identification of highly erodible sediments in the channel reach upstream of the Refuge has implications for channel design on the Refuge. The proposed design includes rock grade control structures in Reach 1 as part of the enhancement project to prevent any channel adjustment upstream of the Refuge boundary. A detailed discussion of the rock grade control structures are presented in Section 5.4.3.

3.4.2. Historical Channel in Reach 1

The geologic investigation also included a geologic characterization in a trench on the Upper Refuge where the Reach 1 channel will occupy the historical channel location. The characterization identified the location of the historical channel under approximately four feet of silt. Site conditions limited accurate measurements, but the channel appears to be approximately 45 feet wide and extends to below elevation -0.8 feet. The historical channel was filled with coarse sands, small gravels and large wood. Of note were the exceptional amount of groundwater in the channel and the permeability of the deposited material. Outside the limits of the historical channel, the subsurface was characterized by dense clay, likely similar to the non-erodible clay excavated from the knick point during Phase 1. The geologic investigation report provides several recommendations for work in and around the historical channel, which are addressed in Section 5 and Section 6.

4. Site Topography, Hydrology and Tidal Boundary Conditions

This Chapter presents characterization of topographic, hydrologic, tidal and geomorphic boundary conditions necessary to analyze site conditions and prepare the Phase 2 design for the Salmon Creek project area.

4.1. Site Topography

A topographic map of the project area was derived from a variety of sources. All survey data were rectified by Graham Matthews & Associates (GMA) in AutoCAD Land Development Desktop 3 software to build a digital terrain model (DTM) from which contour lines were generated.

Spencer Engineering and Construction Management surveyed the Upper Refuge area in November 2000. The survey, performed on an assumed datum, was sufficient to generate 1-foot contours. MLA and GMA surveyed the private property to the south of the Refuge, the Middle and Lower Refuge, and Overflow areas in 2002. MLA surveyed 28 channel cross sections along the existing stream channel between the Hookton Road Bridge and the Salmon Creek tidegate. GMA prepared a topographic survey of the overbank area and Overflow areas of the project area using a combination of a Total Station and Real-Time Kinematic GPS (RTK). Points were surveyed in a rough grid fashion with actual point locations chosen by topographic breaks rather than a set distance apart. To accurately document topography, more points were collected in topographically complex areas. Beyond topographic grid points, slope breaks, water surface edges and elevations, and pond bathymetry points were surveyed.

The survey was conducted within ± 1-foot accuracy. The Salmon Creek in-channel topography between surveyed cross sections was interpolated from the 28 cross-sections, and may not represent the 1-foot accuracy of the surrounding areas. Horizontal control for these surveys were North American Datum 1983 (NAD83) California State Plane, Zone 1, in feet and vertical control was North American Vertical Datum of 1988 (NAVD88) in feet. Figure 4-1 presents the results of the survey overlaid onto a 2005 orthorectified digital aerial photograph.

4.2. Hydrology

The Salmon Creek watershed encompasses approximately 17.4 square miles in the coastal hills of northwestern California. As is characteristic throughout the region, the majority of precipitation falls between November and April, with drier weather persisting for the remaining months. Due to its low elevation and proximity to the Pacific Ocean, the Salmon Creek watershed receives almost all of its precipitation in the form of rainfall. On average, the lower lying portions of the watershed receive approximately 40 to 48 inches of rainfall annually. Due to orographic effects, the upland areas within the watershed receive between 60 and 70 inches of rainfall annually (PRISM, 2007). On average, the Salmon Creek watershed receives approximately 55 inches of rainfall per year.

Salmon Creek is the only sizable stream that flows into South Humboldt Bay. As with most streams within coastal northern California, Salmon Creek experiences its peak flow events between November and March. The stream is highly responsive to rainfall events, with flows both rising and falling rapidly. Extended periods of no precipitation are common in summer and early fall.

Flows in Salmon Creek are not gaged. Therefore, peak storm flows and their associated recurrence intervals were estimated by performing a flow frequency analysis of nearby USGS stream gaging stations. A discrete storm flow hydrograph resulting from the 2-year 24-hour rainfall was also developed using the National Resource Conservation Service (NRCS) methodologies.

		DATE	PREPARED FOR
PREPARED BY	KB	4/06	U.S. FISH AND WILDLIFE SERVICE HUMBOLDT BAY NATIONAL WILDLIFE REFUGE 1020 RANCH ROAD LOLETA, CA 95551
REVIEWED BY			

LEGEND

- INTERMEDIATE 1' CONTOURS
- INDEX 5' CONTOURS
- CROSS SECTIONS WITH ENDPINS

SALMON CREEK CROSS SECTION LOCATIONS Humboldt County, California

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Streamflows at the Refuge boundary were computed assuming that all flows from the watershed will be conveyed to the project area and that the channel on the upstream private property will be improved in the future to prevent loss of overbank flow from the system. Larger flow events were not evaluated due to the complexity and uncertainty associated with flow routing. During large flow events, the floodplain upstream of the Refuge and Highway 101 becomes fully inundated. Much of the overbank flow upstream of Highway 101 is captured by other historical tidal channels that do not drain into current-day Salmon Creek.

4.2.1. 2-year Storm Flow Analysis

Peak Flows

The 2-year peak flow was estimated using long-term streamflow records from the Elk River USGS stream gage (Station Number 11309000). Elk River is a 44.2 square mile watershed adjacent to the north of Salmon Creek, and though larger, is characterized by the same aspect, terrain and rainfall patterns that Salmon Creek experiences. The Elk River gage has a 10-year streamflow record from 1958 to 1967. The Elk River annual peak flow data were fitted to a Log Pearson Type III (LP3) distribution using the procedures outlined in Bulletin 17B (USGS, 1982). The ratio of drainage area for Elk River and Salmon Creek was used to scale the peak flows between basins. The 2-year peak flow estimated by the LP3 analysis for Salmon Creek is 1,059 cfs.

Storm Flow Hydrograph

The unsteady flow routine in the HEC-RAS hydraulic model requires flow for each time step that the model is run. HEC-RAS then computes total storage and water surface elevation in the Salmon Creek project area for each time step during a streamflow or tidal event.

As part of the Phase 1 design of the new Salmon Creek and Overflow tidegates, a 2-year 24-hour storm flow hydrograph was developed for Salmon Creek by applying the standard USDA Soil Conservation Service (SCS) Curve Number Loss Model using the Army Corps of Engineers (ACOE) Hydrologic Engineering Center's Hydrologic Modeling System software HEC-HMS (ACOE, 2000).

Salmon Creek was divided into three sub-basins and one flow routing reach. Soil types were identified using a variety of sources (USFS, Rev. 1975; SCS, 1965; U.C. Davis, 1965). Soils series were then matched to the corresponding Hydrologic Soils Group to assign an SCS Curve number to each land cover type in the Salmon Creek watershed. Curve numbers correspond to Antecedent Moisture Condition (AMC) II.

ACOE recommends an initial abstraction (I_a) for forested areas to range between 10-20% of the total rainfall (ACOE, 2000). An I_a of 20% was used for this analysis. Lag time was computed using the SCS Unit Hydrograph method, which calculates the lag time based on hydraulic flow path length, average sub-basin slope and the SCS curve number.

A 2-year 24-hour rainfall depth of 3.01 inches was obtained by averaging rainfall return periods at the Eureka National Weather office, Table Bluff Lighthouse, Fortuna and Bridgeville rainfall recording stations (CGS, 2003). Rainfall distribution was modeled using a SCS Type 1a hydrograph.

The 2-year 24-hour storm flow hydrograph used for analysis of the Salmon Creek design was conservatively based on AMC III conditions, which assume that the ground is moist and the watershed yields a high amount of runoff. AMC III runoff conditions are estimated by increasing the curve number using methods in the NRCS National Engineering Handbook (NRCS, 2004).

Figure 4-2 presents the 2-year 24-hour hydrograph computed at one-minute time steps. The 2-year peak flow estimated by the SCS method for Salmon Creek is 985 cfs. The 2-year peak flow predicted for Salmon Creek at the Refuge based on the USGS gage data from Elk River was 1,059 cfs, close to the hydrograph peak flow.

4.2.2. Baseflow

Salmon Creek receives freshwater input from the surrounding watershed in the form of precipitation events and baseflow. Estimates of winter and summer baseflow were necessary to evaluate tidal and salinity conditions within the project reaches.

Water surface elevations at XS1 measured by USFWS during a relatively dry period in January 2008 were used to compute winter baseflow discharge. Flows at XS1 are not tidally influenced and reflect freshwater flows entering the Salmon Creek project area. Winter baseflow elevations typically range from 5.8 to 6 feet in elevation at XS 1 (Shea, C., 2009, pers. comm.). Using the hydraulic geometry and slope, an estimate of Manning's roughness, and assuming uniform flow conditions, a winter baseflow of 14.6 cfs was computed for XS1. Based on this, a winter baseflow value of 15 cfs was used for this study.

Summer baseflows observed in Salmon Creek continually decrease through the dry season, likely becoming less than 0.5 cfs by August. A summer baseflow of 2 cfs was used in the unsteady HEC-RAS model. Lower values caused model instabilities.

4.3. Tidal Boundary Conditions

Salmon Creek is tidally connected to Hookton Slough through the muted tidal openings in the Salmon Creek and Overflow tidegates. Tidal boundary conditions at discrete time steps were necessary for development of the unsteady flow HEC-RAS model used for project design.

The Hookton Slough tidal station (No. 9418723), located at the mouth of the slough near Long Pond, was operated from 1977 to 1979. The tidal station experienced an average daily tidal range of 6.95 feet (MLLW to MHHW). Humboldt Bay experiences semidiurnal tides; two high tides and two low tides per day. Various tidal elevations in Hookton Slough based on the NAVD88 datum are presented in Table 4.1.

For design and analysis, a sinusoidal diurnal tidal curve was developed that includes MHHW, MLHW, MLLW and MHLW (Figure 4-2). The curve was constructed from tidal elevations at one-minute time steps.

Table 4-1. Select tidal elevations in Hookton Slough.

Tidal Datum	Tidal Elevation in Hookton Slough (NAVD88 datum)
Mean Higher High Water (MHHW)	6.24 feet
Mean Lower High Water (MLHW)	4.84 feet
Mean Tide (MTL)	3.03 feet
Mean Higher Low Water (MHLW)	1.74 feet
Mean Lower Low Water (MLLW)	-0.71 feet

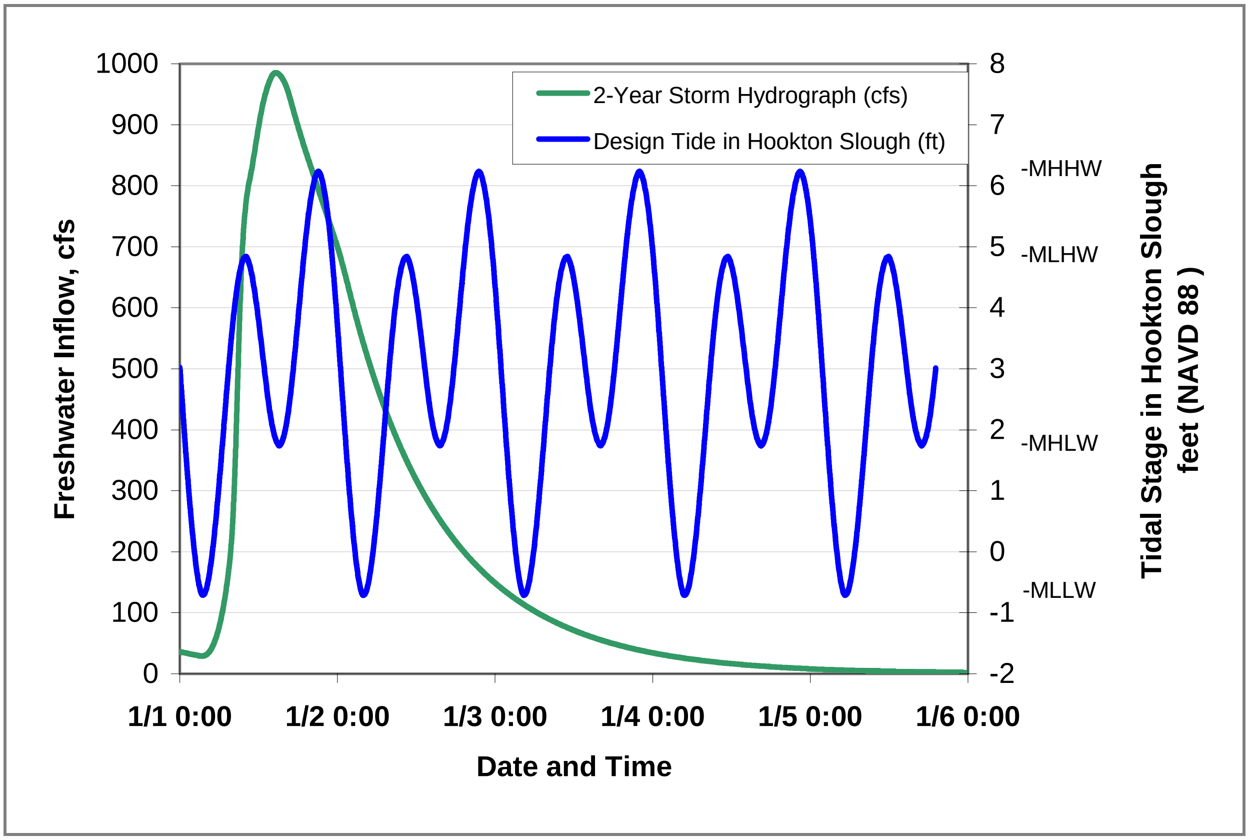

Figure 4-2. Tidal elevations in Hookton slough and freshwater inflow hydrograph for a 2-year flow event used in the HEC-RAS unsteady flow modeling. Curves developed for one-minute time steps.

5. Phase 2 Project Design

This chapter presents design methods and results for each component of the project. Design plans and specifications for the proposed Phase 2 improvements in Salmon Creek are presented in Appendix A.

5.1. Tidal Channel Design

The tidal channel and off-channel rearing pond design was accomplished by implementing an iterative process using:

(1) Use of spreadsheet model, based on equilibrium tidal channel design equations, to develop the tidal channel profile, cross sections, and pond volumes based on an assumed MHHW elevation in Salmon Creek,

(2) Verifying the proposed design using the unsteady HEC-RAS model, and

(3) Revising the channel design based on the resulting MHHW and tidal prism predicted from the HEC-RAS model, followed by updating the project geometry in the HEC-RAS model.

Results from the HEC-RAS model and final spreadsheet model were then used to finalize specific elements of the Phase 2 design.

Channel and pond geometry shown in the design drawings vary slightly from those modeled in HEC-RAS. These changes arose from the iterative nature of the design process. Because overall changes in channel cross section area and pond volume are minor, the changes shown on the construction documents will not impact the design tidal prism or results of the HEC-RAS modeling and associated project element design.

5.1.1. Equilibrium Tidal Channel Design Method

Because of the topography, elevation and the proposed extent of tidal influence within the project area, hydraulic geometry of the channel was assumed to be governed by the daily tidal flux rather than less frequent high flow events from upstream. Therefore, the proposed channel cross section and profile design was based primarily on established tidal channel design methodologies. To refine the channel design, the hydraulic response and sediment transport capability of the proposed channel during the 2-year 24-hour design flow event was evaluated using the HEC-RAS hydraulic model (See Sections 5.4.1 and Section 5.4.2).

Dimensions of the new channel in the Upper Refuge and the new side-channel in the Middle/Lower Refuge were designed based on equilibrium hydraulic geometry relationships for tidal channels, which are summarized in Williams and Orr (2002). Additional information is available in Coats and Williams (1995) and PWA and Faber (2004). A series of three regression equations were used that relate the contributing tidal prism to the channel cross sectional area, top width, and channel depth below MHHW. The contributing tidal prism is defined as the total tidal flux between MHHW and MLLW from channel, pond and overbank storage flowing to a channel reach on an ebb tide. The tidal prism in Salmon Creek is muted, controlled by tidal conditions in Hookton Slough, water surface elevations within Salmon Creek, and tidal prism storage within Salmon Creek. The iterative process used in solving the regression equations yields a channel cross section shape and size and a longitudinal profile in equilibrium with the contributing tidal prism.

Initially, the proposed cross section shape was trapezoidal with a narrow bottom width and 2H:1V side slopes. A MHHW elevation of 4.8 feet in Salmon Creek, determined by the water surface monitoring (Section 3.1) was used to determine the initial tidal prism and tidal channel sizing. After iterating using HEC-RAS results, the proposed condition MHHW elevation in Salmon Creek was determined to be 4.7 feet. The cross section shape of the constructed channels shown on the design drawings (Appendix A) are trapezoidal with a wider bottom width and side slopes of 1.5H:1V. The steeper side channel side slopes are similar to the shape of existing tidal channels in Salmon Creek and the wider bottom width will better facilitate construction and placement of wood features within the channel.

5.1.2. Channel Geometry

Table 5-1 and Figure 5-1 summarize the final proposed tidal channel dimensions and elevations and the contributing tidal prism to the downstream end of each reach. Where channels are expected to self-adjust, the existing and self-adjusted equilibrium channel dimensions are shown.

5.2. Tidal Pond Design

Creation of new tidally influenced off-channel ponds in the Upper Refuge will provide freshwater rearing habitat for salmonids during the wet season and become brackish during the dry season. The ponds were designed based on the form and function of naturally occurring ponds and overflow channels typically found in low-gradient channels.

Tidal channel pond sizing is an integral process of the equilibrium tidal channel design. Tidally influenced ponds can be a substantial component of the contributing tidal prism in a receiving channel. Similar to the channel design, pond design was an iterative process between the tidal channel design equations and HEC-RAS model results to identify the optimal pond storage volume and outlet elevations to maintain freshwater conditions in the pond in the wintertime. The final pond volumes incorporated in the design drawings included three ponds in Reach 2 that contribute to the tidal prism 1.4 AF, 0.6 AF, and 1.5 AF, respectively, and one pond in Reach 3 that contributes 0.35 AF to the tidal prism. Additional information on the pond designs is presented in 5.4.8.

5.3. Design Verification using HEC-RAS

HEC-RAS is an open channel hydraulic model for steady or varying flows (unsteady flow). Steady flow modeling evaluates channel hydraulics at a specified flow, such as peak flow, and fails to account for storage on the floodplain or in off-channel ponds. Steady flow modeling would not accurately represent the constantly changing conditions at Salmon Creek arising from changing tidal flow that affect channel hydraulics and storage within the channel and ponds and on the floodplain. An unsteady flow model is necessary to evaluate the interaction of the incoming streamflow hydrograph with the constantly changing tidal conditions.

Unsteady flow simulation in the HEC-RAS model was used to perform routing of flows through the project area for proposed conditions during specified events, including daily tidal conditions and storm flow events. The results of the model were used to obtain water surface slopes, water depths, water velocities, and channel shear stresses at locations throughout the channel during various tidal and stream flow conditions. These hydraulic parameters were then used to refine the design of specific project elements (Section 5.4).

Table 5-1. Summary of proposed tidal channel cross section dimensions and contributing tidal prism for each reach during summer baseflow conditions with 25 AF of material placed in the Overflow Area. Channel dimensions are based on empirical equations and HEC-RAS hydraulic model results[1].

Reach	Station (Length)	Channel Type	Slope	Bottom Width	Typical Top Width at MHHW	Typical Channel Depth	Contributing Tidal Prism (MHHW-MLLW)[1]
1	49+05 to 41+00 (805 ft)	Constructed	0.9% to 0.07%	5 ft	18 ft	8.2 ft	1.2 AF
2	41+00 to 31+50 (950 ft)	Constructed	0.1% to 0.07%	6.5 ft	25 ft	8.3 ft	6.9 AF[2]
Existing Ditched Channel	(2,200 ft)	Self-Adjusting	varies	varies	13 ft (Existing 14 ft)	7.5 ft (Existing 5.0 ft)	1.4 AF[3]
3	31+50 to 22+25 (925 ft)	Constructed	0.07%	11 ft	31 ft	8.8 ft	9.6 AF
4	(2,100 FT)	Self-Adjusting	varies	varies	22 ft (Existing 15 ft)	7.4 ft (Existing 7.3 ft)	3.3 AF
5	22+25 to 7+00 (1,525 ft)	Constructed	0.08% to 0.04%	14 ft	36 ft	8.2 ft	14.1 AF
6	(700 ft)	Self-Adjusting	0.03%	29 ft (Existing 9 ft)	52 ft (Existing 28 ft)	8.1 ft (Existing 7.9 ft)	21.1 AF
Overflow Area	--	Self-Adjusting	--	--	--	--	90 AF (Existing 105 AF)
				Total Design Tidal Prism for Proposed Conditions			**111.1 AF**

[1] Measured at downstream end of reach
[2] Includes tidal prism contributed by Ponds 1, 2, and 3
[2] Includes tidal prism contributed by Pond 4

Table 5-1. Summary of proposed tidal channel cross section dimensions and contributing tidal prism for each reach during summer baseflow conditions with 25 AF of material placed in the Overflow Area. Channel dimensions are based on empirical equations and HEC-RAS hydraulic model results[1].

Reach	Station (Length)	Channel Type	Slope	Bottom Width	Typical Top Width at MHHW	Typical Channel Depth	Contributing Tidal Prism (MHHW-MLLW)[1]
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Existing Ditched Channel	(2,200 ft)	Self-Adjusting	varies	varies	13 ft (Existing 14 ft)	7.5 ft (Existing 5.0 ft)	1.4 AF[3]
3	31+50 to 22+25 (925 ft)	Constructed	0.07%	11 ft	31 ft	8.8 ft	9.6 AF
4	(2,100 FT)	Self-Adjusting	varies	varies	22 ft (Existing 15 ft)	7.4 ft (Existing 7.3 ft)	3.3 AF
5	22+25 to 7+00 (1,525 ft)	Constructed	0.08% to 0.04%	14 ft	36 ft	8.2 ft	14.1 AF
6	(700 ft)	Self-Adjusting	0.03%	29 ft (Existing 9 ft)	52 ft (Existing 28 ft)	8.1 ft (Existing 7.9 ft)	21.1 AF
Overflow Area	--	Self-Adjusting	--	--	--	--	90 AF (Existing 105 AF)
					Total Design Tidal Prism for Proposed Conditions		**111.1 AF**

[1] Measured at downstream end of reach
[2] Includes tidal prism contributed by Ponds 1, 2, and 3
[2] Includes tidal prism contributed by Pond 4

5.3.1. HEC-RAS Model Geometry

Channel and overbank cross sections and pond storage-elevation tables are used by HEC-RAS to compute channel hydraulics and to compute changing channel, pond and overbank storage volumes with changing boundary conditions. Accurate computation of storage in the model is necessary to evaluate the design tidal prism passing through the channel reaches during incoming and outgoing tides. The resulting tidal flux generates specific channel depth, velocity and water surface elevations. Existing condition cross sections and storage areas were derived from a digital elevation model compiled from the topographic survey.

Cross Sections

Cross sections were used to reflect proposed channel and overbank topography in the Upper, Middle and Lower Refuge areas as well as the channel leading to the Overflow. Cross section location and spacing were selected to represent the proposed channel, overbank storage and channel leading to the Overflow Area (Figure 5-2). Cross sections encompass both the channel and leveed areas that surround most of the project area. Cross sections were also located where monitoring surveys were conducted and were based on stationing of the proposed channel. Proposed cross sections were modeled in HEC-RAS with narrower bottom widths and 2H:1V side slopes rather than the 1.5H:1V and 3H:1V side slopes shown in the construction documents.

The 200-foot area of levee removal between the Upper and Middle Refuge was represented on cross section 30+74 with removal of the levee area to the existing ground elevation. Reach 6 was modeled assuming the channel has self-adjusted to equilibrium conditions. The existing ditched channel and Reach 4 were modeled using their present geometry because substantial channel enlargement is not expected.

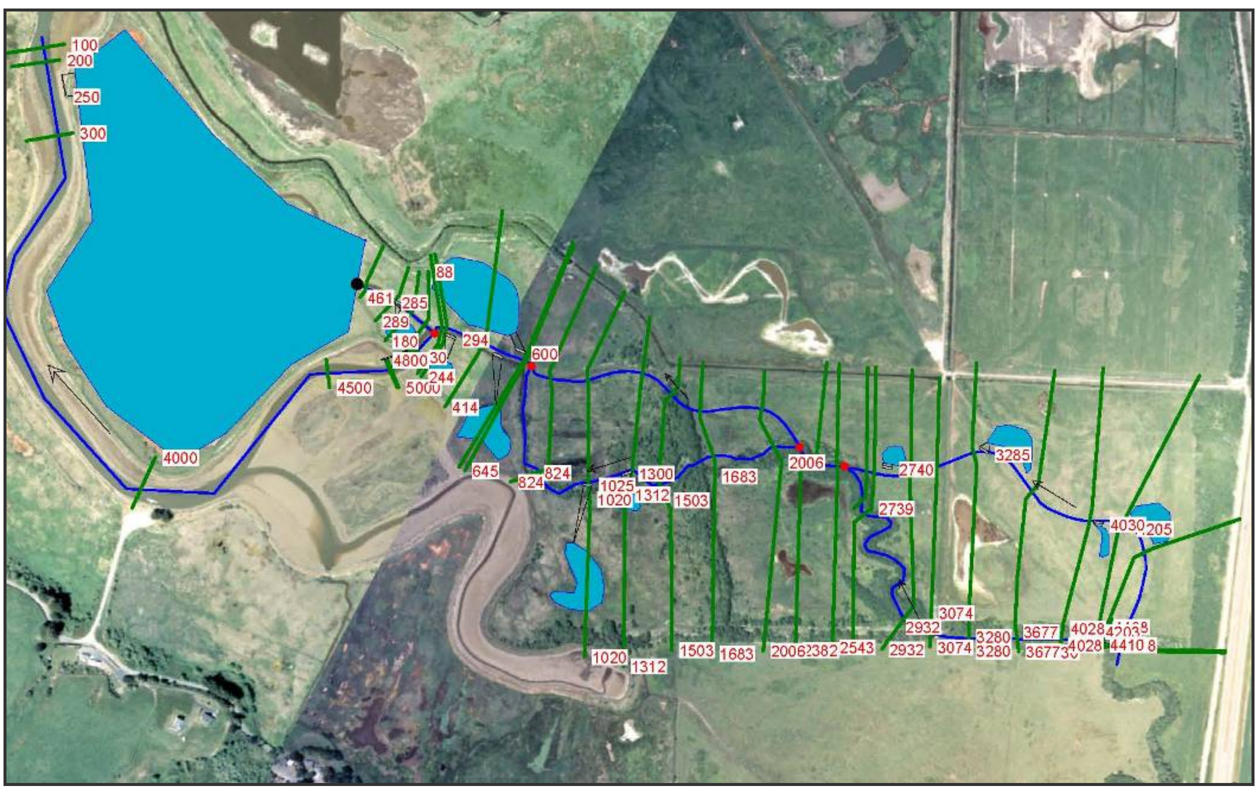

Figure 5-2. Schematic of HEC-RAS cross section locations and pond storage areas.

Manning's roughness values of n=0.04 were used to simulate the nature of the tidal channel, which includes woody debris, tight meanders, and overhanging vegetation. Overbank roughness values of n=0.1 were used to simulate shallow flow through the dense grass and light forests in the project area.

Flow Splits and Junctions

The split in flow between the realigned channel (Reach 1) and the existing ditched channel at the Refuge boundary was modeled as a 20-foot wide lateral weir. The weir invert elevation was set to maintain baseflow and frequent flow events within the Reaches 1 and 2, while allowing a portion of higher flows to overtop the lateral weir and flow through the existing ditched channel (Section 5.4.6).

The split in flow from Reach 3 into Reaches 4 and 5, the junction of Reaches 4 and 5 to Reach 6, and the junction between the Overflow channel and Reach 6 were modeled as Junctions. HEC-RAS automatically optimizes split flow through junctions and over lateral structures during unsteady flow.

Existing and New Pond Storage Areas

Pond storage-elevation relationships were determined for each of the six existing tidal ponds that would contribute to the design tidal prism. Connecting channels between the existing tidal ponds and the channel were modeled as 5-foot wide lateral structures with a weir crest elevation at the same elevation as the pond bottom.

Four proposed ponds located in Reaches 2 and 3 were modeled. Connecting channels between the ponds and the channel were modeled as 30-foot wide lateral structures with weir crest elevations between 2 and 3 feet. Total storage volume between MLLW and MHHW within the new ponds modeled in HEC-RAS is 3.85 AF.

Overflow Area

The Overflow Area was modeled as a storage area connected to Salmon Creek via an existing channel. The Overflow tidegate also drains the Overflow Area directly. Salmon Creek and the Overflow tidegates provide two mechanisms for waters to enter into and drain out of the Overflow.

The project HEC-RAS Model was run with 15 AF and 25 AF of excavated material placed in the Overflow between elevation 2.5 and 7 feet.

Tidegates

The newly constructed Salmon Creek and Overflow tidegates were included in the modeling. For each tidegate, during the incoming tide, a muted tide flows into the project area via a 2-foot high by 6-foot wide incoming flow opening with an invert elevation of -3.0 feet. The incoming flow opening was modeled as a Sluice Gate with a discharge coefficient of 0.6. When the water surface elevation inside the tidegate becomes 0.01 feet higher than in Hookton Slough, the incoming flow gate fully closes in one time step. At each tidegate, the outgoing flow was modeled as a triple cell 8-foot high x 6-foot wide concrete box culvert with flaps that allow flow to leave Salmon Creek, but prevent flow from entering. The outgoing flow gates open in the same time step that the incoming flow gates close.

5.3.2. Simulations and Boundary Conditions

The model was run at one-minute time steps for a variety of incoming freshwater flow hydrographs and tidal tailwater conditions. Model output was summarized in ten-minute time steps. For each scenario, the model was run to simulate a minimum of 3 days to ensure that equilibrium conditions were achieved. The HEC-RAS model was run in the subcritical flow regime with the upstream boundary condition set to normal depth. Inflow was either the 2-year storm flow hydrograph or a constant baseflow. The downstream boundary condition was based on tidal elevations, as determined from the design tide time-series.

Table 5-2 presents the various scenarios modeled and their use in developing the final design. Each modeling scenario was run with both 15 AF and 25 AF of material placement in the Overflow Area so that MHHW and salinity extents could be assessed for varying volumes of material placement. Digital files of the HEC-RAS model are available upon request.

Table 5-2. Five flow scenarios for which HEC-RAS modeling was performed. Each scenario was run with 15 AF and 25 AF of material placed in the Overflow Area. The results of the modeling were used to design various project elements as noted.

Scenario	Purpose
1. Summer baseflow (2 cfs) with semi-diurnal design tide	• Establish MHHW elevation in project area • Verify channel geometry sizing from empirical tidal relationships • Conduct sediment transport analysis
2. Winter baseflow (15 cfs) with semi-diurnal design tide	• Establish MHHW elevation in project area • Sediment transport analysis • Establish pond outlet elevations
3. 2-Year flow event (peak flow of 985 cfs) with semi-diurnal design tide	• Evaluate alluvial and tidal channel capacity • Evaluate extents of out-of-bank flooding • Set elevation of block in existing ditch channel • Set elevation of berm along Cattail Creek • Evaluate channel velocities • Conduct sediment transport analysis
4. Winter baseflow with semi-diurnal MLLW to MHHW	• Prepare salinity mass balance • Establish pond outlet elevations
5. Summer baseflow with semi-diurnal MLLW to MHHW	• Prepare salinity mass balance • Establish pond outlet elevations

5.3.3. HEC-RAS Model Results

The HEC-RAS model results indicate MHHW in Salmon Creek rises to a maximum elevation of 4.74 feet during winter baseflow conditions and to an elevation of 4.66 feet during summer baseflow conditions if the Overflow Area would be filled with 15 AF of material. MHHW rises to a maximum elevation of 4.79 feet during winter baseflow conditions if the Overflow Area would be filled with 25 AF of material. The tidal prism exiting the Salmon Creek and Overflow tidegates is split approximately evenly, though the outflow gate opening and closing timing and peak rate of outflow through the gates are slightly different between the two.

Figure 5-3 presents a profile of the project area showing water surface elevations at the various tidal conditions in Salmon Creek during winter baseflow conditions using 25 AF of material placement in the Overflow Area. Under proposed conditions, tidal influence beyond the Refuge boundary (upstream-most point on profile) is negligible.

Table 5-3 presents muted tide elevations in Salmon Creek at the Salmon Creek Tidegate, at Station 0+30 just upstream of the Salmon Creek Tidegate and at Station 42+03, in close proximity to where the new freshwater ponds 1 and 2 enter the channel.

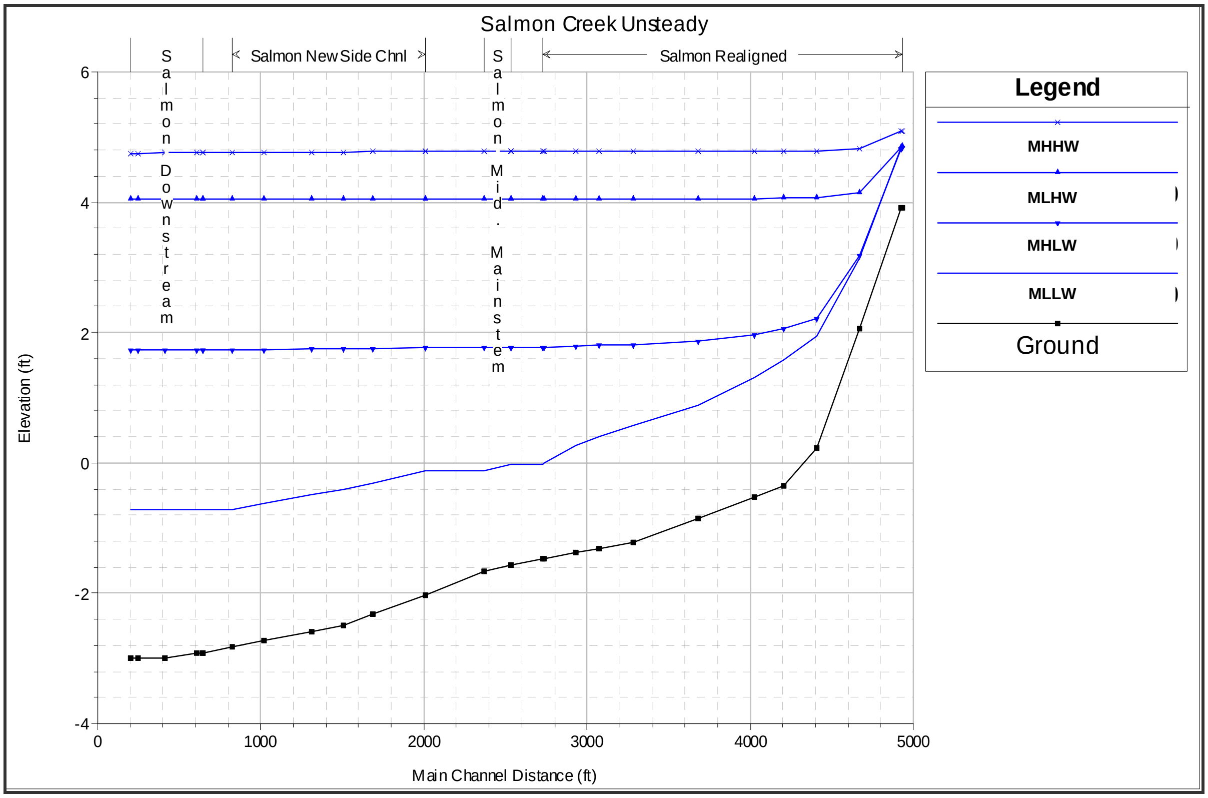

Figure 5-3. Profile of the project reaches showing water surface elevations at the various tidal datums during winter baseflow conditions. Profile shows model results with 25 AF of material placement in the Overflow Area.

Table 5-3. Select tidal elevations within Hookton Slough and muted tide water surface elevations within the Salmon Creek project area during winter baseflow with 25 AF of material placed in the Overflow Area (NAVD88 vertical datum).

Tidal Datum	**Hookton Slough**	**Salmon Creek Tidegate** (RAS Section 0+30)	**Reach 1** (RAS Section 42+03)
Mean Higher High Water (MHHW)	6.24 feet	4.75 feet	4.79 feet
Mean Lower High Water (MLHW)	4.84 feet	4.05 feet	4.06 feet
Mean Higher Low Water (MHLW)	1.74 feet	1.73 feet	2.06 feet
Mean Lower Low Water (MLLW)	-0.71 feet	-0.73 feet	1.58 feet

5.4. Design of Specific Project Elements

5.4.1. Salmon Creek Channel Capacity Assessment

The hydraulics and storage of flood flows on the floodplain within the proposed project is characteristic of systems that experience combined tidal and riverine influences. Reaches 1 through 3 form the transitional zone between a riverine and tidal system. In riverine systems, flows are contained within the streambank typically up to the 1 to 2-year flow event, before overtopping the banks and flowing onto the adjacent floodplain (Leopold, et al, 1964). In high tidal marsh systems, tides higher than MHHW flood onto the adjacent marsh plain. It has been observed that MHHW in these high marsh systems is analogous to bankfull in riverine systems (Leopold, et al, 1964; Myrick and Leopold, 1963).

The Salmon Creek channel cross section and profile design was based primarily on geometric relationships of tidal channels. However, Salmon Creek also receives streamflows from its 17.4 square mile watershed, adding a riverine element to the channel hydraulics. Therefore, the unsteady HEC-RAS model was used to assess the proposed channel conveyance and flow competence during the 2-year design storm. Initial model results were also used to set the elevation of the blockage for the existing ditched channel at the Refuge property boundary (Section 5.4.6) and to set the elevation of the Cattail Creek Berm (Section 5.4.4).

The capacity of the proposed channel and duration of out-of-bank flooding was evaluated using the hydrograph generated from the 2-year 24-hour event combined with the semi-diurnal design tide (Scenario 3), assuming that 25 AF of material may be placed in the Overflow Area. Figure 5-4 presents the peak water elevations for Scenario 2 and 3 in a channel cross section at Station 32+80, located in the Upper Refuge downstream of Pond 3. Figure 5-5 shows flow and water surface elevations at Station 32+80 (downstream end of Reach 2) during the 2-year design storm. Winter baseflow conditions (Scenario 2) are shown on the figure for reference. Figure 5-6 presents a channel profile of the project area with peak water surface elevations through the project area during the 2-year event (Scenario 3). Winter baseflow conditions (Scenario 2) are shown on the figure for reference.

During the rising limb of the 2-year flow event, flows begin to overtop the blockage for the ditched channel at the Refuge boundary when streamflow reaches approximately 230 cfs. The downstream end of Reach 2 (near cross section 32+80) has a capacity of approximately 450 cfs before flows spill onto the floodplain. As streamflow increases above 450 cfs, water begins to flow across the floodplain within the Middle and Upper Refuge. At the peak of a 2-year event, when a total of 985 cfs is entering the project reach, approximately 800 cfs is conveyed through Reaches 1 and 2 (Figure 5-4) and the remaining 185 cfs is conveyed over the blockage and through the existing ditched channel.

During a 2-year flow event on the flood tide, conveyance through the tidegates progressively decreases. This causes a backwater effect that increases both water surface elevations and flood storage throughout the project area (Figure 5-5 and Figure 5-6). As the tide begins to ebb, conveyance through the tidegates increases and water surface elevations decrease. Within approximately 12 hours after the peak of the design flow, flow has drained from the floodplain and is fully conveyed within the channel. Within 48 hours after the design flow peak, water surface elevations closely follow the muted tide predicted for winter baseflow conditions.

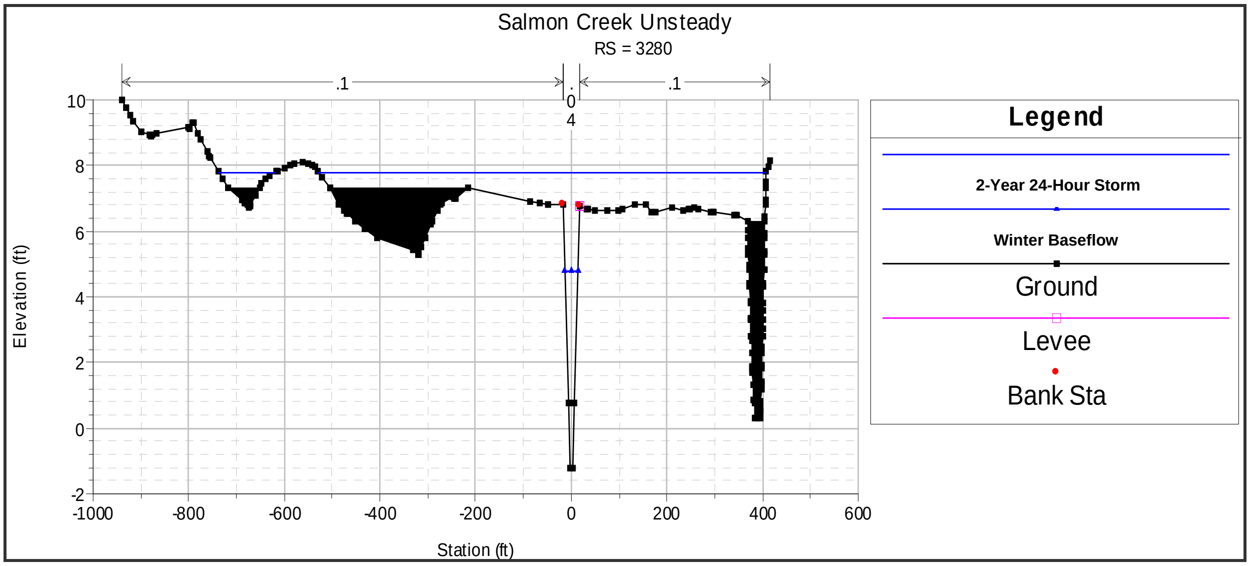

Figure 5-4. Channel cross section at Station 32+80, in the Upper Refuge, showing MHHW during winter baseflow conditions and the peak water surface during the 2-year storm event with 25 AF of material placement in the Overflow Area. At this cross section, flows have transitioned from a riverine to estuarine. The channel conveys MHHW but the 2-year storm event flows onto the floodplain.

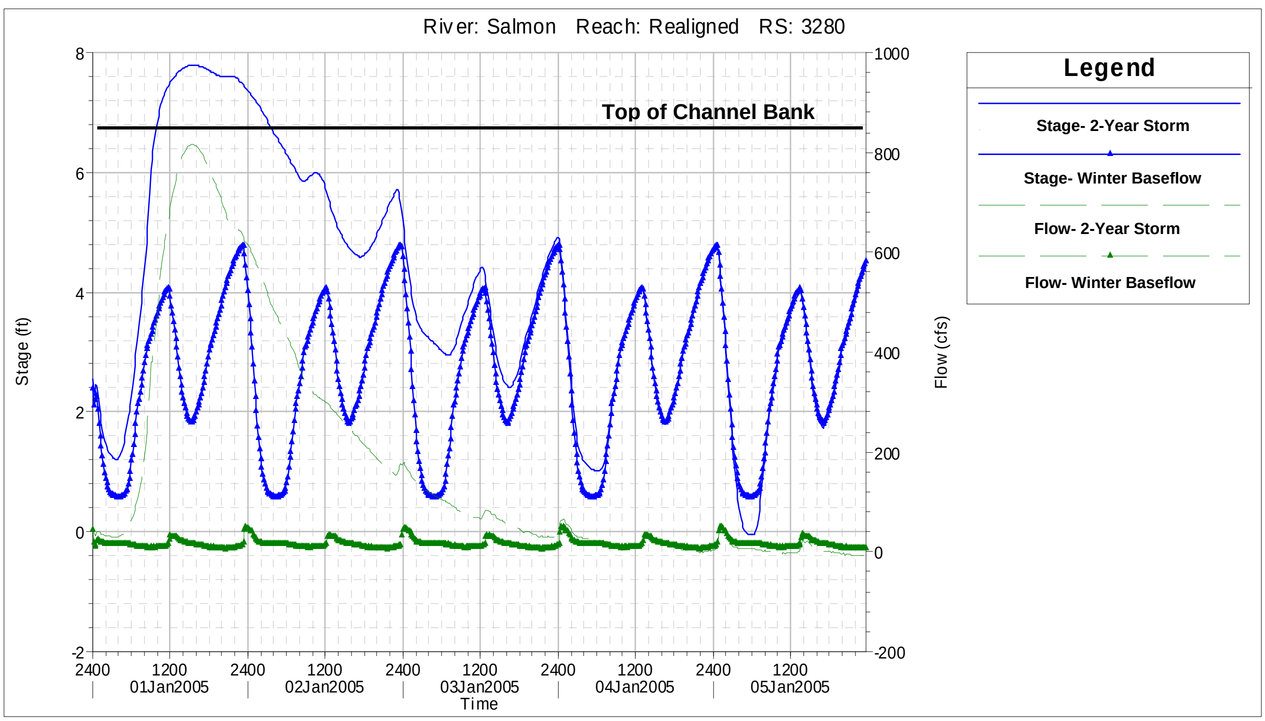

Figure 5-5. Flow and water surface elevations at Station 32+80 (Reach 2, Upper Refuge) during winter baseflow conditions and 2-year the design storm event with 25 AF of material placement in the Overflow Area.

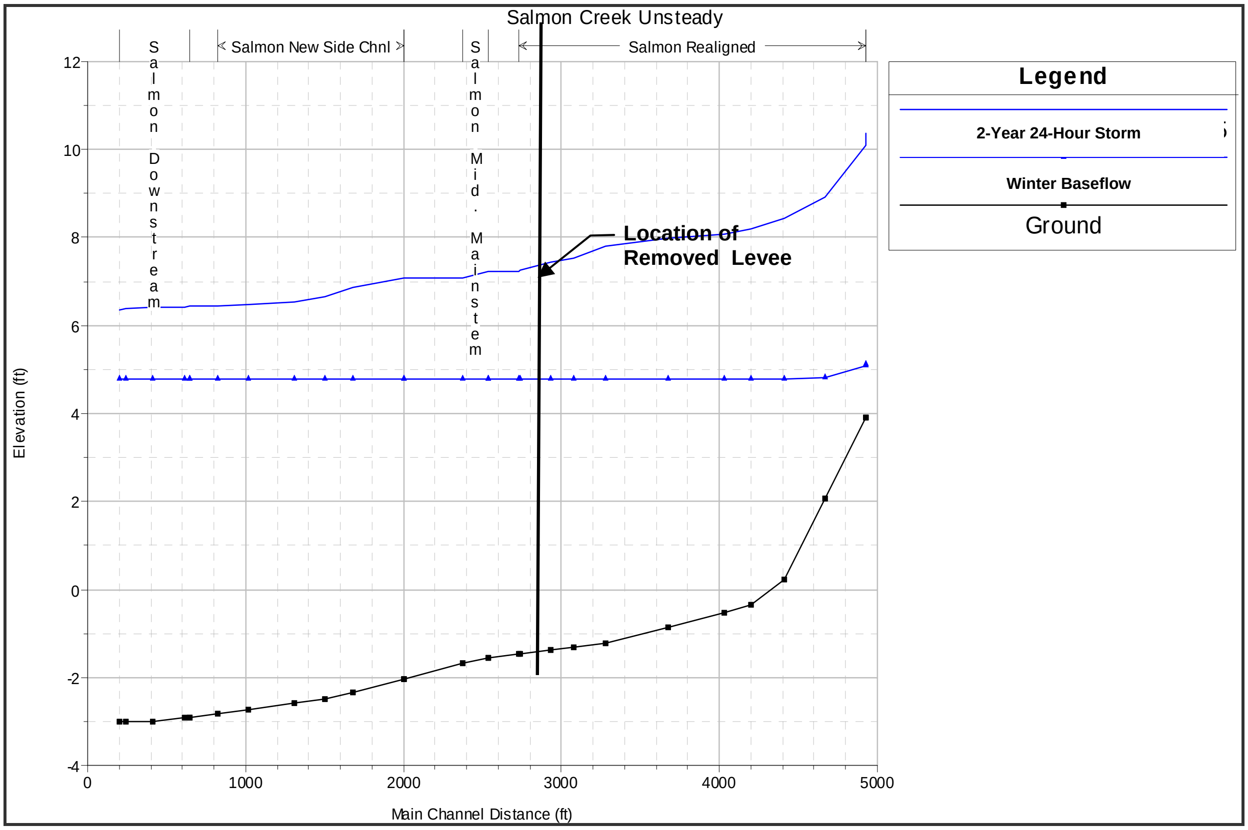

Figure 5-6. Profile of peak water surface elevations through the project area for winter baseflow conditions (Scenario 2) and for the 2-year 24-hour design flow event (Scenario 3) with 25 AF of material placement in the Overflow Area.

The proposed 200 feet of levee removal to the south of the new channel near station 30+70 allows for connectivity of floodplain flows between the Upper and Middle Refuge. Without removal of the levee, floodplain flows are constricted and water velocities in the channel increase near station 30+70. Removal of the levees requires a substantial amount of material excavation, which increases project cost. The appropriate length of levee removal was determined through an iterative process that found the point where additional removal had little to no effect on floodplain or channel hydraulics during the 2-year design storm.

5.4.2. Sediment Transport Competence

Under existing conditions, the present tidal prism does not extend far enough upstream to create sufficient shear stress to mobilize sediments transported into the upper channel reaches located on the Refuge. A project objective was to increase the tidal prism throughout the project area, especially into the Upper Refuge to ensure there are no areas along the proposed channel where concentrated sediment deposition may occur.

Sediment transport competence within the project area under proposed conditions was assessed using the Shields critical shear stress method. Three different scenarios were modeled: summer base flow, winter baseflow, and the 2-year design storm. All used the design semi-diurnal tide in Hookton Slough and assumed 25 AF of material will be placed in the Overflow Area.

The critical stress method compares HEC-RAS computed channel shear stress against the Shields critical shear stress value for a given particle size. If channel shear stress is above the Shields critical shear stress for a given particle size, the flow has the competence to move a particle of that size.

Sediment transport competence was assessed for a 2 mm particle (coarse sand); typical of the larger sized material found along the existing channel bed within the Refuge. The critical shear stress for a 2 mm particle is approximately 0.02 lbs/sf, (Leopold, et al, 1964). Sediment transport competence was also assessed for a 15 mm particle to evaluate mobility of small gravels, which are found within the historical channel fill on the Refuge and upstream (Pacific Watershed Associates, 2009). The critical shear stress value for a 15 mm particle is approximately 0.25 lbs/sf, (Leopold, et al, 1964).

Figure 5-7 shows channel shear stress for the analyzed flow events at Station 42+03, between Ponds 1 and 2 in Reach 2. Tide elevation in Hookton Slough is shown for reference. HEC-RAS results indicate that peak channel shear stress occurs at low tide, except near the peak of the 2-year storm event, when flows exceed the channel capacity and the floodplain is inundated. The peak shear stress during a 2-year event occurs on the rising limb of the hydrograph when flows are contained within the channel and again on the falling limb just after low tide.

Figure 5-8 presents channel shear stress along the main channel of Salmon Creek at different flows. The critical shear stress value of 0.02 lbs/sf, for a 2 mm particle is shown on the figure with a solid black line. The critical shear stress value of 0.25 lbs/sf for a 15 mm particle is shown on the figure with a dashed black line on the figure. During winter and summer baseflow conditions highest shear stress occurs at MLLW.

Channel shear stress at 450 cfs (channel capacity flow) during the rising limb is shown, as well as shear stress at the peak of the design storm event. When viewed in combination, it is evident that shear stress becomes adequate at every location within the proposed Salmon Creek channel to mobilize and transport a 15 mm particle during the 2-year design storm event.

The lower water surface slope near station 30+70 on Figure 5-6 is caused by the existing levee along the north side of the channel that constricts the floodplain, as well as a general narrowing of the floodplain between the Upper and Middle Refuge due to existing topography. Removal of a 200 foot portion of levee to the south of the channel is proposed to be removed to reduce confinement of the overbank flow and constriction of the floodplain. During the 2-year storm event or larger events, when flows are on the floodplain in the Upper Refuge, some sediment deposition may occur on the floodplain as a result of the lower shear stresses caused by the backwater and the lower ground elevation in this area (Figure 5-8). Peak channel shear stresses through the breached levee section are not expected to cause channel erosion.

Tidal action during winter baseflow conditions provide the competence to move a 2 mm particle through the project area to approximately station 13+00, where channel shear stress values drop below the critical shear stress for a 2 mm particle. Summer baseflows and tidal action have the competence to move a 2 mm particle through the project area to approximately station 37+00, where channel shear stress values drop below the threshold transport critical shear stress for a 2 mm particle.

The results of the shear stress analysis indicate that the proposed channel will maintain sufficient shear stress during the 2-year design event and winter baseflow to minimize sediment deposition of 15 mm and smaller material in the project area. A small amount of sediment deposition may occur in the channel over the dry summer months, but winter flows and storm events should have adequate competency to transport it to the tidegates, preventing accumulation.

The analysis presented is not a sediment transport capacity analysis. If the volume and size of sediment delivered to the project reaches are beyond the channels' transport capacity during the flow event, deposition would be expected. However, there has been a substantial amount of work supported within the watershed associated within the Headwaters Forest Preserve and watershed-wide sediment reduction efforts, funded in part by DFG. These efforts have likely contributed to the fact that Salmon Creek is not listed as an EPA 303(d) Sediment Impaired Water Body and excessive sediment delivery to Salmon Creek is not expected to occur on a regular basis.

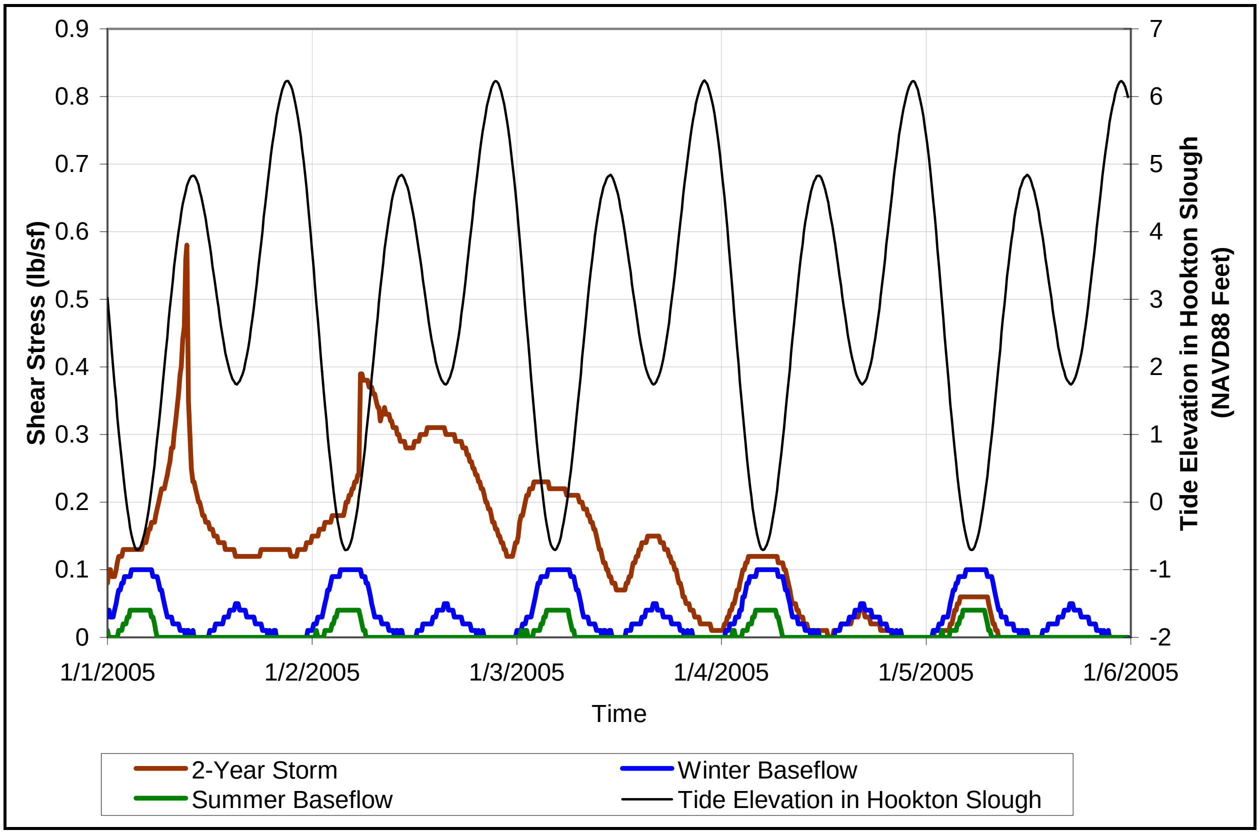

Figure 5-7. Channel shear stress at Station 42+03 (Reach 1, Upper Refuge) during the 2-year design storm, winter baseflow, and summer baseflow conditions. Tide elevation in Hookton Slough is shown for reference. Refer to Figure 4-2 for 2-year event hydrograph timing.

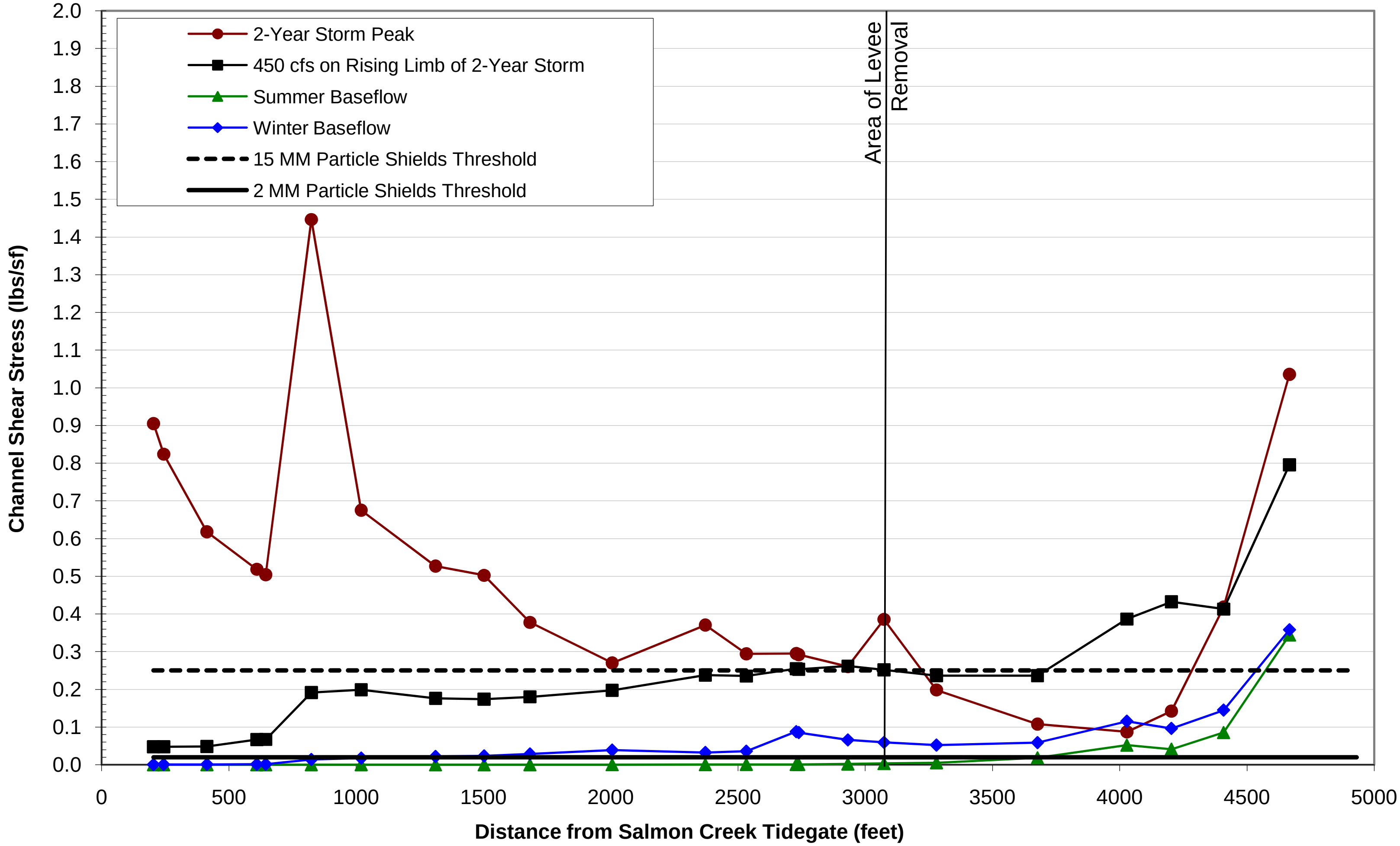

Figure 5-8. Channel shear stress at MLLW for summer and winter baseflow tidal conditions. Also shown are peak channel shear stresses during the rising limb (450 cfs) and (985 cfs) peak of the 2-year design storm event. The solid black line represents the critical shear stress required to move a 2 mm particle. The dashed black line represents the critical shear stress required to move a 15 mm particle.

Large volumes of sediment are not expected to be delivered regularly to Salmon Creek. Repetitive cross sections monitoring (Section 3.3) has indicated that little sediment accumulation has occurred within the existing ditched channel within the Upper Refuge, and the downstream portion of the channel is enlarging. The Refuge has observed little to no sediment deposition in the exiting ponds that are connected to the channel. However, large volumes of incoming sediment may be delivered to the project area after an extreme seismic event or catastrophic floods. USFWS has committed to maintaining Salmon Creek and the new ponds, and is prepared to remove sediment deposition that may occasionally occur.

5.4.3. Rock Grade Control Structures

The proposed grade controls in Reach 1 will consist of short profile (5-foot long) rock grade control structures with sloped crests (See Rock Grade Control Details Sheet 25 in Appendix A). Ten grade controls will be placed in the steeper portion of Reach 1 from the property boundary to a location where the channel is tidally backwatered at MLLW. Drops between individual grade control crests will be 0.4 feet to allow juvenile salmonid passage at all tidal conditions, even with slight shifting or settlement of the grade control rocks (CDFG, 2002; NOAA, 2001). At higher tides and/or higher flow conditions, all ten grade control weirs will be backwatered and all fish could swim upstream unhindered.

The grade control crests will be constructed at grade at the specified channel invert elevation. The top of the structure will slope down to create a chute rather than plunging flow, allowing juveniles to swim across the structures rather than leap. To concentrate low flows, the structures will slope gently towards the center of the channel and will be constructed to a minimum depth of three feet below finished grade to prevent undermining from scour.

The ends of each grade control structure will be keyed into the channel banks and into the clay surrounding the historical channel. Keying the grade controls into the edge of the historical channel will prevent end-around erosion and maintain grade in the event of channel adjustments. The grade control structures will be underlain with a suitable geotextile to distribute the load of each rock structure and minimize differential settlement, as recommended in the project geologic report (Pacific Watershed Associates, 2009). The geotextile will also be wrapped up the sides of the structure to minimize piping through the structure.

The rock grade controls were sized using methods presented in the CDFG manual (CDFG, 2009). The ACOE (1994) method and unit discharge associated with the capacity of the channel was used for initial rock sizing. Structure rock sizing was then increased according to NRCS (2000) recommendations for rock weirs The proposed rock grade controls will be comprised of rock ranging in size from 0.5 to 2.5 feet (D_{50} = 1.3 feet). During construction, the rock will be mixed with native sands, gravels, and clays. The smaller native material will fill void spaces between the larger materials to minimize flow through the structure.

5.4.4. Cattail Creek Berm

To reduce Salmon Creek flow loss into Cattail Creek, a low earthen berm is proposed in the Upper Refuge that will run along the south bank of Cattail Creek (Sheets 11, 12 and 23, Appendix A). The berm is designed to prevent Salmon Creek floodplain flows in Reach 2 from being captured by Cattail Creek up to the 2-year peak design flow. Containing frequently occurring floodplain flows with the berm will create low velocity refuge and foraging habit across the floodplain for juvenile salmonids during these events.

The top elevation of the berm is set at 8.5 feet, which is slightly above the peak water surface elevation in the Upper Refuge during the 2-year design storm event. The height of the berm ranges between 1.5 and 3.5 feet above existing ground. The berm will be constructed of compacted clay salvaged from the channel excavation. The clay will be installed in lifts and compacted with a sheep foot roller or similar equipment. A percent compaction was not specified because the berm's low height and associated low risk does not justify the expense necessary to determine compaction standards for the range of moisture contents expected with the project. Because the berm will not be used as a levee, substantial compaction is not necessary, and woody vegetation can be established on the berm.

The berm will have a sinuous alignment with a top width of 5 feet and side slopes of 5H:1V. These berm dimensions will allow equipment access, but creates what will appear to be a natural floodplain feature that supports a zonation of wetland vegetation. The berm will be topped with salvaged topsoil that will provide a seed bank for re-establishment of native wetland vegetation. Additionally, the Refuge may plant additional trees, shrubs and other woody species in the future.

5.4.5. Revetment at Historical Channel

The project geologic report (Pacific Watershed Associates, 2009) indicated that the material comprising the historical channel may be seasonally saturated and may be erodible. The report recommends that where the new channel turns to the west and exits the historical channel, additional bank revetment may be necessary to maintain channel bank stability. Additionally, the project geologic report indicates that the historical channel may act as a groundwater conduit between the project area and the northern part of the Refuge, though the direction of groundwater flow is unknown.

To maintain groundwater flow and protect the streambanks from erosion, a permeable revetment is proposed consisting of a willow brush mattress and two log vanes. The revetment will extend from the straighter portion of the channel upstream of the bend, through the meander bend, to downstream of where the channel exits the limits of the historical channel.

Two log vanes, each approximately 35 feet in length will be installed on the outer streambank of the channel bend (Plan view Sheet 12 and Log Vane Details, Sheet 28 in Appendix A). The vanes will be placed on finished grade such that they angle from the bottom of the stream bank to elevation 4.0 along the outside bend of the meander. The log vanes will project two to three feet above finished grade, creating an effective structure up to the top of bank at about elevation 7 feet. The log vanes are designed similarly to a single rock wing deflector, a structure intended to deflect flow away from the streambank (CDFG, 1998). The vanes will project at an angle into the flow column, turning flow away from the stream bank. The log vanes will be anchored with rock to maintain their position (See Section 5.4.9).

A willow brush mattress will be installed between elevation 4.0 and the top of the stream bank (See Plan view Sheet 12 and material and installation specifications for Willow Brush mattress, Sheet 31 in Appendix A). Installation at a lower elevation may result in morality of the willow cuttings from brackish conditions during the summer. See Section 5.4.11 for more information on the Willow Brush Mattress design parameters.

5.4.6. Block for Existing Ditched Channel

The existing ditched channel will be partially blocked at the upstream end of the new Salmon Creek channel. The block will prevent baseflow and frequent storm flows from entering the existing ditched channel, converting it into a backwater channel. During larger storm events, water will flow over the channel block, allowing the existing ditched channel to act as a flood overflow channel.

The proposed channel block will be constructed using a combination of log weirs and an Engineered Log Jam (ELJ) (Sheets 12, 26, 29, and 30, Appendix A). The upstream-most log weir will be set at an elevation of 7.5 feet, which is about 3.5 feet above the adjacent channel thalweg and 3.5 feet below the top of the channel bank. During the rising limb of a 2-year storm event, when streamflow reaches approximately 230 cfs, water begin to overtop the log weir and flow down the existing ditch channel (Figure 5-9). At the peak of a 2-year storm event, when a total of 985 cfs is entering the project reach, approximately 185 cfs is conveyed over the log weir and through the existing ditched channel.

Figure 5-9 presents the difference in water surface elevation (head difference) across the blockage during the 2-year storm event. During the peak of the design storm, water surface elevations in Salmon Creek at the blockage are slightly above 10 feet and the tailwater in the existing ditched channel downstream of the blockage are near an elevation of 9 feet, resulting in one foot of head difference across the blockage. During the rising and falling limb of the flow event, less flow enters the existing ditched channel and the overall drop across the blockage increases to 2.5 feet. Because the head drop is greater than 1 foot at times when flows is entering the ditched channel , structures are necessary to create conditions that allow upstream fish passage for adult salmonids.

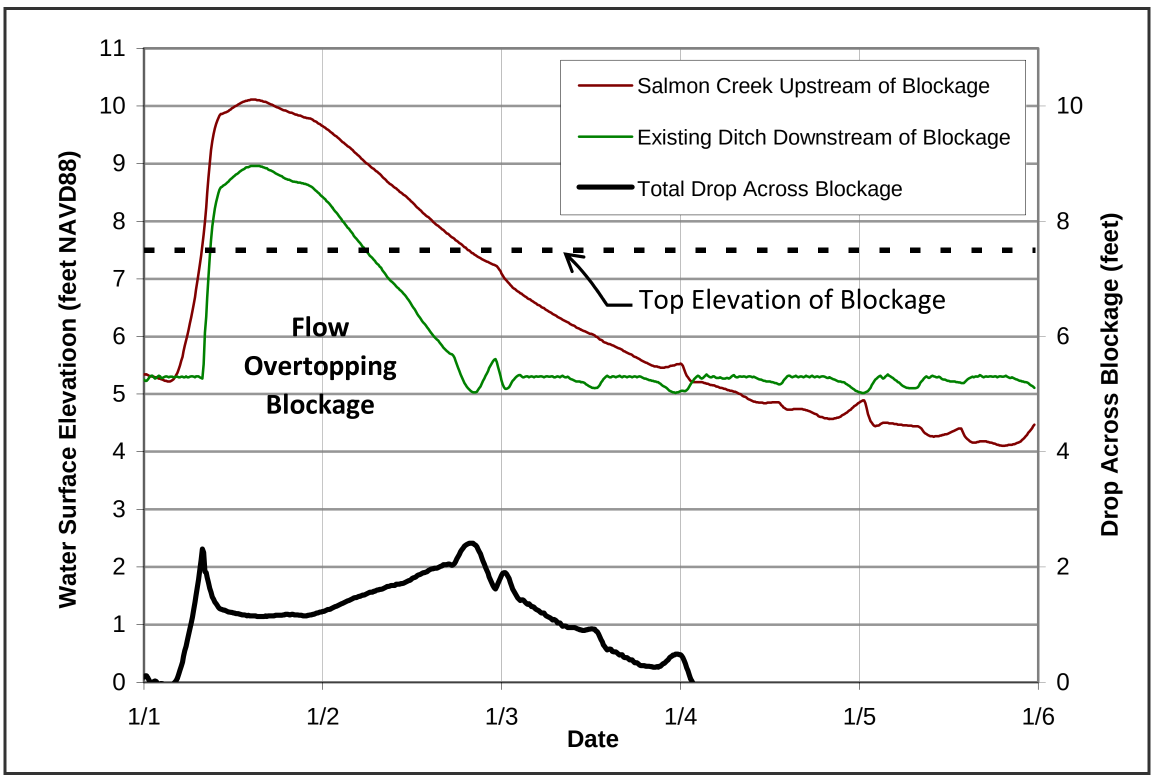

Figure 5-9. Water surface elevations in Salmon Creek upstream of the blockage and in the ditched channel downstream of the blockage. The total water surface drop across the blockage is the difference in the two water surface elevations.

The elevation of the log weirs and the ELJ that comprise the blockage were designed to provide suitable upstream passage conditions for adult anadromous salmonids when flow is spilling into the ditched channel. The blockage contains two log weirs to form step pools. The 1-foot drops between steps and minimum pool depth of 2 feet conform to NOAA and DFG guidelines (CDFG, 2002; NOAA, 2001). Step-to-step spacing is 25 feet, creating a 4% channel slope, which is in the channel slope range for log profile control structures recommended in DFG (2009).

The two log weirs will be constructed of top logs and footer logs that are greater than 2 feet in diameter and have a length sufficient to span the channel and embed into the streambank a minimum of 3 feet. Rock placed around the ends of the logs will protect the channel banks from scour. The minimum depth of the footer logs to avoid undermining from scour was computed using DFG (2009). The weirs will be sealed with compacted clay salvaged from the channel excavation and placed against the upstream face of each weir. At lower flows, the tailout of the last step will be backwatered by the weir log on the ELJ.

The Engineered Log Jam (ELJ) will be located just downstream of the tailout of the last step. The ELJ is intended to raise the tailwater elevation of the downstream-most step, as well as to create channel bottom diversity and habitat. A weir log installed 1.0 to 1.5 feet above the channel invert will act as an upsurge log (CDFG, 1998), and will form the foundation for the ELJ structure. A minimum of 5 large logs (2 feet in diameter and 20 feet in length) will be installed upstream of the weir log so that the logs shingle on the weir log and each other, creating open space between the logs and the channel bottom. The open space under the logs will be stuffed with brush to create habitat complexity, multiple hiding spaces, and a wood source for the stream channel.

The log steps and the ELJ will be anchored in accordance with CDFG (1998), and as presented in Section 5.4.9.

5.4.7. Water Control and Fish Passage Structure

A water control structure is proposed as part of the project to replace the existing First Diversion, which will be abandoned with the relocation of the Salmon Creek Channel. The type and location of the structure is yet to be determined, but will be located between the Upper and Middle portions of the Refuge, adjacent to the new Reach 3 channel. The Refuge wishes to include a fish passage structure as part of the new water control structure to provide fish passage between Cattail Creek and Salmon Creek. The design of the water control and fish passage structures are to be completed under a separate contract and are not part included in this report or the design plans and specifications.

5.4.8. New Pond Design

A project objective is to create winter rearing habitat for coho juveniles in off-channel ponds within the project area. These ponds will be connected to the main channel through an elevated pond inlet/outlet channel, referred to as the pond outfall. To help ensure that the ponds remain predominately fresh during the winter rearing, pond are positioned upstream of the anticipated tidal intrusion front and pond outfall elevations are set above the channel bottom to reduce the risk of brackish water entering the ponds if salt-fresh water stratifications occurs.

Saltwater extent was estimated at winter baseflow conditions using a mass balance approach and two different assumptions of saltwater mixing: (1) full stratification and (2) a tidal intrusion front, which assumes the incoming tide does not stratify. The results from both of these methods were then used to guide setting pond locations and outfall elevations.

Salinity Mass Balance Analysis

A salinity mass balance computes the total volume of fresh and saltwater in a system through a series of tidal cycles. The mass balance for this project was prepared from HEC-RAS modeling results from five tidal cycles fluctuating between MLLW and MHHW with both a summer and winter baseflow freshwater input (Scenario 4). The mass balance was computed for the range of 15 AF and 25 AF of Overflow Area material placement.

For this analysis, the Overflow was assumed fully saline due to its direct connection to both tidegates. For outgoing flows, it was assumed that all of the saltwater discharged through the tidegates before freshwater began to discharge into Hookton Slough. Inflow through the tidegates was assumed to be saltwater. Through each tide cycle, the volume of salt and fresh water within the project area was computed at 10-minute intervals. The total volume of saltwater in the project area at MHHW was then used to estimate the location of the salt-fresh water interface.

Stratification Elevation

When fresh and saltwater stratifies, saltwater is heavier and sinks to the bottom of the channel and the lighter freshwater floats on top, with a small mixed zone between the two. This approach assumes the salt-fresh water interface at MHHW is at the same elevation throughout the channel. Based on an elevation-storage rating table for Salmon Creek, assuming the Overflow is completely saline, the elevation of the salt-fresh water interface at MHHW was calculated.

Location of the Tidal Intrusion Front

The tidal intrusion front assumes that mixing between fresh and salt water is negligible during the flood tide. This approach assumes the salt-fresh water interface at MHHW is a nearly vertical interface at a specific location in the channel. The tidal intrusion front at MHHW was assumed to be located within the channel (between Reach 1 and 6) and the Overflow was assumed to be fully saline. The volume of freshwater within the project area at MHHW was then used to determine the river station that the tidal intrusion front would reach before the tide begins to ebb.

Results

Table 5-4 summarize the results of the salinity mass balance for both summer and winter baseflow with 15 AF and 25 AF of material placement in the overflow. Figure 5-10 and Figure 5-11 graphically show the results of the salinity mass balance for winter and summer baseflow with 25 AF of material placement in the Overflow area.

The volume of material placed in the Overflow Area influences the overall tidal prism flowing through the Salmon Creek and Overflow Tidegates. In comparison, 25 AF verses 15 AF of placed material decreases the tidal prism by approximately 4.5 to 5 AF, depending on the season (Table 5-4). As shown in Table 5-4 , the exact amount of materials placed in the overflow, assuming it will be between 15 AF to 25 AF, will only have minor influence on the volume and spatial extent of saltwater entering Salmon Creek.

During the winter months, tidal intrusion front conditions are likely to dominate in the Salmon Creek system because of the high volume of incoming freshwater. The downstream moving freshwater will push against incoming saline water, forming a sharp, nearly vertical boundary between freshwater and saltwater. Therefore, during the winter baseflow, it is expected that Salmon Creek will be a freshwater dominated system upstream of Station 8+00, located at the downstream end of Reach 5. More conservatively, if stratification occurs, freshwater dominates the channel above an elevation of 3.2 feet at MHHW.

During the summer months, baseflow is extremely low (0.5 cfs), and is not expected to have a sufficient downstream flow component to form a defined tidal intrusion front, and a thus a weaker tidal intrusion front or even stratification is expected to occur. Therefore, during the summer months and low baseflow, it is expected that Salmon Creek will be predominately saline downstream of station 40+00, and stratification will occur in the Upper Refuge at MHHW.

Pond Geometry

Table 5-5 summarizes the properties of the four proposed off-channel ponds. Pond grading, profiles and cross sections are shown in Appendix A (Sheets 18-21). The following sections discuss the pond design in detail.

Table 5-4. Summary of salinity mass balance analysis and locations of salinity in Salmon Creek with the two assumptions of saltwater mixing.

Volumes	Summer Baseflow		Winter Baseflow	
	15 AF Overflow Material Placement	25 AF Overflow Material Placement	15 AF Overflow Material Placement	25 AF Overflow Material Placement
Total Tidal Prism	111.4 AF	106.9 AF	117.4 AF	112.1 AF
Total Saltwater Volume	108.6 AF	104.1 AF	103.7 AF	98.4 AF
Total Freshwater Volume	2.8 AF	2.8 AF	13.7 AF	13.7 AF
Saltwater Volume in Salmon Creek	21.9 AF	23.2 AF	11.4 AF	11.8 AF
Saltwater Elevation (Stratification)	4.0 FT	4.1 FT	3.1 FT	3.2 FT
Saltwater Station (Tidal Intrusion Front)	40+00	40+00	8+00	8+00

Table 5-5. Summary of the four proposed ponds in Salmon Creek.

Pond Number	Pond Outfall Station	Outfall Weir Elevation (NAVD 88)	Tidal Prism from Pond	Residual Pond Depth
1	40+30	2.5 feet	1.4 AF	3.5 feet
2	38+25	3.0 feet	0.6 AF	3.0 feet
3	35+75 Upstream 33+00 Downstream	3.5 feet Upstream 2.8 feet Downstream	1.5 AF	3.8 feet
4	29+75 Upstream 27+50 Downstream	3.0 feet Upstream 3.5 feet Downstream	0.35 AF	5.0 feet

[1] Tidal Prism storage computed from the pond outlet elevation and a MHHW elevation of 4.7 feet.

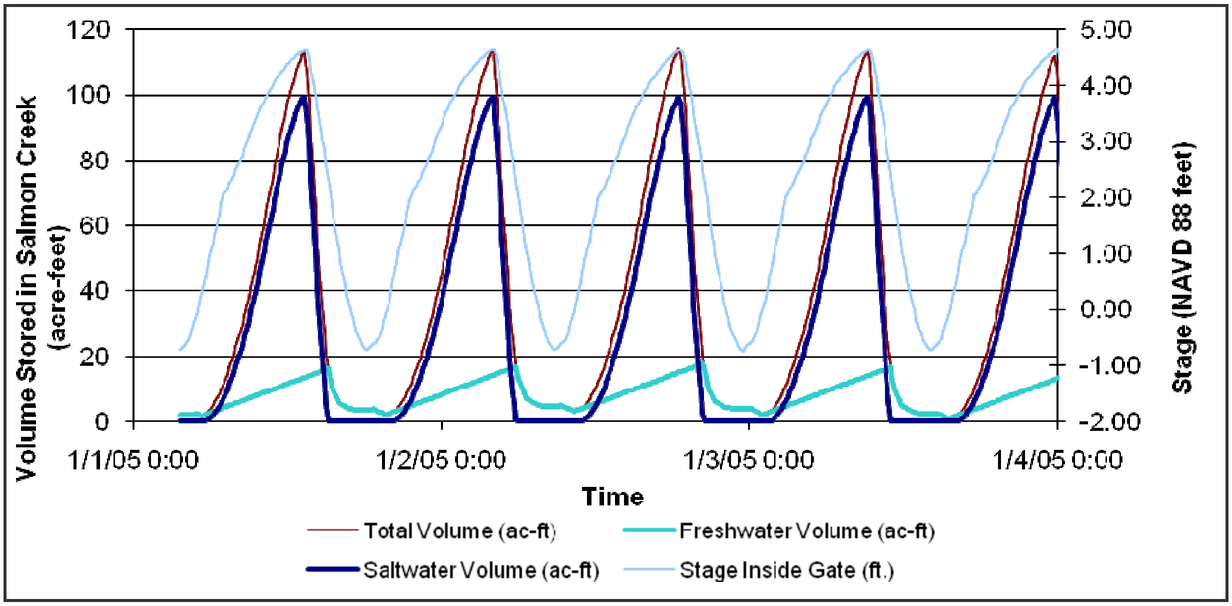

Figure 5-10. Winter baseflow condition salinity mass balance analysis. Total tidal prism and the saltwater and freshwater component of the prism within the Salmon Creek project area between MLLW and MHHW if 25 AF of material is placed in the Overflow Area. On ebb tides the freshwater was assumed to begin draining from the project area after all saltwater had been drained.

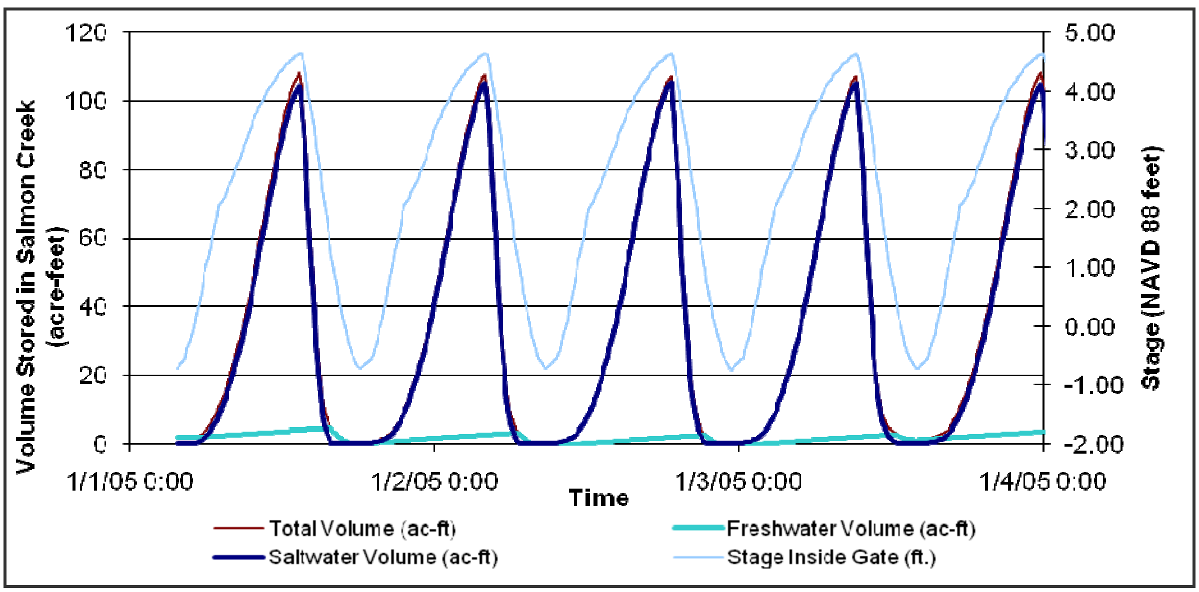

Figure 5-11. Summer baseflow condition salinity mass balance analysis. Total tidal prism and the saltwater and freshwater component of the prism within the Salmon Creek project area between MLLW and MHHW if 25 AF of material is placed in the Overflow Area. On ebb tides the freshwater was assumed to begin draining from the project area after all saltwater had been drained.

Coho Salmon Rearing Preferences

There is a broad body of literature documenting the habitat types juvenile coho salmon use for rearing and foraging during winter months (Stillwater Sciences, 1997; Miller & Sadro, 2003; Roni et al., 2006; Henning et al., 2006; Blackwell et al., 1999, among others). The literature documents off-channel areas in the upper estuarine ecotone as providing important over-wintering habitat for juvenile coho before they out-migrate to the ocean in the spring.

The upper estuarine ecotone is the transition area between riverine channels and the upper tidal limit. The estuarine ecotone provide a gradation of freshwater to slightly saline water as well as rich foraging areas that coho use to maximize growth before smoltification. The highest productivity and largest fish size for juvenile coho are found in areas with good water quality and temperatures, low water velocity, and cover, generally in the form of large wood. Coho prefer deeper pools for thermal regulation, refuge and schooling, and shallow edge areas with emergent vegetation for foraging. Henning et al. (2006) found that fish prefer off channel areas with permanent year round or at least fall-spring connection to the river system. Comparison of fish size of juvenile coho sampled in the estuary ecotone and the adjoining riverine habitats identified a much larger mean fork length within the estuary ecotone (Miller & Sadro, 2003).

Overall Pond Design

The four proposed ponds are designed to create conditions preferred by juvenile coho salmon. They simulate the morphology and hydraulic conditions of meander cutoffs and oxbow lakes, typical off channel habitat found in low gradient systems. Circulation through the ponds will occur from tidal backwater effects and with overbank flows from upstream. The off-channel nature of the ponds and outlet orientations are intended to minimize entry of sediments from the main channel into the ponds. The elevation of outfall sills or "weirs" are intended to minimize entry of bedload sediments from the main channel into the ponds. Some accretion of fine material may occur from smaller grained sediments suspended within the water column during flood events. However, a large volume of the water in the ponds will be flushed twice daily by tidal action, minimizing the amount of time for settlement of smaller particles.

The proposed pond side slopes range from 3H:1V to 10H:1V, depending on location. The more gentle side slopes are intended to simulate point bar geometry, and the steeper slopes to simulate meander channel banks. The side slopes of the ponds will create a shallow littoral area where emergent vegetation will grow. At and above the water line, zones of wetland vegetation will change to more upland vegetation. Below the permanent pool elevation established by the weir, pond side slopes steepen to 1.5H:1V to create a permanent pool a minimum of 3-feet deep. Pond bottom elevations were set to the elevation of the adjacent stream channel so that differential draining will not occur.

Pond Outfall Design

Pond weir elevations and locations were established to limit winter saltwater intrusion while maximizing the amount of time the pond is hydraulically connected to the channel. Pond weir elevations were established below MLHW to ensure the ponds are flooded twice daily by the tidal cycle. This will allow fish ingress and egress, and ensure frequent water exchange and flushing between the pond and main channel. Additionally, each pond elevation was set at a different elevation to create a diversity of off-channel conditions and habitats. A secondary goal was to maintain freshwater conditions in the upstream ponds into late spring and possibly summer months.

Each of the pond outfall weirs is 20 feet wide. HEC-RAS modeling indicates peak velocities across the weirs do not exceed 0.5 fps. Therefore, grade controls on the pond weirs are not proposed, but they should be composed of relatively resistant material, such as clays. Effort should be taken to avoid over-excavation at the outfalls so that the weirs are formed of native undisturbed clay material.

Pond 1

Pond 1 is located at Station 40+30 in Reach 2 where tidal influence begins to dominate over riverine influence. This pond contributes 1.4 AF to the tidal prism at the upstream most limits of the tidal system, which will assist in maintaining sufficient tidal flux and shear stress in the upstream reaches of the channel.

The pond is shaped in the geometry of an abandoned meander bend, forming an oxbow lake. A single outlet allows flow exchange with the Salmon Creek channel. It is also expected that over-bank flows during larger storm events will flow into the pond from the overbank area.

Pond 1 is the farthest upstream proposed pond, and the control weir was set to an elevation of 2.5 feet to maximize water exchange with the channel and to minimize the time that the outfall weir is dry during periods of low flow and low tide. During the summer, when the tidal intrusion front is expected to be located near Station 40+00, the pond may remain fresh. However, if stratification occurs rather than a tidal intrusion front, the pond could become brackish.

Pond 1 was located such that it is outside the limits of the historical channel and within the anticipated dense clay expected to underlie the Upper Refuge. Locating the pond in the clay will ensure that the pond outfall weir can be constructed out of undisturbed material that is resistant to erosion.

Pond 2

Pond 2 is located at Station 38+25 in Reach 2, where the channel is tidal. The pond is shaped in the geometry of a meander scar, with a steeper 3H:1V scarp bank and a 10H:1V bank simulating an abandoned point bar. A single outlet allows flow exchange with the Salmon Creek channel.

The control weir of Pond 2 was set at an elevation of 3.0 feet. Though located above the predicted location of the winter tidal intrusion front, the pond is located just downstream of the expected tidal intrusion front during summer conditions. Therefore, the weir was set at an elevation that will allow daily flushing, but will limit the amount of saline water entering the pond during the summer, potentially making this pond suitable for salmonids year-round.

Pond 3

Pond 3 in Reach 2 is shaped in the geometry of a split side-channel with an island formed of unexcavated ground. The inlet for Pond 3 is located at Stations 35+75 and the outlet at 33+00. The outside perimeter of the pond will be graded to 3H:1V to form a scarp bank, and the island will be transitioned at a 10H:1V slope towards the pond to simulated an abandoned point bar.

Located upstream of the predicted location of the winter tidal intrusion front, the control weir elevations of Pond 3 were set at an elevation of 3.5 feet upstream and 2.8 feet downstream. The downstream weir is set lower to increase the contributing tidal prism for tidal flushing while the upstream weir is set higher to reduce the amount of sediment entering the pond from Salmon Creek. During the summer, this pond is expected to be saline.

Pond 4

Pond 4 in Reach 3 is shaped in the geometry of a split side-channel with an island formed of unexcavated ground. The inlet for Pond 4 is located at Stations 29+75 and the outlet at 27+50. The outside perimeter of the pond will be graded to a 3H:1V scarp bank and the island will be transitioned at a 10H:1V slope towards the pond to simulated an abandoned point bar.

Located upstream of the predicted location of the winter tidal intrusion front at MHHW, the control weir elevations of Pond 4 were set at an elevation of 3.0 feet upstream and 3.5 feet downstream. This weir configuration will maintain a deeper permanent pool and reduce the ability of saltwater from entering the pond. During the summer, this pond is expected to be saline.

Pond Habitat

Log Habitat Structures will be installed in all ponds to create complex overhangs and cover (Sheet 27, Appendix A). A minimum of 3 logs will be installed so that they intertwine, creating open space between the logs and the channel bottom. The open space under the logs will be stuffed with brush to create habitat complexity, multiple hiding spaces, and a wood source for the ponds. Additional logs and other woody material may be installed in the ponds depending on availability. The Log Habitat Structures in the ponds will be anchored in accordance with CDFG (1998), and as presented in Section 5.4.9.

Pond vegetation establishment and planting is addressed in Section 5.4.11.

5.4.9. Wood Features and Anchoring

Large wood features will be constructed within the proposed project area to provide cover, habitat complexity, and a source of nutrients. Several types of large wood features are proposed for the project area including Log Vanes in Reach 1, Log Pond Habitat Structures in Ponds 1-4, and the Log Step Pools and an Engineered Log Jam in the existing ditched channel. Specifications for the installation of the wood features are shown on the design plans (Sheet 27, Appendix A), and follow CDFG (1998) guidelines, except where indicated.

Specific design aspects of each log features are discussed in the report section that describes where the feature will be installed. The number of wood features and their complexity is governed by the amount of wood available for construction of the features. The Refuge has stockpiled a moderate quantity of large old growth redwood logs ranging from approximate 5 to 25 feet in length, and two to four feet in diameter. Additional wood may be available from other sources, but in very limited supplies. Therefore, the size, number and complexity of the wood structures proposed on the design plans are based on the wood currently stockpiled.

This section of the report presents the engineering aspects of the wood feature design, specifically anchoring the logs to maintain the logs firmly in the position in which they were placed. The two primary forces that may cause wood to move include buoyancy and impingement of higher flow velocities (NRCS, 2007). Both of these forces were evaluated for the types of wood features designed for Salmon Creek. Buoyant forces were computed assuming the entire log was submerged, conservatively using the dry density of old growth redwood. Forces resulting from flow velocities were computed assuming that the average channel velocity was acting perpendicularly on the largest area of the log. For both analyses, the downward force of soil overburden was conservatively neglected. Because of the location of the wood placement, the specific gravity of fresh water was used for the computations.

Computations for wood placed for the Salmon Creek project indicated that the buoyant forces acting on a structure are the most significant forces, and flow velocities generate negligible force on the structures. Therefore, anchoring for each structure was determined using the results of the buoyancy analysis. Anchor weight for each structure was determined by providing an anchor weight that is twice the total upward buoyant force of the entire wood structure, providing an anchoring factor of safety of 2.0.

Log anchoring to the ground to counteract all buoyant forces will consist of Log to Rock Anchoring. Cables attached to rebar installed through the log will be epoxied into anchor rocks. Approximate log dimensions and anchor weight are specified in the design plans for each structure type for the project (Sheets 26-29, Appendix A). During construction, a USFWS engineer will select the wood for the construction of each structure and compute the total anchor weight, as well as anchor weight per Log to Rock anchor. The final anchor weight and distribution of the anchoring will be dependent on the dimensions of the wood selected as well as how it is interconnected.

Log to Log anchoring will also be installed between any touching logs. This anchoring will consist of rebar installed through both logs and bolted in accordance with DFG (1998). The Log to Log anchoring is intended to maintain the logs firmly in the position they were placed and to ensure that the structure is fully tied together to resist buoyancy.

5.4.10. Overflow Marsh Enhancement

For tidal marsh restoration projects, PWA and Faber (2004) recommend placing material approximately one foot below the desired marsh plain elevation, which occurs near MHHW. Creating a surface at this elevation results in sinuous, high order tidal channel formation and elevations suitable for establishment of marsh plain vegetation.

After Phase 2 implementation, MHHW within Salmon Creek is expected to be approximately 4.7 feet. Material will be placed in the Overflow to create a marsh plain between 3 and 5 feet in elevation (Sheet 23, Appendix A). An eco-levee will connect the proposed marsh plain with the existing levees surrounding the Overflow Area.

The project will use excavated material from upstream reaches to raise existing mudflats within the Overflow Area to a suitable elevation to establish a marsh plain. In the Overflow, there is approximately 33 acres below elevation 3.0 feet that is currently mudflat and designated suitable for placement of material (Hatched area Sheet 13, Appendix A). Assuming that nearly 25 AF of material excavated from the channel and ponds are placed in the Overflow (See Section 6.1), up to 14 acres of new marsh can be created.

The actual area of marsh created will depend on the location, volume, and depth of material placed. As indicated on the design drawings, actual locations of material placement in the Overflow will be at the direction of the project engineer and appropriate USFWS staff to ensure that the proposed marsh plain has sufficient positive drainage and existing native marsh vegetation is undisturbed. Construction access and potentially soft ground will likely also limit the locations where material can be placed.

To provide flexibility in material placement location the design drawings designate all potential marsh creation areas, totaling 33 acres (Sheet 13, Appendix A). It is expected that materials will not be placed in some of designated areas because of existing native marsh vegetation, access or material limitations, or the desire of the Refuge to maintain open water or mudflat in some areas. It is the intent of USFWS to obtain a permit to place material within the available 33 acres of mudflat to allow flexibility in the location of material placement to avoid impacts to pockets of existing native salt marsh vegetation and to maintain open water features.

It is critical that a minimum of 15 AF of material be placed as specified within the Overflow. The inflow opening in the new tidegates can only allow a limited amount of saltwater into the project area during each tidal cycle. The placement of material will decrease the overall tidal prism in the Overflow, allowing a larger tidal prism within Salmon Creek, Reaches 1 through 6. This will ensures that the design MHHW elevation is achieved and that the desired tidal flux is established throughout the Refuge. As shown in Section 5.4.8, increasing the amount of material placement in the Overflow Area from 15 AF to 25 AF has negligible effects on MHHW elevation or location of saline waters within Salmon Creek.

Channel improvements are not proposed in the Overflow. The low ground elevation and complex channel patterns make construction access and dewatering extremely difficult. Substantial channel widening and deepening since completion of the Overflow tidegate in January 2008 indicate that the channel banks and bed in the Overflow are responding rapidly to the increased tidal prism resulting from Phase 1 of the project. It is expected that the tidal channels within the Overflow will adjust rapidly to accommodate the new tidal prism.

5.4.11. Bank Stabilization and Riparian Area Establishment

Notes and specifications for erosion control, site seeding, and planting are shown on Sheets 7 and 31 of the design plans and specifications in Appendix A.

Stabilization of Construction Access and Floodplain Areas

Areas disturbed by the project will be seeded and mulched with a seed mix approved by the Refuge. This seed mix will be a combination of annual grasses for rapid site stabilization, along with perennial herbaceous wetland seeds. Salvaged topsoil containing a native seed bank will be installed to finished grade along the Cattail Creek Berm, Eco-levee, and pond side slopes.

Channel Banks: Reach 1

The soils expected to form the banks of Reach 1 consist of the more erodible non-cohesive soils of the historical channel. To stabilize these soils, coconut soil stabilization matting will be installed from the toe of the streambank to the top of bank. A rapidly germinating seed mix will be used to obtain root strength within the bank material, and the area will be planting with live willow cuttings at 2-foot spacing. The willow cuttings are expected to rapidly develop a dense root mat for bank stabilization as well as provide riparian cover.

The proposed rock weirs and bioengineering are intended to supplement the channel bank strength to maintain stability. As indicated in Section 5.4.3, the proposed rock weirs were designed to remain stable during flood flows. Channel Shear stresses in the nearly 1% slope of Reach 1 range from 1 to 3 lbs/ft^2. Dense bioengineering and riparian plantings after establishment are stable under shear stresses up to 6 lbs/ft^2. (Schiechtl and Stern, 1994). Therefore, it is expected that the streambanks Reach 1 will remain stable.

At the meander bend where the new channel diverges from this historical channel, log vanes will be used to turn flows away from the outside of the meander bend. A willow brush mattress will be installed between the tops of the log vanes and the top of the streambank to provide streambank coverage and a quickly establishing dense root mat. The dense interweaving of the willow brush mattress will be able to withstand channel shear stresses of up to 6 lbs/ft^2 (Scheitl and Stern, 1994). Channel shear stresses in this area are less than 1 lbs/ft^2. Even accounting for additional shear stresses generated by the meander bend, the brush mattress is expected to maintain bank stability in this area. The willow brush mattress material and installation specifications are modified from CDFG (1998).

It is expected that USFWS will install a wider riparian area along the new channel using other funding sources and volunteers.

Channel Banks: Reaches 2, 3 and 5

The excavated streambanks banks in Reach 2 and 3 will be stabilized above tidal influence with live willow cuttings planted at 2-foot spacing. Because of the low shear channel stresses and expected higher cohesion of the streambanks, coconut matting soil stabilization will not be installed.

The excavated banks of Reach 5 will not be planted with live willow cuttings because of saline conditions. It is expected that the banks will rapidly colonize with *Sarcocornia virginica* and other native salt marsh plants, similar to the observed rapid recolonization of other disturbed tidal marsh areas within the Refuge.

Ponds

Salvaged topsoil will be placed on pond shoreline and banks to provide a seed bank of native wetland seed. Occasional willow thickets will be planted on the steeper pond banks to provide root strength to the soil, bank complexity, shade, and a wood source to the ponds. The more gentle side slope will be naturally colonized by native vegetation or vegetation planted by USFWS.

Overflow Area

Disturbed area of the existing levees and eco-levees will be seeded and mulched with a seed mix specified by USFWS. The constructed marsh plain of the Overflow Area will not be seeded. It is expected that the marsh plain will rapidly colonize with *Sarcocornia virginica* and other native salt marsh plants. The seed bank contained within the topsoil placed in the Overflow Area will also provide a revegetation source.

6. Construction and Permitting Issues

6.1. Earthwork

Table 6-1 summarizes total excavation volumes for the constructed channels and ponds. The proposed project will result in a total excavation volume of 48,135 CY, with material originating from the tidal channel and pond construction. Material needed to construct the Cattail Creek berm and channel bottom for the log step pools will require approximately 3,100 CY of clay material excavated and stockpiled during the channel construction. The net volume of excess material, consisting of approximately 45,035 CY or 28 AF can be used to enhance the Overflow area and for already permitted levee improvements within the Refuge.

Table 6-1. Summary by reach of excavation and fill volumes for the constructed channel, ponds, Cattail Creek Berm and Overflow area.

Location	Excavation Volume (CY)	Fill Volume (CY)
Reach 1	4,867	-
Pond 1	8,113	-
Pond 2	4,678	-
Reach 2	5,645	-
Pond 3	5,884	-
Reach 3	6,046	-
Pond 4	2,270	-
Reach 5	10,632	-
Cattail Creek Berm/Clay for Log Step Pools	-	3,100
Total	**48, 135 CY (30 AF)**	**3,100 CY**
Net	**45,035 CY (28 AF) Excess Material**	

6.2. Construction Access, Sequence, Water Management and Erosion Control

6.2.1. Construction Access

A Construction Access Plan for the project is shown on Sheet 4 of the design plans in Appendix A. Construction access will be from the paved Ranch Road along the eastern edge of the Refuge. The road is on the Refuge property at the access turnoff location. Construction access will be via existing gravel roadways on the Refuge levees. These existing levee roadways provide access to all portions of the Refuge and can be used in the future for maintenance of the project, if necessary.

The intent of the Construction Access Plan is to facilitate a one-way loop for the construction vehicles taking materials to the Overflow Area. Though not required, it is expected that the vehicles will travel from work areas along the levee to the north of the project area, to the Overflow Area. After disposing of materials in the Overflow Area, the vehicles will continue south around the Overflow Area, across the Salmon Creek Tidegate, First Diversion, and north along the west levee between the Upper and Middle Refuge. It is understood that the existing diversion structures and the Salmon Creek and Overflow Tidegates were designed and constructed for HS-20 loading, thus will be able to sustain the loading of construction vehicles.

To facilitate access to the Upper Refuge, a Temporary Ford will be installed in the existing ditch between the First and Middle Diversion. This ditch is dry during the summer, thus the Ford will not block stream flow. The Ford will be removed at the end of the construction season.

Construction access into the work area is limited by the Limit of Disturbance (LOD). The LOD was established to minimize disturbance to existing vegetation, avoid high quality habitat, and to provide the contractor with sufficient space to move equipment and materials.

6.2.2. Sequence of Construction

The Sequence of Construction for the project is shown on Sheet 5 of the design plans (Appendix A). The Sequence of Construction is broken into eight phases, each of which details the limits of work, methods of water management, and order of activities for each phase. Because of the volume of excavation, it is expected that the proposed project may need to be constructed during the summer months over a two-year period. Construction will proceed from downstream to upstream, beginning in Reach 5. The phasing of the construction is as follows:

• Phase 1	Reach 5 in off-channel conditions
• Phase 2	Live channel portion in the downstream limits of Reach 3
• Phase 3	Upstream portion of Reach 3 in off-channel conditions
• Phase 4	Water Control/Fish Passage Structure in off-channel conditions
• Phase 5	Reach 2 in off-channel conditions
• Phase 6	Reach 1 in off-channel conditions
• Phase 7	Log step pools and ELJ in Exiting Ditched Chanel in isolated conditions
• Phase 8	Levee removal (Upland)

The sequence of construction was phased to facilitate construction access, water management, erosion and sediment control, handling of materials, and impacts to natural resources. Constructing the project from downstream to upstream will expand the limit of tidal influence upstream into the Refuge without affecting the construction of the upstream components of the project. Constructing the downstream reaches will also facilitate dewatering during construction of the upstream reaches. This will occur because the constructed channel will be much lower in elevation than the existing channel, allowing gravity drainage during construction of the upstream work areas.

To ensure that the construction activities do not affect any threatened or endangered aquatic species, the Sequence of Construction addresses fish removal for each construction phase.

6.2.3. Erosion and Sediment Control

Erosion and Sediment Control for the project, including water management, will be in accordance with California Stormwater Quality Association Stormwater Best Management Practice Handbook for Construction, 2003 (WQCB, 2003). Specific sections of the manual are referenced in the design drawings for the erosion and sediment control measures and other construction practices expected to be implemented at Salmon Creek. Additionally, General Notes on the Erosion and Sediment Control Sheet of the design drawings (Sheet 7, Appendix A) specify additional measures.

A water management plan and notes for the project are shown on Sheets 6 and 8 of the design plans in Appendix A. Construction is expected to occur during the summer months when there is very little freshwater flowing in Salmon Creek. Additionally, the Refuge will close the adjustable openings in the Salmon Creek and Overflow Tidegates to eliminate tidal inflows into the project area. Freshwater will still be able to drain out of the tidegates. As indicated in Section 6.2.2, the Sequence of Construction will proceed from downstream to upstream, and baseflow in Salmon Creek will remain within the existing channel until later phases of construction.

Most of the project area construction will occur in off-channel conditions because of construction phasing and most of the improvements are along new channel realignments. Water management and erosion and sediment control in off-channel work areas will consist of isolation from the existing channels by retaining earthen berms of existing material that will serve as earth dikes to isolate the work area from the active stream channel. After construction off-channel occurs, the new channels and ponds will be connected to the exiting channel using Filter Fabric Isolation methods.

Though construction will occur off-channel, it is expected that dewatering of work areas will be necessary because of groundwater conditions. The design plans present methods for dewatering the channel that include pumping of the work area and discharge of the pumped water onto the flat fields of the Refuge away from the work area. Velocity dissipaters at the pump outfall will prevent erosion of the ground.

Reach 3 will be constructed within a live channel. As requested by USFWS, the proposed channel was moved further north than shown on the 30% plans. The intent of the channel movement was to be able to dewater the work area by maintaining the streamflow in the existing channel and constructing the new channel along-side the existing channel. A low berm of existing material will be retained to maintain flow in the existing channel during construction (Typical Section C, Sheet 22, Appendix A). Flows will be diverted into the newly constructed downstream channel. The elevation of the existing channel is approximately 4.5 feet; therefore, the wide top of bank width of this reach of channel will not substantially affect the design tidal prism.

Though it will be constructed in off-channel conditions, Reach 1 may present a dewatering challenge during construction. The geologic investigation conducted in January 2009 (Pacific Watershed Associates, 2009) identified an exceptional amount of groundwater in the channel. It is unknown whether this channel is connected to the regional groundwater table or if the historical channel within the limits of the trenching was storing groundwater. Excavation of Reach 1 will occur during the summer when groundwater conditions are expected to be lower than encountered during the

January trenching. However, because actual groundwater conditions are uncertain, the construction documents provide detailed specifications on dewatering measures for Reach 1. Isolation of the work area using native earthen berms and pumped dewatering is specified. High capacity pumps may be necessary to dewater the work area. If high groundwater elevations or flow volumes cannot be managed with pumps, sheet pile cofferdams are specified within the limits of the historical channel upstream and downstream of Reach 1. The cofferdams are specified to be 60 feet wide to span the width of the historical channel, and will be installed to an elevation of -3.0, below the expected bottom elevation of the historical channel. The cofferdams will prevent groundwater from flowing into the isolated work area and facilitating dewatering. The construction cost estimate for water management for the project area reflects the potential difficulty of water management expected.

Streamflow will need to be diverted for the construction of the Log Step Pools and ELJ in the existing ditched channel. To isolate this work area, an earth berm is specified to divert streamflow from Salmon Creek into the constructed Reach 1 channel.

6.3. Implementation Cost Estimate

An implementation cost estimate is presented in Appendix E. The cost estimate includes line items with quantities, unit costs and total costs or a lump sum price for each activity that is anticipated during construction. The implementation cost for the project was based on quantities measured from the construction drawings and from material and installation costs from bid tabulations of other recent and similar projects. Prices were adjusted based on anticipated level of difficulty of implementation and length of haul. The construction cost estimate for dewatering considers the higher costs of high volume pumps that may be necessary for dewatering of Reach 1.

The implementation cost estimate has a separate section listing quantities and costs for the principal materials necessary for the project. The cost of installing the principal materials is itemized, separated under the Construction section of the cost estimate. USFWS currently has funding to purchase all or a portion of the primary materials necessary for project implementation and may purchase these materials before the commencement of construction. Therefore, they were broken out separately in the cost estimate to facilitate this purchase. Additional materials will be needed for project implementation, such as anchoring for the log structures and other incidentals that USFWS will not provide. Costs for these materials were incorporated into the installation cost for the relevant item.

A contingent item is included for additional excavation that may be necessary to obtain stable side slopes in Reach 1 or to install additional rock in the grade control structures.

The final details of bidding and payment for implementation will be determined between the 90% and 100% design phase.

7. References

ACOE. 2000. Technical Reference Manual: Hydrologic Modeling System (HEC-HMS).

Blackwell, C.N., C.R. Picard, and M. Foy. 1999. Smolt Productivity of Off-channel Habitat in the Chilliwack River Watershed, Watershed Restoration Project Report No. 14. Watershed Restoration Program Ministry of Environment, Lands and Parks and Ministry of Forests.

CEC. 2009. The Future is Now: An Update on Climate Change Science Impacts and Response Options for California. CEC-500-2008-071. California Climate Change Center. May 2009. 114 pages.

CDFG. 2009. Fish Passage Design and Implementation. Part XI in Salmonid Stream Habitat Restoration Manual 3rd edition. California Department of Fish and Game.

CDFG. 2002. Culvert criteria for fish passage. Appendix A in California Salmonid Stream Habitat Restoration Manual 3rd edition. California Department of Fish and Game.

CDFG. 1998. California Salmonid Stream Habitat Restoration Manual. California Department of Fish and Game.

CGS. 2003. California Rainfall and Runoff CD. California Geologic Survey.

Coats, R.N., P.B. Williams, C.K. Cuffe, J.B. Zedler, and D. Reed. 1995. Design Guidelines for Tidal Channels in Coastal Wetlands. Prepared for U.S. Army Corps of Engineers, Waterways Experiment Station by Philip Williams & Associates, Ltd.

Henning, J. A., R. E. Gresswell, and I. A. Fleming. 2006. Juvenile Salmonid Use of Freshwater Emergent Wetlands in the Floodplain and Its Implications for Conservation Management. North American Journal of Fisheries Management 26:367–376.

Laird, Aldaron. 2008. Historic Atlas of Humboldt Bay and Eel River Delta. Prepared for the Humboldt Bay Harbor, Recreation, and Conservation District (HBHRCD) and California Department of Fish and Game (CDFG).

Laird, Aldaron. November 2005. Salmon Creek Anadromous Salmonid Access, Tide Water Habitat Enhancement and Flood Control Maintenance Projects: Environmental Assessment, November 2005.

Laird, Aldaron. November 2005. Salmon Creek Anadromous Salmonid Access, Tide Water Habitat Enhancement and Flood Control Maintenance Projects: Biological Assessment, November 2005.

Largier, J.L. 1992. Tidal Intrusion Fronts. Estuaries 15(1).

Miller, B.A., and S. Sadro. 2003. Residence Time and Seasonal Movements of Juvenile Coho Salmon in the Ecotone and Lower Estuary of Winchester Creek, South Slough, Oregon. Transactions of the American Fisheries Society 132:546-559.

Montgomery, D.R. and Buffington J.M. 1993. Channel classification, prediction of channel response, and assessment of channel condition. Report TFW-SH10-93-002. WA State Timber/Fish/Wildlife Agreement.

NMFS. 2001. Guidelines for salmonid passage at stream crossings. NOAA Fisheries, NMFS SW Region.

NRCS. 2007. National Engineering Field Handbook, Technical Supplement 14J - Use of Large Woody Material for Habitat and Bank Protection. U.S. Department Of Agriculture, Natural Resources.

NRCS. 2004. National Engineering Field Handbook, Part 630 Hydrology, Chapter 10 - Estimation of Direct Runoff from Storm Rainfall. U.S. Department Of Agriculture, Natural Resources. Conservation Service.

Pacific Watershed Associates. 2009. Geologic Investigation of Upper Salmon Creek Estuarine Enhancement Project.

PCFWWRA, 2003. Lower Salmon Creek Delta Salmonid Habitat Enhancement Opportunities.

Philip Williams and Associates, and P.M. Faber. 2004. Design Guidelines for Tidal Wetland Restoration in San Francisco Bay. Prepared for The Bay Institute and California State Coastal Conservancy by Philip Williams & Associates, Oakland, CA.

PRISM 2007. *Parameter-elevation Regressions on Independent Slopes Model.* Oregon State University.

Roni, P., S. A. Morley, P. Garcia, C. Detrick, D. King, and E. Beamer. 2006. Coho Salmon Smolt Production from Constructed and Natural Floodplain Habitats. Transactions of the American Fisheries Society 135:1398-1408.

Schiechtl, H.M. and R. Stern. 1996. *Water Bioengineering Techniques for Watercourses, Bank and Shoreline Protection.* Blackwell Science Ltd., Cambridge, Massachusetts, 86 pages.

SCS. 1965. Soils of Western Humboldt County, Agricultural Soil Survey Conducted by the Soil Conservation Services For Humboldt County. Soil Conservation Services.

Stillwater Sciences. 1997. A review of coho salmon life history to assess potential limiting factors and the implications of historical removal of large woody debris in coastal Mendocino County.

WQCB. 2003. California Stormwater Quality Association Stormwater Best Management Practice Handbook for Construction, 2003. California Stormwater Quality Association. http://www.cabmphandbooks.com.

Williams, P.B., M.K. Orr, and N.J. Garrity.2002. Hydraulic Geometry: A Geomorphic Tool for Tidal Marsh Channel Evolution in Wetland Restoration Projects. Restoration Ecology 10(3):577-590.

U.C. Davis. 1965. Soils of Western Humboldt County California, Sheet 14, Loleta. . University of California Davis Dept. of Soils and Plant Nutrition.

USGS. 1982. Guidelines for determining flood flow frequency. Bulletin #17B of the Hydrology Subcommittee. Geological Survey, Virginia.

Appendix A
90% Submittal Design Drawings

Appendix B

Technical Memorandum: Salmon Creek Phase 2 Habitat Enhancement Preliminary Conceptual Design

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Sent via email

Technical Memorandum

DATE: July 28, 2008

To: Technical Advisory Committee Members for the Salmon Creek Phase 2 Habitat Enhancement Project

From: Michael Love P.E., Principal Engineer, Michael Love & Associates
mlove@h2odesigns.com / ph: 707-476-8938 / fax: 707-476-8936

Subject: Salmon Creek Phase 2 Planning Project – Background, summary of preliminary conceptual design, and proposed analyses to further inform design development and refinement.

Purpose

The purpose of this Technical Memorandum is to provide members of the Salmon Creek Phase 2 Planning Project Technical Advisory Committee (TAC) a brief overview of the project background and goals and objectives, followed by a description of the preliminary conceptual design developed by the project design team. The first TAC meeting is scheduled for August 1st, 2008 starting at 2:00 PM at the Humboldt Bay National Wildlife Refuge (HBNWR). This memorandum is intended to provide TAC members background information and project understanding to better facilitate discussion at the upcoming meeting.

Project Background

In 2001 California Department of Fish and Game (DFG) funded Pacific Coast Fish Wildlife and Wetlands Restoration Association (PCFWWRA) to evaluate existing conditions and develop an overall plan for the HBNWR to improve fish access to Salmon Creek and fisheries habitat within the Refuge. Michael Love & Associates (MLA) and Graham Matthews & Associates prepared the report for PCFWWRA, *Lower Salmon Creek Delta Salmonid Habitat Enhancement Opportunities* (PCFWWRA, 2003). The report characterized current conditions and limiting factors for salmonid production on the Refuge and developed three alternative restoration approaches. The intent of the proposed alternatives strived to create a self sustaining estuarine system while working within the current physical constraints imposed by the land use objectives of the Refuge, upstream land owners and transportation infrastructure. The HBNWR selected Alternative B (near-term alternative) and choose to design and implement the project in two phases.

Implementation of Phase 1, funded by US Fish and Wildlife Service (USFWS) and DFG, is nearing completion. Engineering design and environmental permitting of Phase 2 is currently funded by USFWS and the DFG Fisheries Grants Program. Preliminary design for Phase 2 began in early

2008. MLA is providing project engineering and Aldaron Laird is serving as environmental planner. Pacific Watershed Associates will be characterizing geomorphic stability of the upstream channel reach and its likely response to the proposed project.

The preferred alternative included the following elements, shown in ATTACHMENT 1.

Phase 1 Components (Completed)

Install Two Tide Gates. Replace the existing Salmon Creek tide gate (East Gate) and construct a new tide gate further towards the west (West Gate). The new tide gates triple outflow capacity and include adjustable openings that permit seawater to flow into lower Salmon Creek. The openings enlarge the muted tidal prism within the Salmon Creek estuary from 35 acre-ft to approximately 135 acre-feet (tidal flux measured between MLLW and MHHW). The openings in the tide gates were designed to increase MHHW in the Salmon Creek estuary from approximately 3.0 feet (as measured in 2002) to an elevation of 4.8 feet (NAVD 88). The increased tidal prism serves to alleviate in-channel sedimentation through daily tidal flushing and channel enlargement. The increased outflow capacity drains stored floodwaters more rapidly, increasing stream power and reducing sedimentation within the Refuge. The new tide gates also provide unimpeded fish passage. The West Gate was completed December 2007 and the East Gate is under construction. Following completion of the West Gate, one of the three doors on the existing East Gate was permanently opened to further increase tidal inflow.

Removal of High-Point in Channel. A high point in the lower channel identified in the 2003 report and referred to as the knick-point, functioned as a hydraulic control that limited upstream tidal influence. The channel knick-point, composed of material resistant to erosion, was excavated in 2006 to increase upstream tidal influence and promote channel downcutting and enlargement. The location of the knick-point coincided with where the downstream end of a channel constructed by the Refuge in 1994 tied into an existing channel.

Connect Off-Channel Ponds to Salmon Creek. The 2003 report identified opportunities to increase connectivity between the Salmon Creek channel and off-channel ponds. Small connection channels were excavated in 2006 to make these ponds an active component of the estuary and contribute to the overall tidal prism. The pond connections were intended to allow juvenile salmonids access to suitable off-channel rearing habitat during winter flows (freshwater habitat) and provide aquatic marine species access during summer low flows when the ponds and channel are more saline.

Replace Two Tide Gates on Tidal Channels in Hookton Slough. Two existing tide gates on small drainage channels to Hookton Slough were replaced in 2006. The new tide gates allow a small muted tide inside of the levees to create estuarine habitat and promote sediment flushing. The new gates also allow fish access and eliminate stranding potential for adult and juvenile salmonids that arises during larger over-bank flow events in Salmon Creek.

The Environmental Assessment (Laird, 2005) and Biological Assessment (Laird, 2006) provides detailed descriptions for Phase 1 of the project.

Phase 2 Components

Relocate Salmon Creek within the Upper Refuge. The upper reach of Salmon Creek on the Refuge will be realigned out of the existing ditch to improve geomorphic function and habitat diversity. The reconstructed channel will be designed to function as part of the upper estuarine ecotone; tidally influenced but predominately freshwater during the wet season and brackish during the dry season. Dimensions of the new channel will allow for conveyance of the daily tidal flux and frequently occurring high storm flow events and associated sediment load. The new channel design will strive to improve connectivity with the floodplain and off-channel ponds while reducing the risk of fish stranding. The design will allow the channel to evolve with time through geomorphic processes, including lateral channel migration, avulsion and formation of new side channels, formation of emergent wetlands, and creation of new off-channel habitats.

A potential ancillary benefit of the realigned channel is to improve sediment transport and initiate channel degradation and enlargement within the channel reach upstream of the Refuge, which frequently floods out of bank. The improvements on the Refuge are expected decrease the frequency of overbank flows and risk of channel avulsion in the channel reach upstream of the Refuge. If characterization of the upstream channel reach indicates that the rate of channel degradation and resulting sediment release will be problematic, measures can be incorporated into the design to slow the adjustment.

Construct Off-Channel Habitat within the Upper Refuge. Creation of new, tidally influenced off-channel ponds in the upper refuge will provide freshwater rearing habitat for salmonids during the wet season and become brackish during the dry season. The ponds will be constructed to mimic the form and function of naturally occurring ponds and overflow channels typically found in low-gradient channels. The pond outlets will be graded to maintain minimum water depths during low tide and aid in reducing introduction of saline water during winter baseflow conditions. The ponds will be designed with the anticipation that smaller order channels and marshes will form within them through erosion and sedimentation.

Construct Side-Channel within the Middle Refuge. A side-channel in the middle portion of the Refuge will be constructed to increase conveyance of the tidal prism to the Upper Refuge, which will also improve routing of floodwaters and sediment. A clay layer may underlie the existing channel upstream of the removed knick-point, preventing it from self-adjusting vertically in response to the increased tidal prism. The new side channel can serve as the primary tidal channel rather than relying on self-adjustment of the existing channel.

Raise Subsided Lands in Overflow. A portion of the spoils generated from excavation of the channels and ponds will be used to raise the ground elevation within parts of the Overflow to elevations suitable for sustaining native salt marsh vegetation, specifically the *Salicornia virginica* vegetation complex. The Overflow has experienced several feet of subsidence since it was diked and drained. As a result, much of the area is too low to sustain salt marsh vegetation with the increased muted tide.

Develop Water Diversion Strategy. A new screened water diversion was originally included as part of Phase 2, but was recently removed from the project. Rather, the existing diversion ditch will be temporarily blocked as part of Phase 2. Design of the new diversion facility and fish screen will be postponed until after the Phase 2 channel improvements are implemented and the channel is fully functioning. As part of Phase 2 potential diversion strategies will be evaluate for the HBNWR and recommendations will be provided. Recommendations will address potential diversion locations, division rates and bypass flows.

Post Phase 1 Monitoring

Both physical and biological monitoring have been conducted before and after implementation of Phase 1 to improve our understanding of the system's response to the changes in tidal conditions. Information gained through this ongoing monitoring continues to inform the design of Phase 2 and adaptive management decisions.

Tidal Stage Monitoring (USFWS)

USFWS has installed four continuous water level and temperature recorders. They are located inside and outside the West Gate and at cross sections (XS) 1 and 6 (XS locations shown in ATTACHMENT 3). The stage monitors were installed in October 2007, prior to construction of the West Gate, and monitoring continues to date. The monitoring indicates that since completion of the West Gate and removal of one of the doors from the existing East Gate the water surface inside the levees is reaching about 4.8 feet when the tide at Hookton Slough reaches MHHW (6.24 feet NAVD88). XS 6 experiences full tidal influence during both low and high flows. Tidal influence is not observed at XS 1. Additional results from this monitoring will be presented at the TAC meeting.

Monitoring of Salinity, Temperature, and Dissolved Oxygen

Prior to Phase 1 implementation, fully saline conditions extended slightly upstream of the knickpoint area, between XS's 6 and 7 in early September (PCFWWRA, 2003). In July 2008, during a mean lower high water tide (MLHW), brackish conditions extended to over 400 feet upstream of XS 5, suggesting that during higher tides brackish conditions extend to near XS 4 and the First Diversion.

On July 10th 2008 during an incoming tide, salinity, water temperature and dissolved oxygen was measured at the surface and 2 feet below the surface at five locations between the East Gate and the First Diversion. Salinity measurements found stratification between salt and freshwater occurring throughout much of the channel, including at XS 11 near the East Gate. Temperature of the slightly brackish and freshwater on the surface water was considerably lower (16.9^0 C to 17.4^0 C) then the highly saline water (19.1^0 C to $23.2\ ^0$ C) measured two feet below the surface. Dissolved oxygen of the saline water was relatively high near the East Gate, likely due to good circulation. However, saline water measured 2 feet below the surface at XS 10, XS 7, and XS 6 was only between 2.2 mg/l and 3.4 mg/l, likely explained by decreased tidal circulation in the upstream portions of the channel. The freshwater contained dissolved oxygen levels above 7 mg/l. Both temperature and dissolved oxygen levels within the freshwater and brackish surface water were within suitable ranges for supporting salmonids.

Channel Adjustments after Phase 1 Implementation

In July 2008 MLA resurveyed 14 monumented cross sections located throughout the Refuge and established in 2006 (locations shown in ATTACHMENT 3). Un-monumented cross sections were surveyed in 2002. ATTACHMENT 2 illustrates the channel thalweg profile created from the 2002 cross section survey, with the 2006 and 2008 surveyed channel inverts shown.

Comparison between the 2006 and 2008 cross sections show the tidal channels in the Overflow (XS 12 and XS 13) have widened and deepened. Cross sections in the Middle Refuge (XS 4 through XS 11) showed minor widening but little vertical adjustment. Tension cracks and slumping on the banks indicate the onset of the enlargement process. Trends in XS 1 through XS 3 are less evident.

Additional information from the cross section surveys, including cross section plots, will be available at the TAC meeting for review.

Biological Monitoring

Mike Wallace, fisheries biologist with DFG has been conducting fish sampling at several locations in Salmon Creek and Hookton Slough since 2006. He will present some of his findings to-date at the upcoming TAC meeting.

Andrea Pickart, botanist with USFWS, conducted vegetation mapping of the project area prior to implementing Phase 1, and she plans to resurvey the vegetation in the near future to document vegetation changes.

Phase 2 Preliminary Conceptual Design

The preliminary conceptual design is schematically described in ATTACHEMENT 3. ATTACHMENT 4 presents a profile of the proposed channel invert in the project area. TABLE 1 summarizes total excavation volumes for the constructed channels and ponds, and anticipated sediment yields resulting from channel self-adjustment.

Tidal Channel Design Approach

Dimensions of the new channel in the Upper Refuge and the new side-channel in the Middle Refuge were designed based on hydraulic geometry relationships for tidal channels, which are summarized in Williams & Orr, 2002. Additional information is available in Coats and Williams 1995 and PWA 2004. A series of three regression equations were used that relate the contributing tidal prism (defined as the tidal flux between MHHW and MLLW) to the channel cross sectional area, top width, and channel depth below MHHW. Constructed reaches were sized based on equilibrium conditions, which is a function of the contributing tidal prism. Cross section shape of constructed channels was assumed to be trapezoidal with side slopes of 2H:1V. Some reaches within the project area are to enlarge through self-adjustment until reaching equilibrium conditions. It is expected that channel self-adjustment will also occur in the Overflow.

For preliminary design, it is assumed that tidal flux within the project area will govern hydraulic geometry of the channel rather than less frequent high flow events from upstream. Following the TAC meeting the hydraulic conveyance of these channels during large flow events will be evaluated and the design will be refined base on the results.

Proposed Channels and Ponds

Salmon Creek within the Refuge Boundary was divided into six reaches.

Reach 1

Reach 1 is a transition reach between the upstream channel located on the adjoining property and the first constructed pond. The proposed channel alignment in this reach matches the historical location of the Salmon Creek, as seen in the 1890 mapping and clearly visible in the 1945 aerial photograph (Laird, 2008). Placing Reach 1 in the historical channel location is intended to avoid cohesive soils (i.e. clays) that may impede vertical channel adjustments. Prior to diking and draining, this reach of channel up to the Hookton Road Bridge was a large tidal channel flanked by salt marsh. It is reasonable to assume that the invert of the historical channel in this location was below MLLW.

The channel invert at the downstream end of the 500-foot reach is placed at -0.3 feet (NAVD88), which is the equilibrium tidal channel elevation at the outlets of the upper two ponds in Reach 2. The upstream end of the Reach 1 ties into the existing channel elevation of 3.9 feet (NAVD88) at the property boundary. This produces a channel slope of 0.84%, which is uncharacteristically steep. The final design of this reach is dependent on findings from the geomorphic characterization of the upstream channel to be conducted by Pacific Watershed Associates. If necessary, temporary grade control can be included in Reach 1 to slow upstream channel adjustments.

At the Refuge boundary the existing channel will be blocked, or plugged, thus converting this section of existing channel into a backwater channel. The crest of the plug will be placed slightly lower than the top of bank, allowing water to enter into the backwater channel at high flows before going overbank. Design elevation and other features of the plug will be determined through hydraulic analysis.

Reach 2

Reach 2 is 1,750 feet in length and contains four ponds placed near the upper extent of tidal influence. These ponds will contribute to the overall tidal prism and are important in maintaining Reach 2 as a tidal channel. Due to concerns about sediment deposition, the proposed ponds are not located in-line with the channel. The pond designs simulate meander cutoffs and remnant channel scars. Circulation through the ponds will occur from backwater effects and with overbank flows from upstream. Freshwater conveyed in the channel during the wet season is expected to keep Reach 2 and the adjoining ponds fresh, and provide low velocity, freshwater winter rearing habitat for salmonids. A simplified mass balance analysis will be used to estimate the extent of the salinity wedge at winter base flow, to help ensure the reach will not become excessively brackish during winter base flow. Pond depth and hydraulic control elevations will be established based on hydraulic analysis to meet specific objectives, including maintaining a minimum water depth in the ponds at low tide low-flow, needed volume of tidal prism, and other aquatic and avian habitat objectives.

To minimize issues concerning stranding of salmonids during high flow events, the existing diversion ditch to Cattail Creek will be plugged where Reach 2 crosses it, with the understanding that this may be come the future water diversion point. Additionally, a small vegetated berm will be placed along the south side of the Cattail Creek ditch to prevent frequently occurring overbank flow from entering the ditch, which is presumed to cause fish stranding. The two existing freshwater ponds located in the Upper Refuge that receive water from overbank flows will be connected to the new Salmon Creek Channel to decrease stranding potential and increase habitat diversity.

Reach 3

Reach 3 is 300 feet in length and is part of the existing channel that was constructed by the Refuge in 1994. Through excavation, the existing channel in this reach will be widened and deepened to the predicted equilibrium configuration. This will require dewatering this reach and disturbing some of the existing riparian alder forest during construction.

The existing channel invert elevation in this reach is nearly 3 feet higher than predicted for post Phase 2 tidal equilibrium conditions. Allowing Reach 3 to self-adjust was considered to involve excessive uncertainty and risk. We suspect the resistant material that formed the knick-point further downstream may also underlie the channel bed in Reach 3 (and portions of Reach 4). This is suggested by comparing the 2008 resurveyed cross sections to the 2006 cross sections, which shows that in response to the recently increased tidal prism, the channel is widening but not deepening, as expected. If left to self-adjust, this reach could become a long-term hydraulic constriction, inhibiting tidal inflow into Reach 2 and conveyance of higher streamflows and associated sediment loads from upstream to downstream.

Reach 4

Reach 4 is 2,100 feet in length and part of the existing Salmon Creek channel. This channel is expected to widen and deepen through self-adjustment in response to the increased tidal prism. The upper half of the reach is part of the channel constructed by the Refuge in 1994. Like Reach 3, this section of Reach 4 is suspected of lying over a less erosive soil layer. Consequently, it is expected to widen much more rapidly than it deepens. Even though the upper portion of Reach 4 may take some time to self-adjust to equilibrium conditions, the proposed side channel (Reach 5) will provide hydraulic conveyance between the upstream and downstream reaches.

Reach 5

Reach 5 is a newly constructed 1,550-foot long side channel paralleling Reach 4, splitting the tidal prism between the channels. The downstream portion of Reach 5 is located in an existing channel, which was originally constructed by ranchers as a drainage channel. From the upstream end of this drainage channel Reach 5 crosses through an open field before rejoining the existing channel at the downstream end of Reach 3.

Reach 6

No channel improvements are proposed in Reach 6. Over time, Reach 6 is expected to widen through self-adjustment from approximately 48 feet to 75 feet wide. The existing channel invert is already at the equilibrium depth (same as the invert elevation of the tide gates).

Overflow Area

A portion of the excavated material from the project will be used to raise subsided lands in the Overflow area to an elevation suitable for sustaining salt marsh vegetation, specifically the *Salicornia virginica* vegetation complex. Currently, within the 53-acre Overflow area there are 34 acres below elevation 3-feet and 7 acres below elevation 2-feet. Nearly all of this area consists of un-vegetated mudflats. Philip Williams & Associates (2004) recommends placing fill approximately 1 foot below the desired marsh plain elevation, which occurs near MHHW. Placing fill at this elevation results in sinuous, high order tidal channel formation and elevations suitable for establishment of marsh plain vegetation. For muted tidal systems, it may be necessary to place fill at a slightly higher elevation than 1 foot below MHHW, depending on the duration of tidal inundation.

TABLE 1 - Summary by reach of excavation volumes for the constructed channel and anticipated sediment yields resulting from channel self-adjustment.

Reach	Excavation Volume (CY)	Sediment Yield from Self-Adjustment (CY)
1	6,000	-
2	16,000	-
New Ponds	6,500	-
3	2,000	-
4	-	6,000
5	10,000	-
6	-	5,000
Total (CY)	**36,500 (23 acre-feet)**	**11,000**

Approximately 15 acre-feet of the 23 acre-feet of material excavated from the proposed channels and ponds will be used to raise ground elevation throughout portions of the Overflow. The following is to give a general idea of the area that could be raised to the desired elevation for salt marsh vegetation using 15 acre-feet of fill material. Assuming the fill is placed on a gentle slope with an average depth of 1.5 feet, approximately 10 acres of the Overflow can be raised to the desired elevation for establishment of salt marsh in areas currently consisting of mud flats. Fill locations, elevations and suitable soil types will be established with assistance from USFWS botanists. Construction access will likely limit the locations where fill can be placed in the Overflow.

Decreasing tidal storage volume in the Overflow area also ensure that the design MHHW elevation is achieved and that the desired tidal flux is established throughout the Refuge. The new tide gates were designed to allow a specific amount of tidal water into the Salmon Creek estuary. Enlarging the overall tidal storage volume within the project area beyond the inflow capacity of the new tide gates will decrease the elevation of MHHW in the project area. Decreases from the design MHHW elevation would affect the extent and benefits of the tidal influence in the middle and upper areas of the Refuge.

Design Refinement

Pond-Storage Routing Model

A pond-storage routing model was developed to evaluate proposed water surface elevations inside of the new tide gates relative to tidal conditions in Hookton Slough. The model was developed to compare tidal elevations inside the tide gates after implementation of Phases 1 and 2. Stage-storage rating tables were developed for both post-Phase 1 conditions and post-Phase 2 equilibrium conditions. The model used a "design" tide cycle in Hookton Slough and an assumed baseflow of 1 cfs for Salmon Creek. Phase 2, as proposed, results in a slight increase in the overall tidal storage volume within the Refuge, which influences the behavior of the muted tide. Results, as shown in ATTACHMENT 5, indicate that the increased tidal prism as part of Phase 2 causes the MHHW inside the tide gates to decrease 0.10 feet, from elevation 4.8 feet to 4.7 feet (NAVD88). This was considered an acceptable decrease in elevation of MHHW in the Salmon Creek estuary.

HEC-RAS Modeling

HEC-RAS is an open channel hydraulic model that can be run for steady or varying flows (unsteady flow). Unlike the Pond-Storage Routing Model, unsteady flow simulations in HEC-RAS model performs actual routing of flows through the channels. It also provides water surface slopes, water depths, and water velocities at locations throughout the channel throughout various tidal and stream flow conditions. A HEC-RAS model of the Phase 2 improvements will be developed and used to refine the preliminary design. Results will assist in evaluating channel capacity during high streamflow events, channel velocities, areas of potential scour or sedimentation, establishment of the proposed pond outlet control elevations and depths, identify elevations for vegetation establishment, and design of the existing channel plug at the Refuge boundary. The results of the HC-RAS modeling will also be used in computations to predict the location of the freshwater/saltwater interface during winter baseflows. The HEC-RAS model will be run to simulate unsteady flow conditions for proposed conditions during summer baseflow and during a 2-year storm event. The HEC-RAS modeling effort is planned to begin following agreement by the TAC on the Phase 2 project direction, put prior to submittal of the 30% design plans.

Next Steps

Following comments received by the TAC, the design team will continue to refine the project design based on findings from the upcoming geomorphic characterization of the upstream channel and through additional analysis (i.e. HEC-RAS results). Once completed, schematic plans (30% Design) of the preliminary design will be prepared, along with a brief memorandum.

References

Laird, Aldaron. 2008. Historic Atlas of Humboldt Bay and Eel River Delta. Prepared for the Humboldt Bay Harbor, Recreation, and Conservation District (HBHRCD) and California Department of Fish and Game (CDFG).

Laird, Aldaron. November 2005. Salmon Creek Anadromous Salmonid Access, Tide Water Habitat Enhancement and Flood Control Maintenance Projects: Environmental Assessment, November 2005.

Laird, Aldaron. November 2005. Salmon Creek Anadromous Salmonid Access, Tide Water Habitat Enhancement and Flood Control Maintenance Projects: Biological Assessment, November 2005.

Montgomery, D.R. and Buffington J.M. 1993. Channel classification, prediction of channel response, and assessment of channel condition. Report TFW-SH10-93-002. WA State Timber/Fish/Wildlife Agreement.

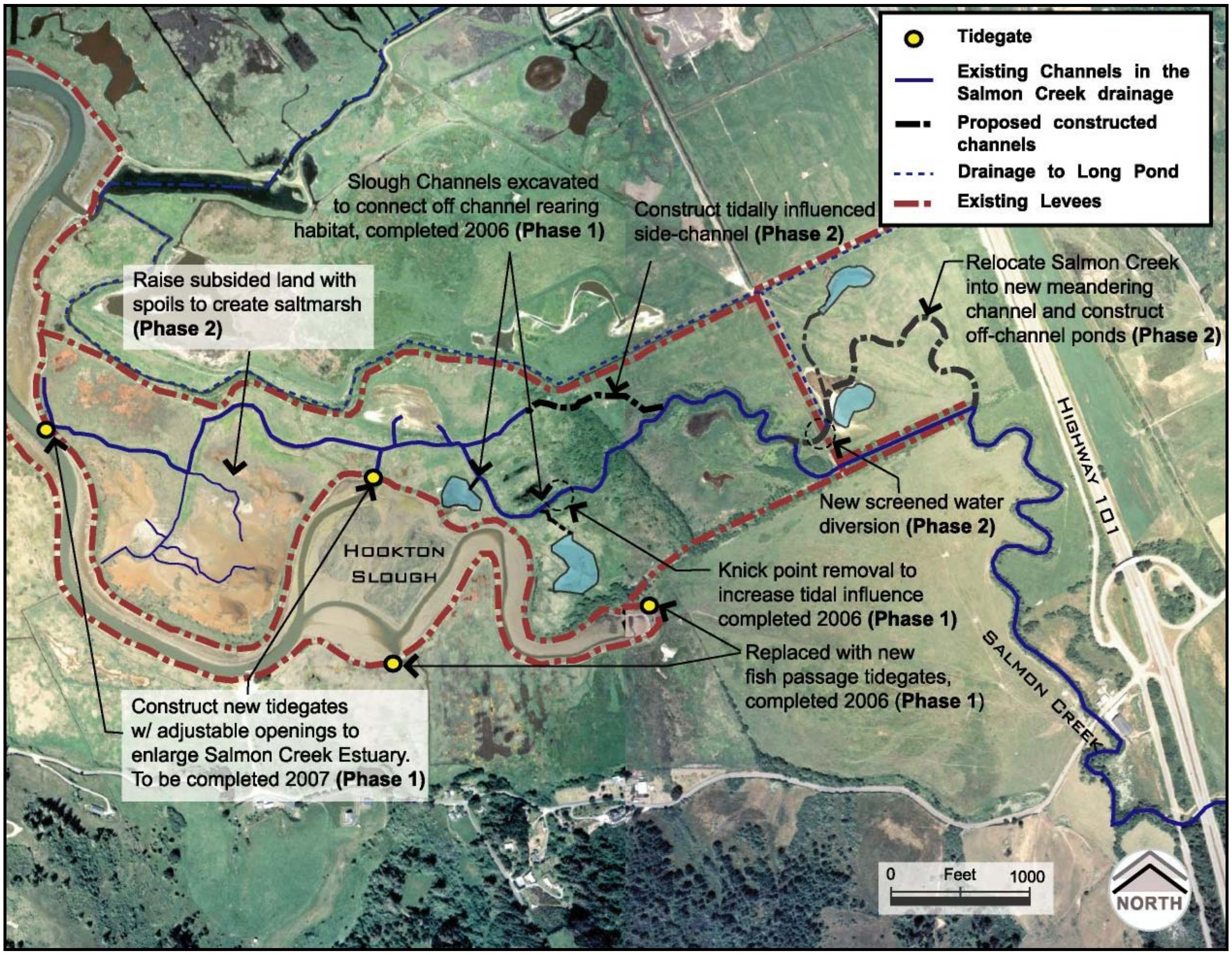
PCFWWRA, 2003. Lower Salmon Creek Delta Salmonid Habitat Enhancement Opportunities.

Coats, R.N., P.B. Williams, C.K. Cuffe, J.B. Zedler, and D. Reed. 1995. Design Guidelines for Tidal Channels in Coastal Wetlands. Prepared for U.S. Army Corps of Engineers, Waterways

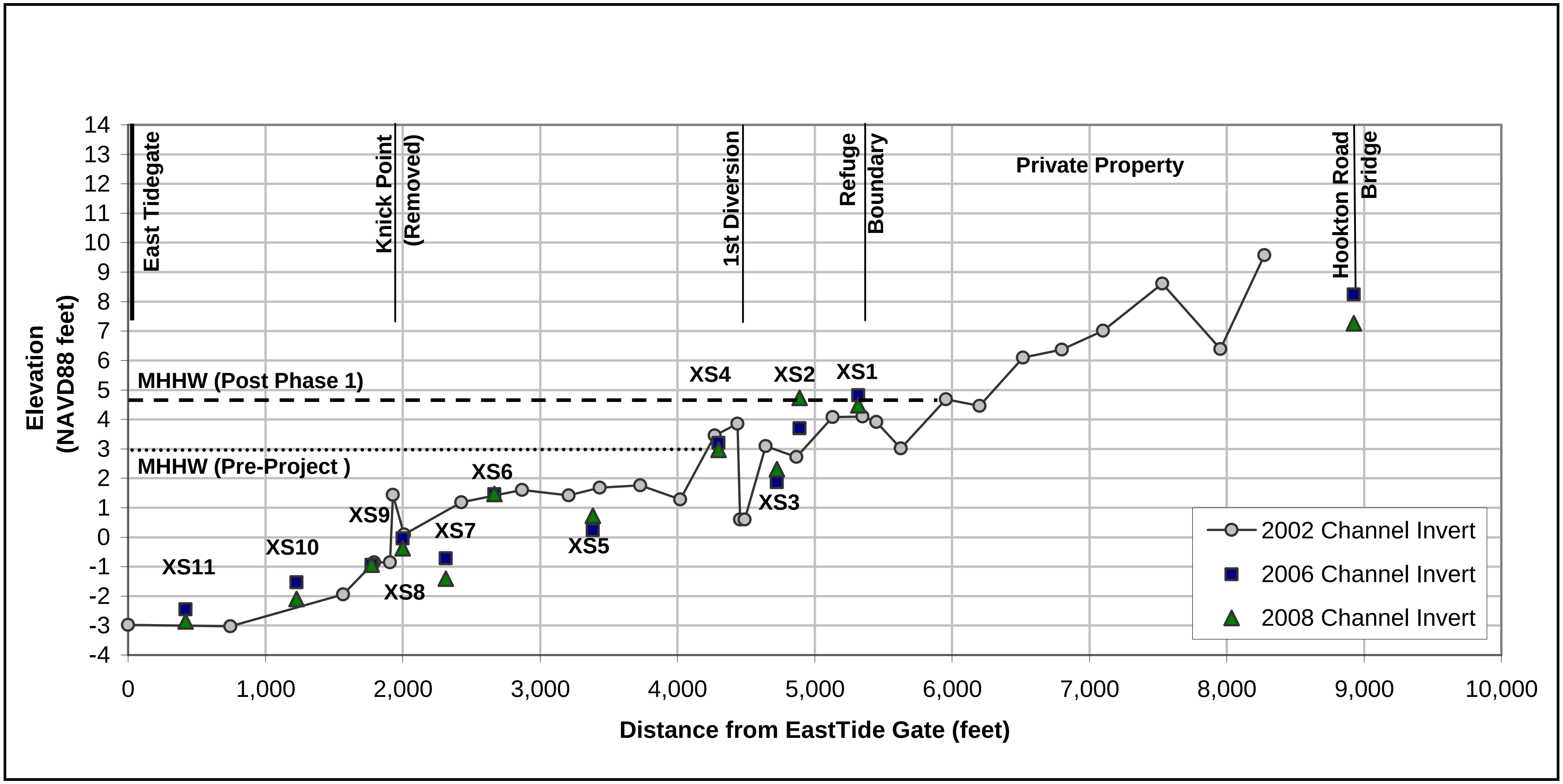
Experiment Station by Philip Williams & Associates, Ltd. http://www.h2odesigns.com/library/TidalWetlands/DesignGuidelns-TidalWetlnds-RevSept24_02.pdf

Philip Williams and Associates, and P.M. Faber. 2004. Design Guidelines for Tidal Wetland Restoration in San Francisco Bay. Prepared for The Bay Institute and California State Coastal Conservancy by Philip Williams & Associates, Oakland, CA. http://www.wrmp.org/design/

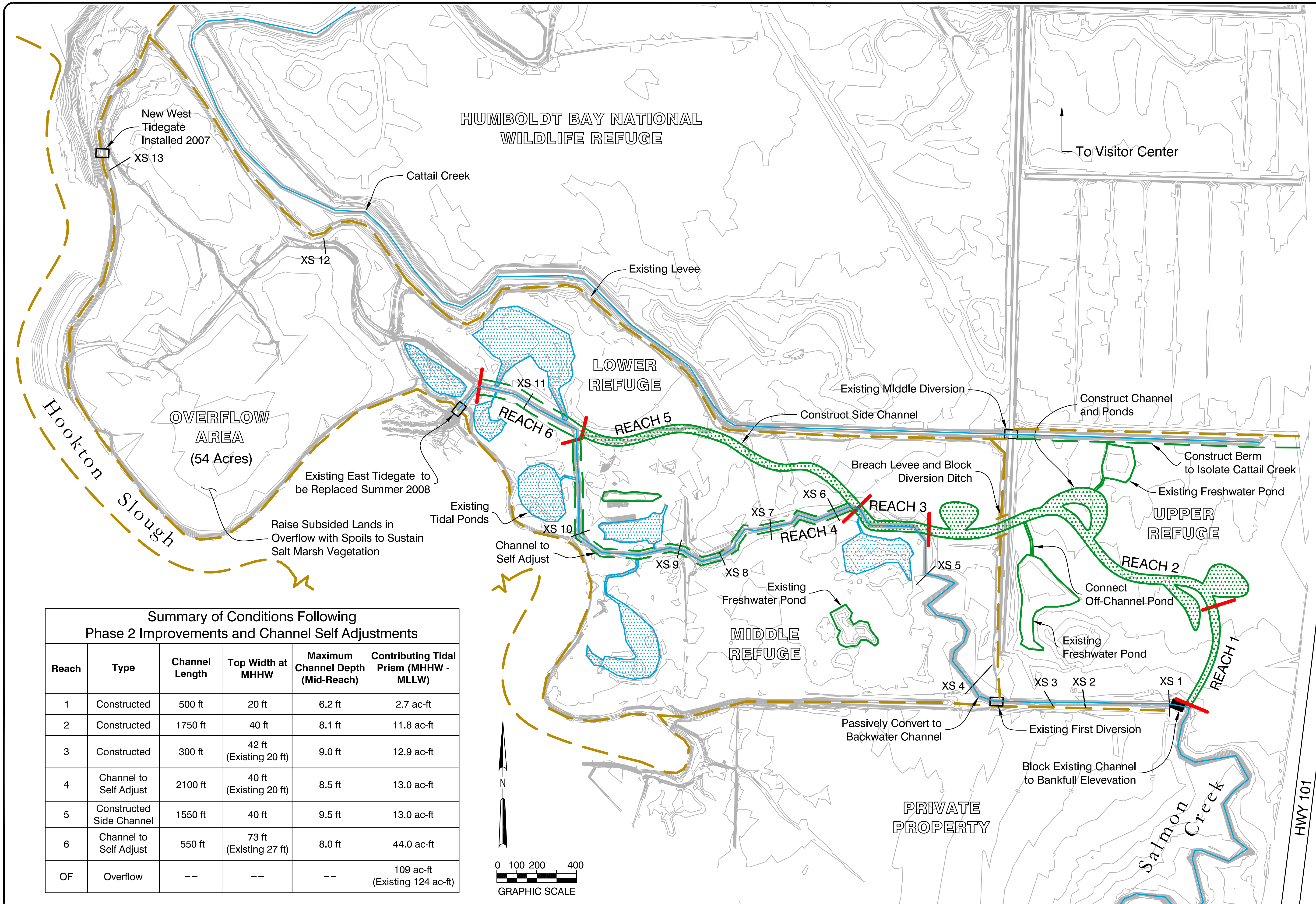
Williams, P.B., M.K. Orr, and N.J. Garrity.2002. Hydraulic Geometry: A Geomorphic Tool for Tidal Marsh Channel Evolution in Wetland Restoration Projects. Restoration Ecology 10(3):577-590. http://www.h2odesigns.com/library/ChannelMorphology/Williams_2002_Hydraulic_Geometry_Geomorphic_tool_for_wetland_restoration.pdf



ATTACHMENT 1 - Summary of Phase 1 and Phase 2 Improvements to Salmon Creek (adapted from the Salmon Creek Delta, Phase 2 Planning Project grant submittal to DFG).



ATTACHMENT 2 - Profile of channel invert surveyed in 2002 through the project area. Blue squares and green triangles indicate 2006 and 2008 cross section invert elevations, respectively.



Summary of Conditions Following
Phase 2 Improvements and Channel Self Adjustments

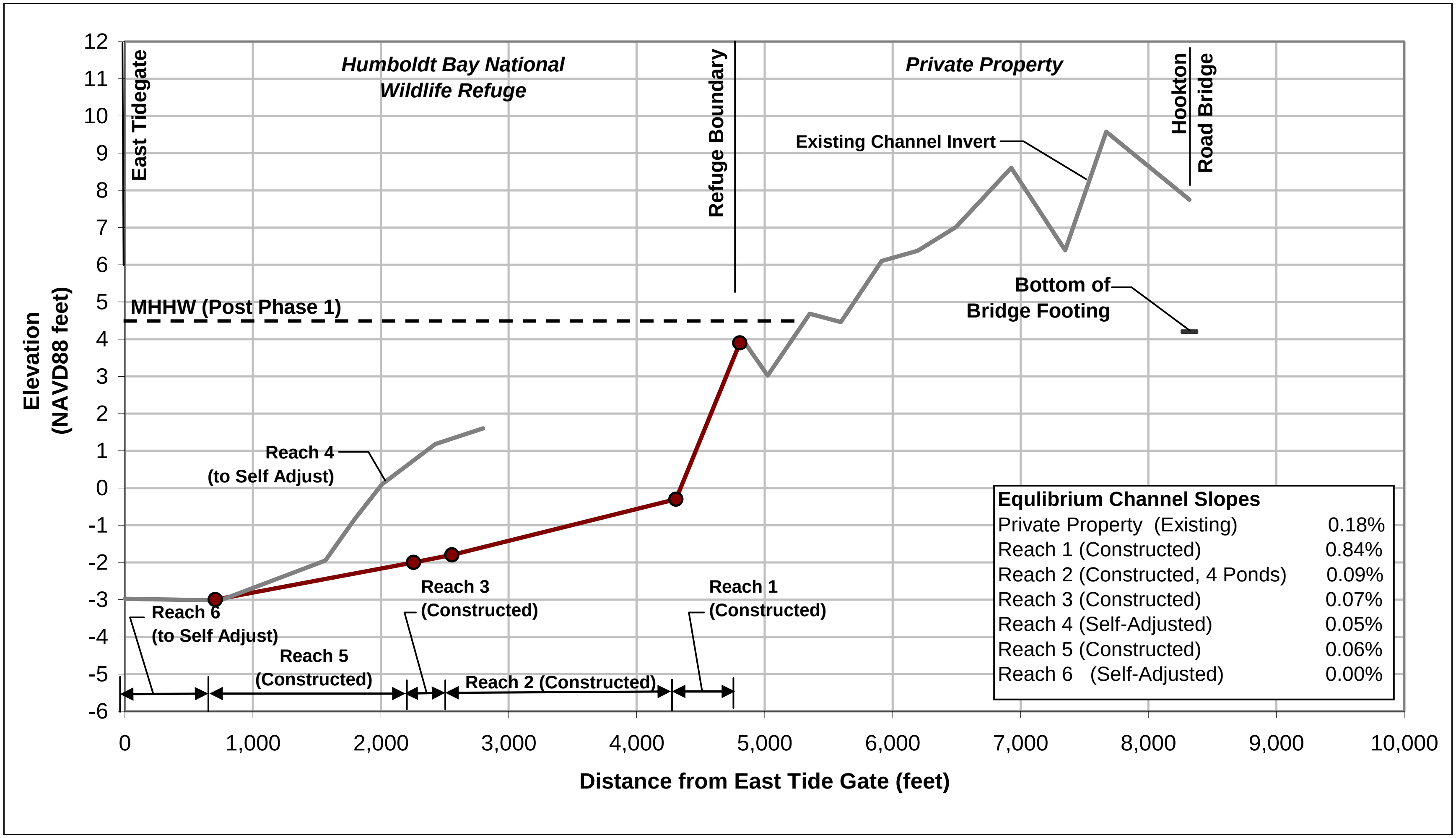
Reach	Type	Channel Length	Top Width at MHHW	Maximum Channel Depth (Mid-Reach)	Contributing Tidal Prism (MHHW - MLLW)
1	Constructed	500 ft	20 ft	6.2 ft	2.7 ac-ft
2	Constructed	1750 ft	40 ft	8.1 ft	11.8 ac-ft
3	Constructed	300 ft	42 ft (Existing 20 ft)	9.0 ft	12.9 ac-ft
4	Channel to Self Adjust	2100 ft	40 ft (Existing 20 ft)	8.5 ft	13.0 ac-ft
5	Constructed Side Channel	1550 ft	40 ft	9.5 ft	13.0 ac-ft
6	Channel to Self Adjust	550 ft	73 ft (Existing 27 ft)	8.0 ft	44.0 ac-ft
OF	Overflow	--	--	--	109 ac-ft (Existing 124 ac-ft)

Michael Love & Associates
Hydrologic Solutions
PO Box 4477 • Arcata, CA 95518 • (707) 476-8938

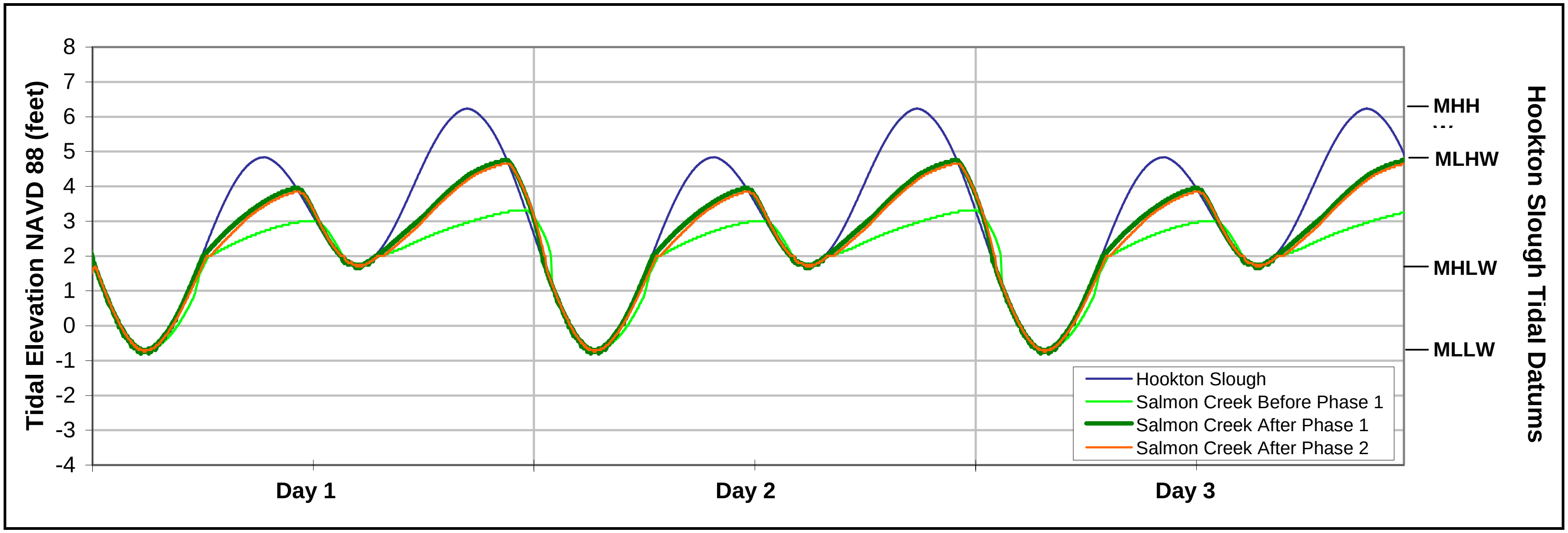
Humboldt Bay National Wildlife Refuge
Salmon Creek Enhancement Plan
PHASE 2

ATTACHMENT 3
CONCEPTUAL DESIGN

DATE 28 JULY 08
DESIGN Love/Shea
DRAWN Llanos
SHEET 1 of 1



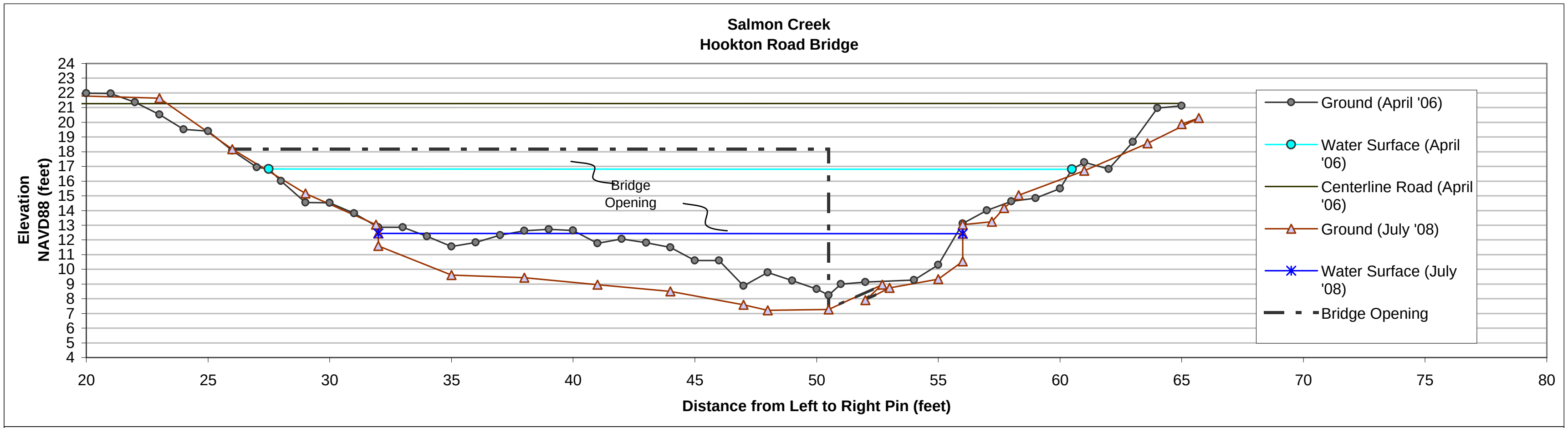
ATTACHMENT 4 - Profile of the proposed channel invert in the project area (Vertical Exaggeration: 300).

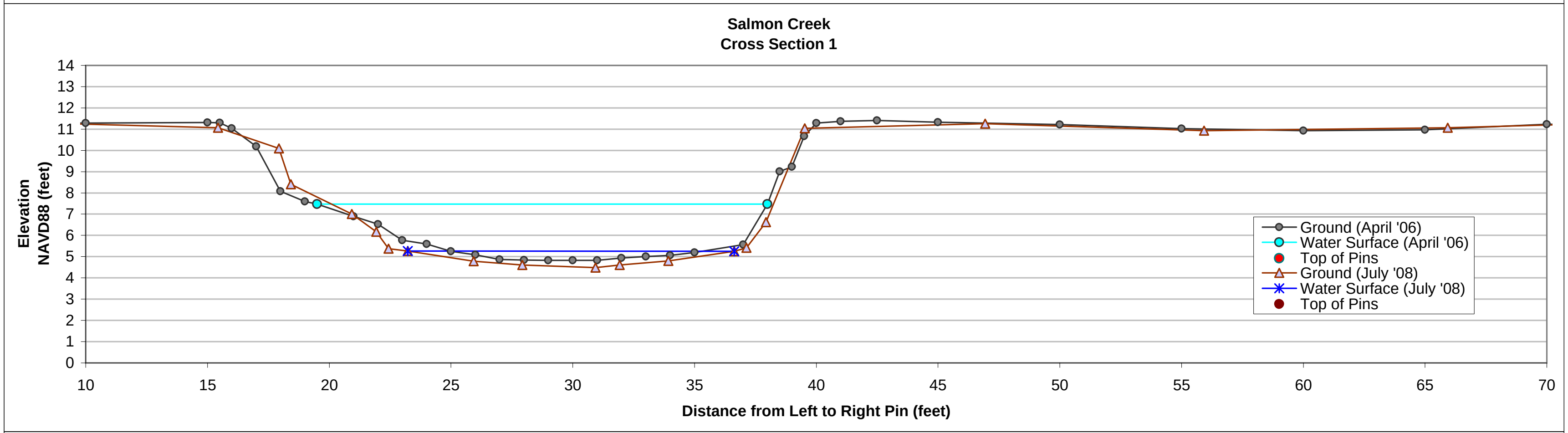


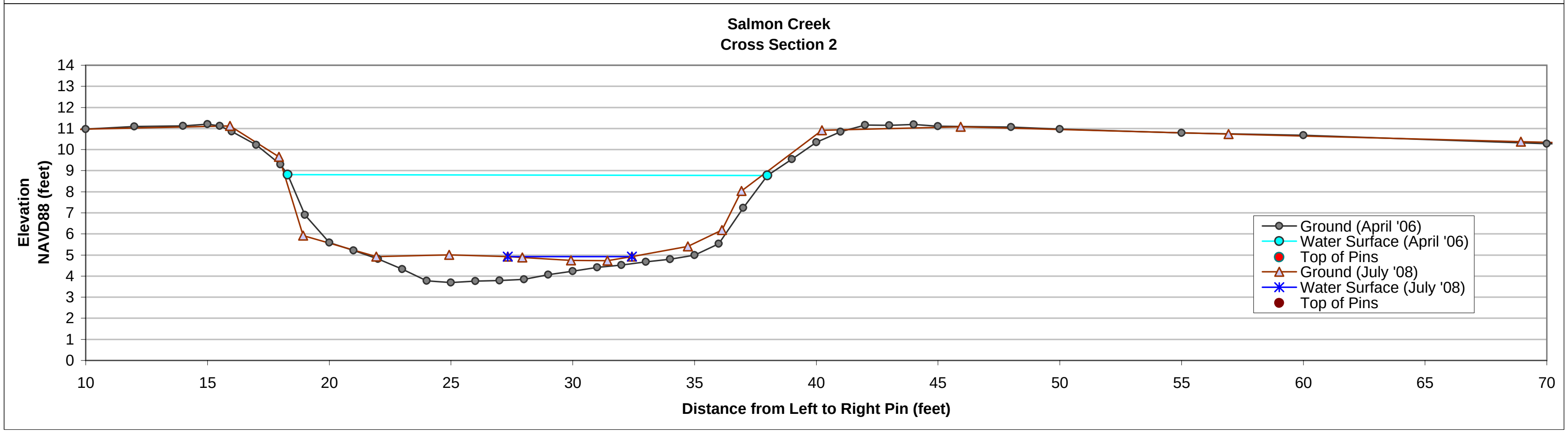
ATTACHMENT 5 – Predicted water surface elevations inside of the new tide gates for post-Phase 1 conditions and post-Phase 2 equilibrium conditions. Results were generated from the Pond-Storage Routing Model using a "design" tidal cycle in Hookton Slough and baseflow of 1 cfs for Salmon Creek.

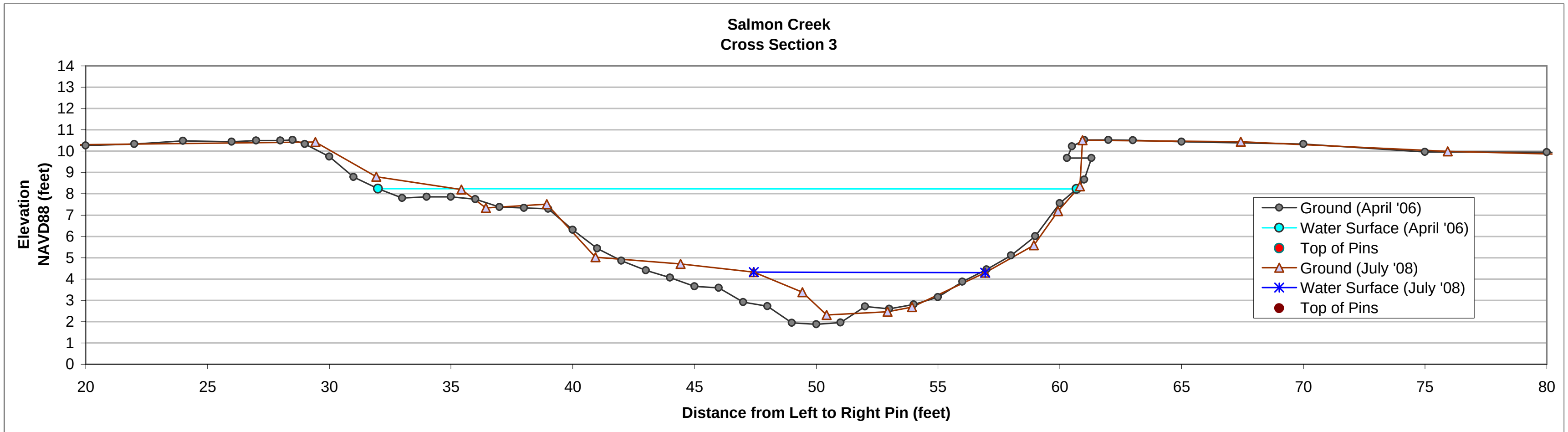
Appendix C

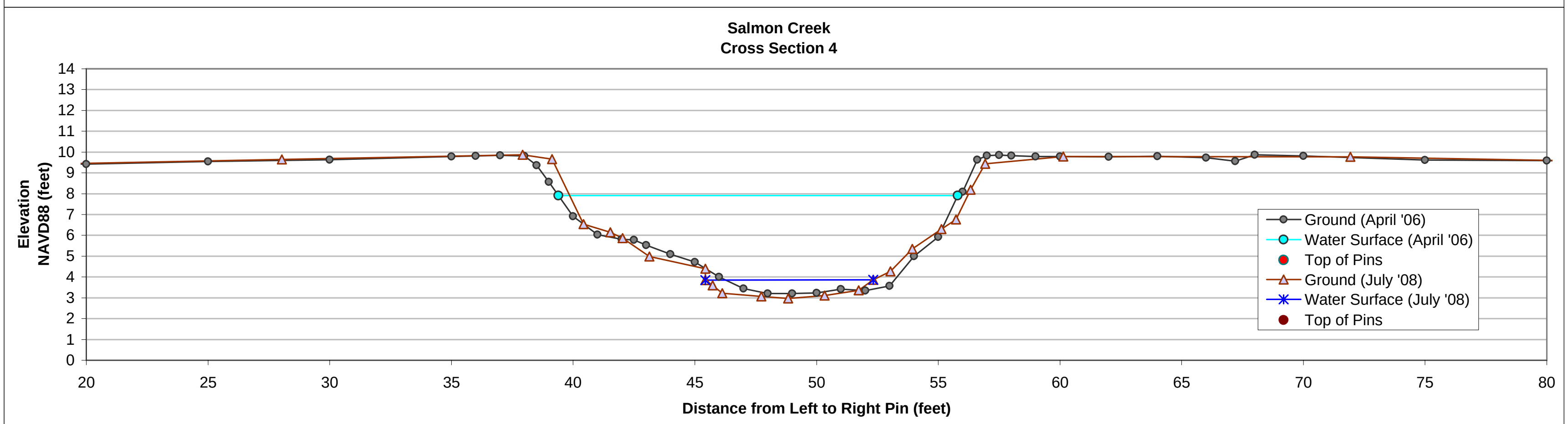
Monitoring Cross Section Survey Results

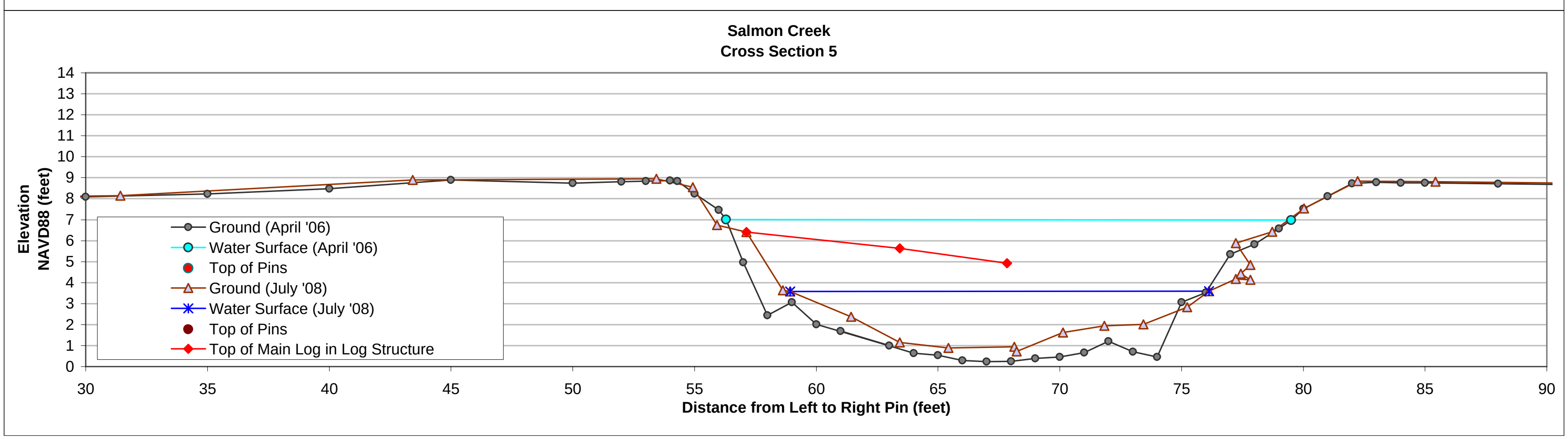

Salmon Creek
Hookton Road Bridge
Elevation NAVD88 (feet)
Distance from Left to Right Pin (feet)
Bridge Opening
Ground (April '06)
Water Surface (April '06)
Centerline Road (April '06)
Ground (July '08)
Water Surface (July '08)
Bridge Opening

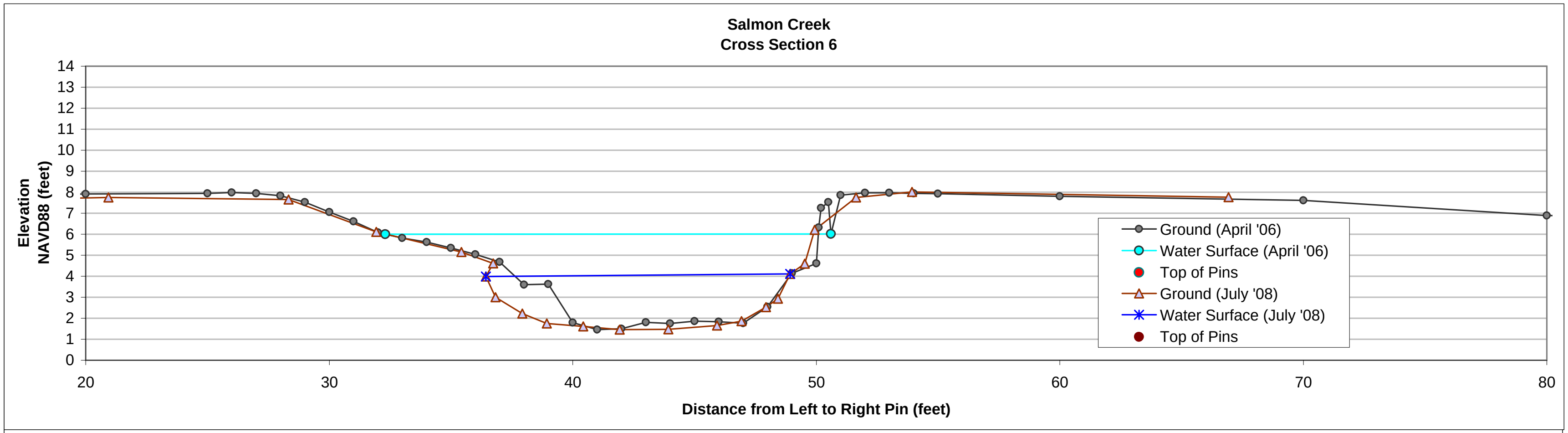

Salmon Creek
Cross Section 1
Elevation NAVD88 (feet)
Distance from Left to Right Pin (feet)
Ground (April '06)
Water Surface (April '06)
Top of Pins
Ground (July '08)
Water Surface (July '08)
Top of Pins

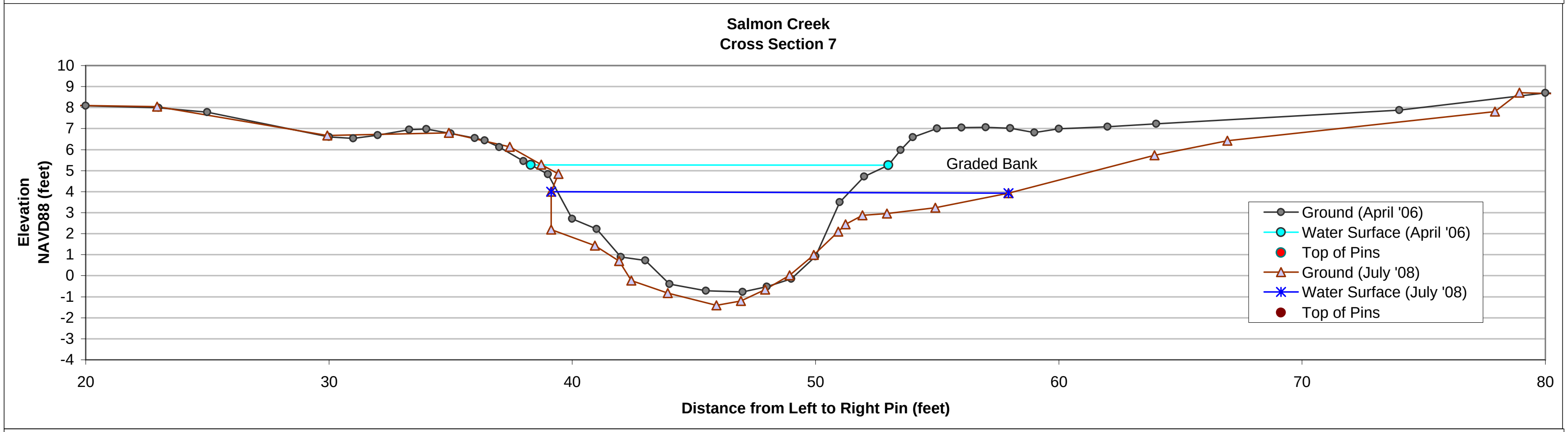

Salmon Creek
Cross Section 2
Elevation NAVD88 (feet)
Distance from Left to Right Pin (feet)
Ground (April '06)
Water Surface (April '06)
Top of Pins
Ground (July '08)
Water Surface (July '08)
Top of Pins

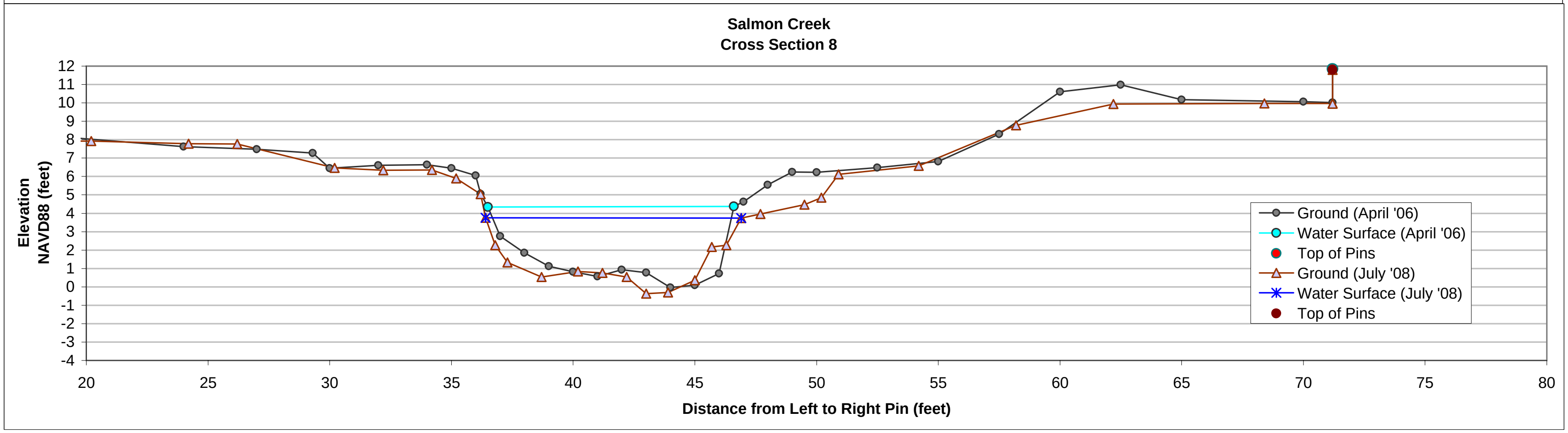

Salmon Creek
Cross Section 3
Elevation NAVD88 (feet)
Distance from Left to Right Pin (feet)
Ground (April '06)
Water Surface (April '06)
Top of Pins
Ground (July '08)
Water Surface (July '08)
Top of Pins

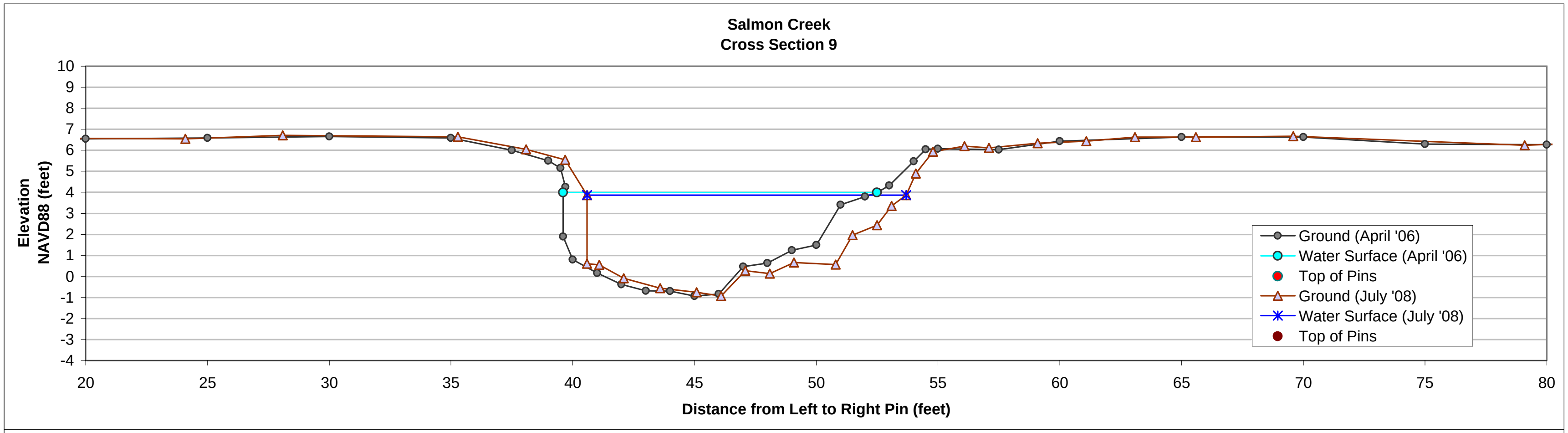

Salmon Creek
Cross Section 4
Elevation NAVD88 (feet)
Distance from Left to Right Pin (feet)
Ground (April '06)
Water Surface (April '06)
Top of Pins
Ground (July '08)
Water Surface (July '08)
Top of Pins

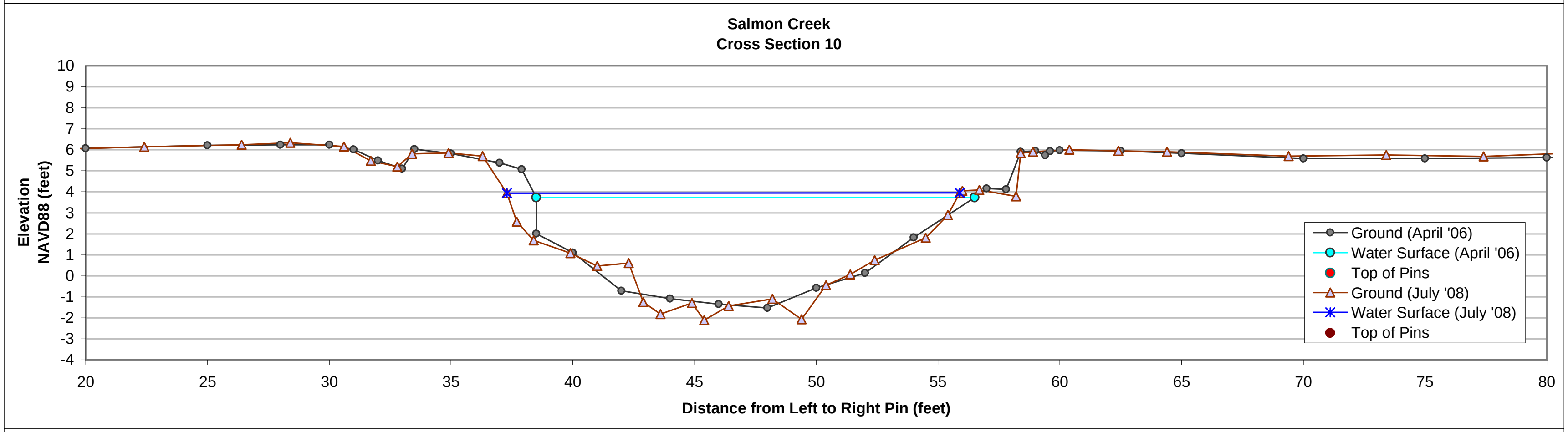

Salmon Creek
Cross Section 5
Elevation NAVD88 (feet)
Distance from Left to Right Pin (feet)
Ground (April '06)
Water Surface (April '06)
Top of Pins
Ground (July '08)
Water Surface (July '08)
Top of Pins
Top of Main Log in Log Structure

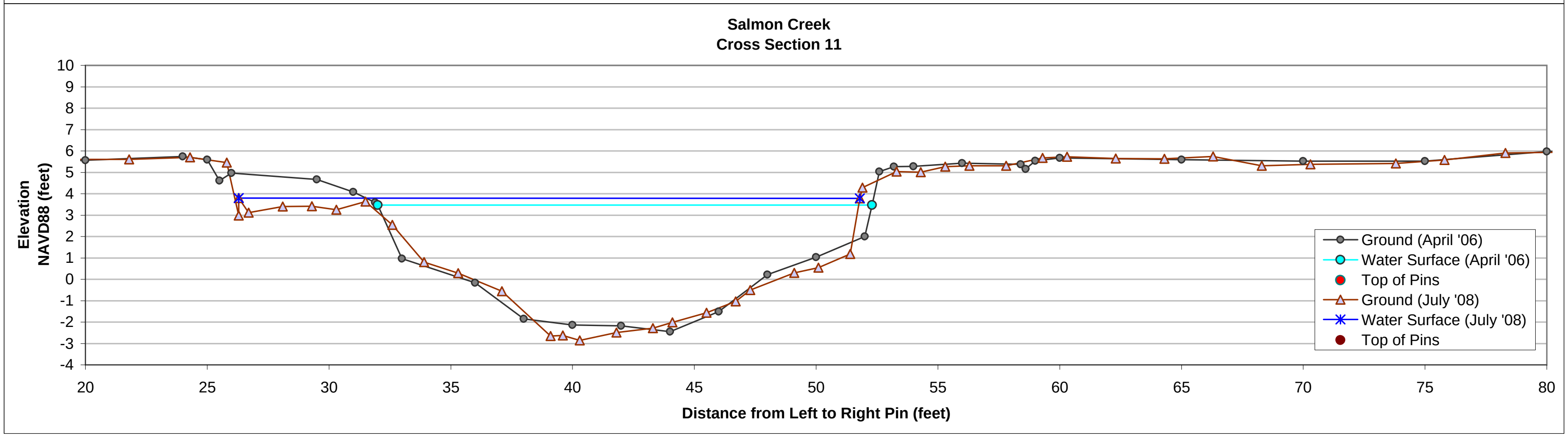

Salmon Creek
Cross Section 6
Elevation NAVD88 (feet)
Distance from Left to Right Pin (feet)
Ground (April '06)
Water Surface (April '06)
Top of Pins
Ground (July '08)
Water Surface (July '08)
Top of Pins

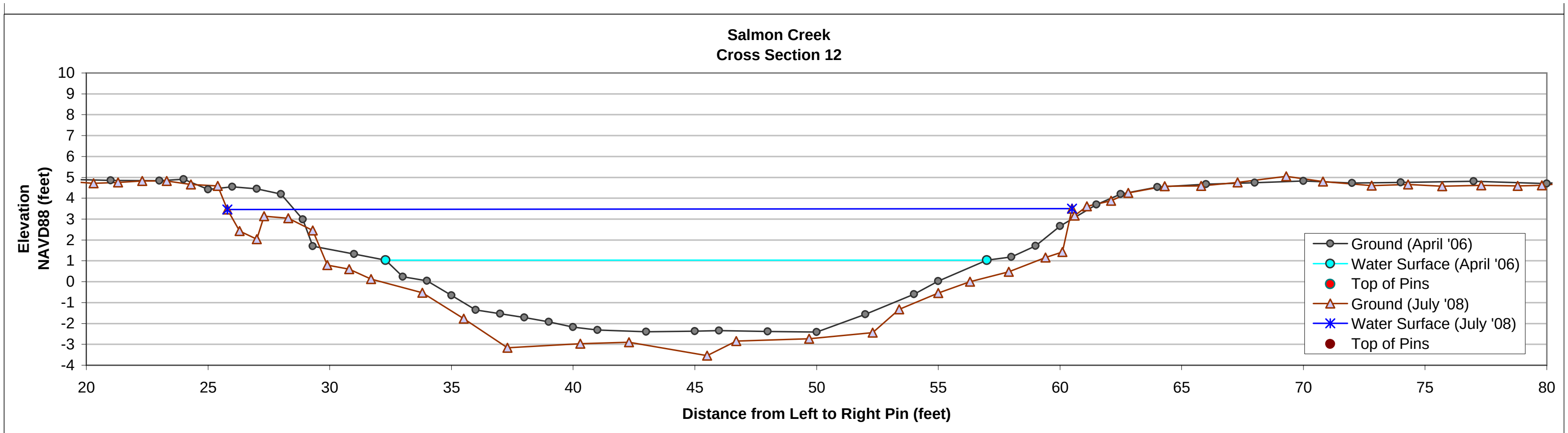

Salmon Creek
Cross Section 7
Elevation NAVD88 (feet)
Distance from Left to Right Pin (feet)
Graded Bank
Ground (April '06)
Water Surface (April '06)
Top of Pins
Ground (July '08)
Water Surface (July '08)
Top of Pins

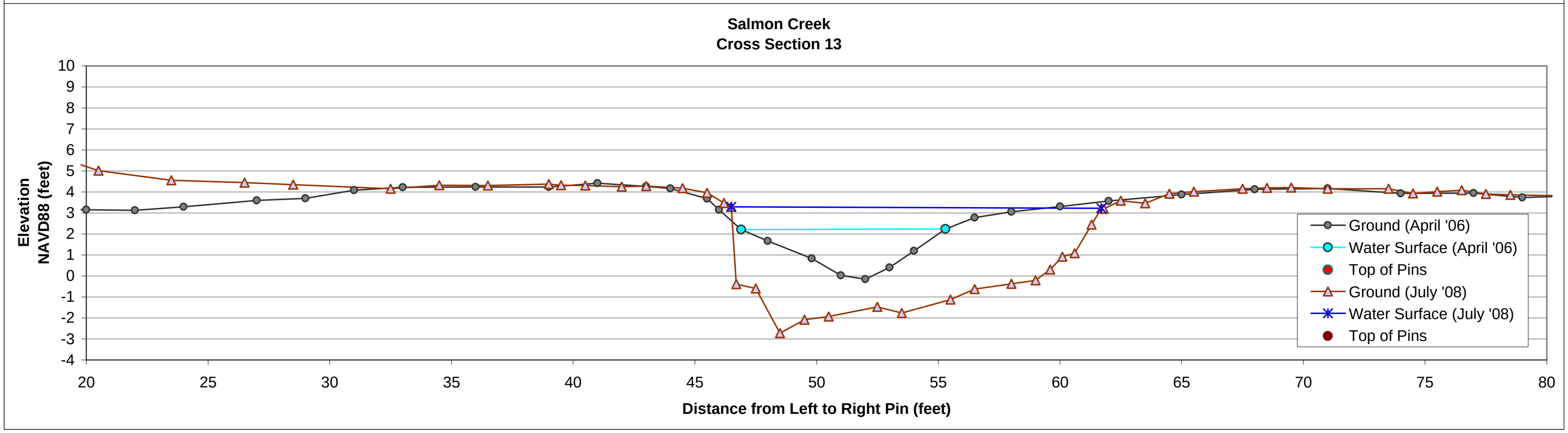

Salmon Creek
Cross Section 8
Elevation NAVD88 (feet)
Distance from Left to Right Pin (feet)
Ground (April '06)
Water Surface (April '06)
Top of Pins
Ground (July '08)
Water Surface (July '08)
Top of Pins


Salmon Creek
Cross Section 9
Elevation
NAVD88 (feet)
Distance from Left to Right Pin (feet)
Ground (April '06)
Water Surface (April '06)
Top of Pins
Ground (July '08)
Water Surface (July '08)
Top of Pins


Salmon Creek
Cross Section 10
Elevation
NAVD88 (feet)
Distance from Left to Right Pin (feet)
Ground (April '06)
Water Surface (April '06)
Top of Pins
Ground (July '08)
Water Surface (July '08)
Top of Pins


Salmon Creek
Cross Section 11
Elevation
NAVD88 (feet)
Distance from Left to Right Pin (feet)
Ground (April '06)
Water Surface (April '06)
Top of Pins
Ground (July '08)
Water Surface (July '08)
Top of Pins


Salmon Creek
Cross Section 12
Elevation NAVD88 (feet)
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
20
25
30
35
40
45
50
55
60
65
70
75
80
Distance from Left to Right Pin (feet)
Ground (April '06)
Water Surface (April '06)
Top of Pins
Ground (July '08)
Water Surface (July '08)
Top of Pins


Salmon Creek
Cross Section 13
Elevation NAVD88 (feet)
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
20
25
30
35
40
45
50
55
60
65
70
75
80
Distance from Left to Right Pin (feet)
Ground (April '06)
Water Surface (April '06)
Top of Pins
Ground (July '08)
Water Surface (July '08)
Top of Pins

Appendix D
Geologic Investigation Report

Geologic Evaluation of the Upstream Portion of the Salmon Creek Estuary Enhancement Project, Humboldt County, California

PWA Report No. 09085201
February 2009

Prepared for:
Pacific Coast Fish, Wildlife and Wetlands Restoration Association
PO Box 4574, Arcata, CA 95518

California Department of Fish and Game
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US Fish and Wildlife Service

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1 PROJECT SUMMARY

This report presents the findings of a geologic evaluation by Pacific Watershed Associates Inc. (PWA) of the upper portion of the Salmon Creek Estuary Enhancement Project in Humboldt County, California. The purpose of our investigation was to compile geologic background material and evaluate potential geologic constraints as they relate to implementing estuary enhancement activities proposed in the development phase (Phase II) of the project. The investigation included field documentation of the extent and geomorphic conditions of the levee along the upstream reach between the Humboldt Bay National Wildlife Refuge (HBNWR) and the Hookton Road Bridge, and a characterization of subsurface geologic units at the area where the proposed project channel will transition to the existing Salmon Creek Channel.

In the upstream reach between the HBNWR and the Hookton Road bridge only the southwestern portion of Salmon Creek is bordered by a levee. The levee appears to have been constructed in two phases, probably beginning in the 1970s or early 1980s. The first phase (Section A) was likely constructed when an original channel section of Salmon Creek was bypassed. The second levee section (Section B) is thinner, lower in geometry, and not as well constructed as Section A. Both levees were probably constructed to help keep flood flows in the channel and off the adjacent agricultural fields to the west.

We examined the subsurface stratigraphy at 2 locations in the area where the existing upstream channel will transition to the proposed new channel on HBNWR lands: (1) within the margins of the existing channel, close to where it currently enters the straight-line ditched channel on the HBNWR; and (2) on the HBNWR property approximately 60 m north of the location where the channel currently transitions to the ditched channel. The subsurface sampling consisted of core sampling at the former location and excavator trenching at the latter. The geologic substrate in the transition area is composed of clay-sand silt deposits overlaying thick bay mud deposits. The historic channel of Salmon Creek was identified in excavator trench exposures and is observed as a generally trapezoidal shaped feature inset into bay mud deposits and overlain by the clayey and sandy silt deposits. The channel deposits consist primarily of poorly sorted sand with secondary fine gravel and finer grained sands and silts.

Several geological constraints to the proposed project were evaluated and recommendations were developed to address them. The primary constraints include: (1) the potential for the newly constructed project channel to be flanked or bypassed by flooding and channel diversion upstream of the HBNWR; (2) the potential for excessive headcutting and incision in the upper part of the proposed channel and the upstream off-property channel due to the expected gradient increase at the transition between the proposed channel and the existing channel; 3) the functionality and stability of the proposed grade control structures; and (4) other geologic project constraints such as surface fault rupture, hard ground shaking, liquefaction, relative sea-level changes, tsunami inundation, and extreme flooding and sediment deposition.

2 INTRODUCTION

2.1 Previous Work and Project Goals

The Lower Salmon Creek Estuary Enhancement Project is located within the Salmon Creek Delta where it enters the southern portion of Humboldt Bay, locally known as South Bay (Maps

1, 2 & 3). The entire project is located within the USGS Fields Landing 7.5' Quadrangle in Section 5 Township 03N, Range 01W, Humboldt County, California. The Cal Watershed is 18010102.

The Salmon Creek Delta has been extensively protected with dikes and levees since the early 1900's but still allows runs of anadromous fish species through the refuge up to spawning grounds in the upper watershed. All of the project area is within the historic tidal prism of Humboldt Bay, but the tidal inundation extent is now controlled through a series of recently replaced tide gates which impart a muted tidal cycle into the delta area. Elevations within the project area range from -3.0' - 9.5' (NAVD88). Mean High High Water within the project area is controlled by the newly installed tide gates and is approximately 4.8 ft; this is an increase of 1.8' from pre-tide gate replacement conditions (PCFWWRA, 2003). Similarly, Salmon Creek has historically flooded the delta region and levees have been constructed to locally control and prevent flooding of adjacent agricultural lands.

This report presents the findings of Pacific Watershed Associates' (PWA's) geologic evaluation of the upper portion of the Salmon Creek Estuary Enhancement Project (Map 2). The purpose of our investigation was to compile geologic background material and evaluate potential geologic constraints as they relate to proposed estuary enhancement activities outlined in the report: *Lower Salmon Creek Delta Salmonid Habitat Enhancement Opportunities* (PCFWWRA, 2003). The overall goals of the Lower Salmon Creek Estuary Enhancement Project (LSCEEP) are to create a self sustaining estuarine channel system within the Humboldt Bay National Wildlife Refuge (HBNWR) in southern Humboldt Bay, while working within the constraints imposed by the land use objectives of the refuge and upstream land owners and transportation facilities.

Phase I of the LSCEEP was conducted by Michael Love and Associates and Graham Mathews and Associates. In Phase I of the project, several tide gates were replaced, connections between several ponds were established to the existing channel, and a knickpoint in the existing channel was removed, and a report was generated that summarized topographic, hydrologic, and land use data. Phase II of the project is currently in the design phase and proposes three unique conceptual designs for reconfiguring the slough channel system through the HBNWR. From information provided to them in the conceptual proposal, managers at the refuge selected design Alternative B which entails several enhancements to the estuary within the boundaries of the refuge. The estuary enhancement Alternative B consists of replacing a system of diversion structures and straightened and channelized ditches with a series of lower gradient, less confined, more sinuous channels and ancillary off-channel ponds. The Alternative B design is described in the Report: *Lower Salmon Creek Delta Salmonid Habitat Enhancement Opportunities* (PCFWWRA, 2003).

Phase II of the LSCEEP includes the 30% design of Alternative B. The primary elements of the project will include: 1) Relocating the Salmon Creek channel within the upper refuge, 2) Constructing off-channel habitat along the newly constructed channel within the upper refuge, 3) Constructing side-channel habitat within the middle refuge, 4) Raising subsided lands within an existing overflow area, and 5) Developing a water diversion strategy consistent with ecological and management goals of the refuge. All proposed estuary enhancement activities and design options are planned to be implemented entirely within the boundaries of the HBNWR. The design life of the estuary enhancement project has not been explicitly stated in the conceptual design proposal. For the purpose of this report we assume a project design life of approximately

50 years, recognizing that severe floods, tsunamis and tectonic events can occur at any time within the design life and compromise the performance of one or more of the project elements.

Our investigation focused on evaluating existing geologic conditions and potential channel response to enhancement activities from implementation of the first element of Design Alternative B: "relocating Salmon Creek within the upper refuge". This portion of the project will entail excavating a new channel between the private property upstream of the refuge to the levee between Cattail Creek and the first diversion (Map 2). The recommendations outlined in this report will be considered during the final design of the estuary enhancement project.

In this report, we provide the following:

- Review of pertinent geologic maps
- Review of pertinent geologic reports
- Review of historic aerial photography for the entire plan area and adjacent lands
- Documentation of the extent and geomorphic condition of the existing levee system within the private property between the HBNWR and the Hookton Road Bridge
- Geologic characterization of the subsurface stratigraphy in the vicinity of the proposed channel confluence where the currently existing channel will transition to the proposed channel that is to be constructed
- Analysis of observations, data, and geologic constraints
- Recommendations for mitigating all or part of the identified geologic constraints as they pertain to proposed enhancement activities within the scope of the project

2.2 Project Constraints

To assure all restoration activities on the HBNWR are well conceived, a technical advisory committee (TAC) was assembled to provide scientific ideas and input to the project planners. This was done to assure the project is utilizing appropriate practices, considering feasible alternatives, and adequately evaluating and incorporating input provided by funding institutions and regulatory agencies. During the technical advisory committee meeting on August 1, 2008 two primary areas of geologic concern were identified where potential project constraints needed further analysis to facilitate the final design.

2.2.1 Potential overbank flooding for sections of Salmon Creek

In the phase II report: *Lower Salmon Creek Delta Salmonid Habitat Enhancement Opportunities*, locations of recent overbank flooding along Salmon Creek were documented (PCFWWRA, 2003). Results of this documentation indicate the stream segment located on private property upstream of the proposed project site, between the HBNWR and Hookton Road, has several locations where the channel capacity is regularly exceeded and flow is routed west over agricultural fields and out to the terminal end of Hookton Slough (Map 2). There, the flow is then routed through 2 tide gates on lands managed by the HBNWR into the Hookton Slough and Humboldt Bay. The two observed locations where the flood flow overtops the channel banks most frequently are at the area near the Hookton Road Bridge and at a significant levee breach that has developed downstream of the bridge (Map 4). The Salmon Creek Delta TAC determined this was a significant issue due to the possibility of the entire LSCEEP becoming flanked and bypassed during a future flood event (TAC meeting August 1, 2008). Topographic maps provided in the *Lower Salmon Creek Delta Salmonid Habitat Enhancement Opportunities* report support the assertion that this is a significant constraint as they demonstrate the route between Salmon Creek and Hookton Slough, through the private property, is steeper in gradient and shorter in distance than the proposed channel through the HBNWR. During the TAC meeting it was determined that an understanding of the current extent and conditions of the levee system between the HBNWR and Hookton road was a necessary first step in addressing this issue.

2.2.2 Potential problems caused by abrupt changes in channel gradient

In order to construct a tidally driven, self sustaining (self-flushing) channel through the HBNWR the proposed channel needs to be constructed at a tightly constrained channel gradient and specific elevation relative to the existing tide gates. One issue related to this design constraint occurs where the Salmon Creek stream channel is designed to transition into the proposed HBNWR channel. At this transition reach the channel grade will be significantly over-steepened compared to the channel grades above and below it. The preliminary design shows an average grade of 0.84% in the over-steepened segment compared to a grade of 0% to 0.09% below it and 0.18% above it. The technical advisory committee determined that this over-steepened reach had the potential to initiate a migrating headcut and channel incision within Salmon Creek located on adjacent privately owned land. From an engineering perspective this was initially perceived as a positive result as it would theoretically increase the channel dimensions and channel capacity and reduce flooding and the potential for water diversion above the refuge. However, several potential issues were identified that needed further review or analysis prior to this occurring: A) Allowing a headcut to migrate off of the HBNWR and onto private property would require negotiations and the agreement of upstream property owners, B) Project permitting would be significantly more difficult if it entailed both Federal requirements (HBNWR) and state requirements regulating actions on private property, C) There were no estimates of the vulnerability of the channel deposits to headcut erosion or estimates of the rate of potential headcut migration, D) A migrating headcut has the potential to undermine the bridge abutments at Hookton Road if the expected channel incision were of sufficient magnitude, and E) Large inputs of sediment derived from this channel incision as well as from upstream sediment sources could be delivered into the newly constructed HBNWR channel and this would have an unpredictable effect on the hydraulic model parameters used to design the self sustaining (self-cleansing) tidal channel.

With the above issues identified it was determined that a series of grade control structures placed in the over-steepened channel segment on the HBNWR property would be the best alternative for reducing the likelihood of developing a significant headcut that could migrate upstream. Conceptually, these grade control structures could be removed or incrementally lowered over time to meter the amount of headcutting onto the adjacent private property once an agreement has been reached with the upstream landowner. Alternatively, the grade control structures could be installed as permanent, non-deformable structures. For this reason the TAC determined it would be necessary to characterize the bed materials in the current channel of Salmon Creek as well as the sediment deposits in the adjacent channel transition area of HBNWR to determine their susceptibility to potential channel incision and headcutting.

Finally, approximately 700’ of the proposed channel (through the planned over-steepened reach) was likely to follow or intersect an abandoned slough channel from the era before the Salmon Creek delta was converted from wetlands to pasture (Map 2). This historic Salmon Creek channel is no longer visible on the ground (anecdotal accounts suggest it was intentionally filled to improve the pasture land) but it can be identified on old aerial photography. Based on this observation it was determined the project would require a clear understanding of the subsurface geologic substrate that is likely to be encountered during the excavation of the proposed channel and the placement of the grade control structures.

3 RESULTS I: GEOLOGICAL MAP AND LITERATURE REVIEW

3.1 Local Geologic Setting

Published geologic mapping (Ogle, 1953; McLaughlin et al., 2000) shows that the project area is underlain by Quaternary alluvium. For the California Geologic Survey, Kilbourne (1985) mapped the project area as undivided Quaternary sedimentary rocks (Map 3).

Recently, detailed studies of the subsurface stratigraphy in the vicinity of the project area have been conducted within the areas collectively mapped as alluvium (Patton and Witter, 2006; Witter et al., 2002). These studies have provided a much more detailed characterization of the sediments comprising the Salmon Creek delta. Patton and Witter (2006) and Witter et al (2002) provide the best description and characterization of the subsurface stratigraphy adjacent to the LSCEEP (Map 3). Their observations indicate that the subsurface stratigraphy in the area is composed primarily of interstratified mud (clay and silt) and peat deposits with minor sand layers.

3.2 Regional Tectonic Setting

The HBNWR is located in the northern Coast Ranges Geomorphic Province, northeast of Cape Mendocino (Map 1), within the on-land portion of the accretionary prism of the Cascadia subduction zone (Clark, 1987; Clark and Carver, 1992; Map 1). The regional geologic and tectonic framework of the HBNWR area is complex and driven by two primary plate boundary features: the Cascadia subduction zone to the west; and the San Andreas Fault system to the south. These fault systems meet at the Mendocino Triple Junction (MTJ) approximately 35 km south of the project area (Kelsey and Carver, 1988; Williams, 2003; Map 1), and the resulting complex contractional deformation in the North American plate is manifest as active northwest-striking thrust faults and fault-related folds in the Humboldt Bay region (Kelsey and Carver, 1988; McCrory, 2000; Maps 1 and 3). Deformation of Neogene rocks (Wildcat Group and Falor Formation) as well as Pleistocene marine terrace deposits attests to ongoing tectonic activity over the last million years and provide two regionally identified unconformities that have be used as datums to evaluate long term slip rates on local faults (McCrory, 1996).

3.3 Seismic Setting

As noted in Section 3.2, the HBNWR is located northeast of the Mendocino Triple Junction and there are several active faults mapped within or adjacent to the HBNWR property (Map 3). There are also abundant distal active seismic sources which are capable of producing strong ground motions (Table 1)

Data on peak ground accelerations within the study area are equivocal but the California Geological Survey has attempted estimates (CGS, 1999). According to CGS, there is a 10% probability that the area will experience 0.75 - 0.80 g between the calendar years 1999-2049.[1]

[1] The CGS seismic probability map is available at: http://www.conservation.ca.gov/cgs/rghm/psha/PublishingImages/pga.jpg

Table 1. Sources of Seismicity in the vicinity of the Lower Salmon Creek Estuary Enhancement Project[1]

Seismic Source	Historic Peak Intensities[2]	Historic Magnitudes[2]
Cascadia subduction zone	NA (≥ X expected)	NA (9.0 expected)
Southern Cascadia subduction zone	NA (≥ X expected)	NA (8.5 expected)[3]
Northern segment of the San Andreas Fault system	VII-IX	8.3
Mendocino Fault	VII-VIII?	5-7.5?
Faults within the Gorda plate	VII-VIII	5-7.5
Faults within the Cascadia Subduction zone fold and thrust belt	NA (≥ IX expected)	6.5-8+[4]
Inland faults related to the shear couple associated with the San Andreas fault system	NA[5]	3.5?[6]

[1] Modified from Dengler et al. 1992.

[2] Site responses during strong ground motion will depend on complex interactions between site specific conditions and nature of earth materials, topography, hydrologic conditions, and the distance to the earthquake source.

[3] Based on rupture of the southern segment only

[4] A more recent estimate of maximum earthquake magnitude is 7.3 (Geomatrix, 1994)

[5] There has been minimal historic seismicity in this area north of the wilits area

[6] The only recent historic seismicity has been the Garberville swarm (McPherson, 1989)

3.4 Active faulting

Of the active faults within the region, the Little Salmon fault and the Table Bluff fault have the highest potential to impact the LSCEEP (Map 3). The Little Salmon Fault is considered the most active fault in the southern Cascadia accretionary prism (McCrory, 1996) and is the closest Holocene fault to the LSCEEP (Map 3). A number of studies have attempted to characterize the Holocene activity on the Little Salmon Fault with varying results (Carver, unpublished; Woodward-Clyde, 1980; Carver and Burke, 1988; Vadurro et al., 2006; McCrory, 1996; Witter et al., 2002). McCrory (1996) attempted to summarize the investigations and fault parameters on the Little Salmon Fault. She determined a slip rate of 2.8 - 4.4mm/yr and a recurrence interval of 0.4 – 1 ky depending on the assumed fault geometry. Witter et al. (2002) suggest a slip rate between 2.9 - 6.9 mm/yr and Carver and Burke (1988) suggest a slip rate of 5.3 - 6.3 mm/yr. Published estimates for coseismic slip per event on the western trace of the Little Salmon fault range from 1.7 m to 4.5 m (Carver and Burke, 1988; Witter et al., 2002).

The Table Bluff Fault (Maps 1 and 3) is considerably less understood as it has no identifiable surface trace. Data on the geometry and location of the fault are limited to marine terrace data, well data, and seismic reflection data (Woodward Clyde Consultants, 1980; McCrory, 1996; Vadurro, 2006). The best data available on the geometry of the fault suggest that it is a thrusting wedge that is manifest as an asymmetric fault bend fold at the ground surface (Vadurro, 2006). A sequence of marine terraces on the fold allow uplift and slip rates to be calculated. McCrory (1996) estimates the slip rate to be 0.6 - 1.1 mm/yr and associated uplift rate to be 0.4 - 0.8 mm/yr, based on an assumed a fault dip of 45 degrees.

3.5 Regional Co-seismic land level changes

Regional coseismic subsidence events are well documented in the South Bay as well as other areas in Humboldt Bay (Vick, 1988; Valentine, 1992; Jacoby et al., 1995; Patton, 2004). Patton's interpretation of subsurface stratigraphy as old as 3,500 yr in the Hookton Slough area suggests a history of continual sediment accumulation in the bay primarily as mud flats and salt marsh punctuated by probable subsidence events. During his investigation he interpreted 5 stratigraphic horizons including buried wetland soils as evidence for coseismic subsidence. The stratigraphy also included sedimentary deposits consistent with concurrent tsunami deposition. Patton's estimates for vertical subsidence are equivocal but range from 0.9 m to 3.1 m per event (Patton, 2004).

4 RESULTS II: FIELD INVESTIGATION

4.1 Upstream Levee Conditions

Map 4 shows the area where the extent and conditions of the upstream levee were evaluated and documented. Based on analysis of sequential aerial photos, the levee appears to have been constructed between 1970 and 1981 to straighten the river and bypass a meander of the river to the east (Map 4). Several geometric parameters of the existing levee conditions were collected during the investigation as well as a field description of the primary levee and channel bed materials (Table 2).

Table 2. Levee Conditions on the Private Property Upstream of the HBNWR

Levee section	Length	Width[1]	Height[2]	Fill slope angle[3]	Setback distance	Material
Levee Section A		3-6m	2-1m	1:1	0	clay silt
Levee Section B		3-6m	0.5-1m	1:1	0	clay silt
Natural levee		≈ 5m	≈ 0.5m	1:1	0	clay silt

[1] Width measured at the base of the constructed levee where it contacts the natural levee

[2] Height measured from top of levee to base at contact with natural levee

[3] Fillslope angle is approximate and only applicable on outside edge of levee as the inside edge is typically eroded

Salmon Creek flows through a confined channel on the private property above the HBNWR. The banks are nearly vertical in this area with densely growing riparian trees providing root support to hold the steep banks. Where present, the levees are built right up to the channel banks with little to no setback. Channel deposits consist of silts, sands, and gravels that have accumulated as an area of overbank and channel deposition since dike construction along the bay was initiated in the early 1900s (PCFWWRA, 2003; Love, personal communication, 2009).

Based on field observations, only the southwestern portion of the evaluated channel reach (Map 4) is bordered with an artificial levee. Geometric channel characteristics and field observations suggest that the levee may have been constructed in two phases, described in Table 2 and shown on Map 4 as "Section A" and "Section B" although an alternative explanation for the difference in levee characteristics is that the levee in Section A has been more recently upgraded as some anecdotal evidence suggests. Section A was likely constructed during or shortly after an original channel section of Salmon Creek was bypassed near the farmhouse on Hookton Road and Hookton Bridge. This levee section appears to be more robust and stronger than Section B but exhibits several erosional features on its inside edge. Section B of the levee is generally narrower and lower in height than Section A and it appears to be less well constructed. Generally, the Section B levee decreases in height and width from south to north. Stratigraphy observed in eroded portions of both levee sections indicate they have undergone repair in the past, primarily consisting of raising the levee by adding additional material to the top.

Considering the extent and variable heights and widths of the levee section, as well as the amount of setback from the channel, the levee was probably not designed by an engineer but rather constructed by a landowner to reduce flooding on the adjacent pasture lands to the west.

During our field investigation several localities were observed where bank erosion had eroded portions of the levee (Map 4). The erosional features were typically between 3 - 6 m wide and 0.3 - 0.6 m deep, of which up to 40% of any individual feature was levee material. The erosional features were highly variable in size throughout the assessment area and, except at one location, do not appear to have significantly compromised levee integrity, The one exception occurs where bank erosion, levee morphology, and hydraulic conditions have previously resulted in the breaching of the levee (see Map 4). The breaching of this levee section resulted in not only water diversion but a sediment fan composed of silt sized material. The sediment fan had an apex at the breach and covered the floodplain with up to 3" of silt observable over an area of approximately 5000 ft^2. This breach was repaired in the winter of 2008 by the landowner in conjunction with the HBNWR. Observations of further overbank silt deposition made during this investigation suggest the banks of Salmon Creek have overtopped the natural channel just downstream from this site since the repair of the breach. These deposits covered an area of approximately 800 ft^2 up to 1" deep. Although the downstream natural channel is clearly subject to overtopping during normal flood events, the leveed portion of the channel has not been analyzed for the flood recurrence interval that would cause overtopping and potential breaching at other locations.

4.2 Subsurface investigation of the area where the existing channel of Salmon Creek will transition to the proposed channel on HBNWR lands

Currently the proposed channel alignment of the LSCEEP will reoccupy the historic Hookton slough channel through the upper refuge from its southern boundary for approximately 700 feet (Map 2). Observations of historic aerial imagery and anecdotal accounts of previous management activities suggest this channel reach had been abandoned prior to 1948, and is now completely filled with channel sediments; overbank silts, and fill material spread by the previous landowner. There is no obvious remnant topographic expression of the channel within the project area but vegetation changes identifiable on most historic aerial imagery clearly define the previous alignment.

Two localities were chosen to characterize the subsurface stratigraphy in the area where the existing channel will transition to the proposed channel. The first was within the margins of the existing channel, close to where it currently enters the ditched channel on the HBNWR and turns due west. This area was investigated utilizing a gouge core. The second sampling site was on the HBNWR roughly 60 m north of the first location and directly on top of the filled historic Salmon Creek channel (Map 5). This area was trenched with a hydraulic excavator. These two sampling locations were chosen because they were likely to represent the range of geologic substrates expected to be encountered during the excavation and construction of the proposed project channel.

The first site, a channel margin area, was sampled with a gouge core. This hand-driven coring device is used to extract a 2.5 cm diameter core, in multiple sections up to 1 m long, with very little disturbance or compaction. During this investigation we were able to drive the core 1.8 m before refusal. The depth at the base of the core was approximately 1 m below the channel bottom in the existing thalwag. In general the retrieved core sample consisted of unconsolidated muck in the upper section, overlying unconsolidated sand and gravely sand deposits in the lower portion of the core (Map 5). All of the alluvial units described in the core sample were very loose and highly saturated, which made retrieval of intact samples difficult. The contact between the upper silty portion of the core and the sandier section below was gradational over a distance of 2 - 4 cm; the contact between the sandy unit and the gravely sand was diffuse over a distance of 10 - 20cm. Map 5 contains detailed descriptions of the units retrieved in the core.

The trench was located on the HBNWR property where we thought the channel construction work would encounter the historic channel of Salmon Creek. The trench was approximately 60 m long, between 3 and 5 m deep, and susceptible to collapse (Map 5). The trench was logged from the ground surface as it was too dangerous to enter and infeasible to shore. The stratigraphic units were measured by hanging a tape over the edge of the trench and logging the wall from the opposite side in several locations along the trench. The basic stratigraphic section consisted of 1.3 m of clay and sand rich silt overlying mud (silts and clays), with the historic channel of Salmon Creek channelized into the mud unit and overlain by the silt unit. Anecdotal accounts from staff at the HBNWR suggest the previous landowner intentionally spread silt material over portions of the refuge where the trenching was conducted. Although these is no documentation suggesting exactly where this activity occurred, it is possible some of the observed silt deposits in the trench are anthropogenic in origin. Detailed descriptions of the lithologic units are shown on Map 5.

5 DISCUSSION

5.1 Levee Conditions along the Upstream Channel Reach between Hookton Road and the HBNWR

Based on observations of the channel geomorphology and levee conditions, as well as anecdotal accounts, the channel reach on the private property upstream of the HBNWR has an on-going potential to overtop and divert from Salmon Creek into Hookton Slough during annual flood events. This will result in at least partial flanking of the proposed LSCEEP during annual floods and could result in significant diversions and main stem avulsion during large floods. In part, this is likely due to the fact that the entire area historically consisted of tidally influenced mudflats and salt marsh that has artificially been converted to low elevation pasture lands. Recent observations of the Hookton slough area show that significant rainfall, particularly in conjunction with high tides, can cause flooding of the entire South Bay lowland area including the bulk of the HBNWR and sections of Highway 101. Recently, the landowner has obtained a permit to maintain the levee and that the HBNWR, NOAA Fisheries, and PCFWWRA have been conducting ongoing discussions with the landowner about potential methods to address the flow flanking issues.

Based on historic mapping of the wetland areas of the South Bay, the land use history, and the recent observations of flooding conditions, it is likely the flooding problem in the project area is not the direct result of management by any current individuals or entities, but rather an inherent problem associated with high rates of sedimentation from the upper watershed in combination with land conversion of the delta region from wetlands to agricultural/pasture land. The proposed project is located in a delta, and deltas are areas of coastal sediment deposition, dynamic geomorphic processes and frequent flooding. With or without the project, it is likely these phenomena will be unavoidable in the future.

Although the largest floods will certainly inundate the entire project area with water, there is still an opportunity to increase the mainstem channel capacity on Salmon Creek through the private property reach located immediately upstream of the HBNWR. Increasing the capacity of the main channel through this reach could reduce flooding and potential flanking of the project during small to medium sized runoff events and maintain a source of freshwater through the refuge. Three ways to accomplish this would be to: 1) build a setback levee system through the private property reach, 2) increase the channel capacity by deepening or otherwise excavating a larger channel along the same alignment as the existing channel, and 3) allow a controlled headcut from the refuge to propagate upstream. Any endeavor undertaken upstream of the HBNWR would entail negotiations with the upstream landowner to assure that enhancement activities are consistent with the landowners long term management objectives. Furthermore, the limitations and uncertainty related to the success of the project would need to be evaluated and disclosed.

5.1.1 Building a setback levee system

Constructing a setback levee system could allow more flow capacity through the upstream channel reach. This could minimize the amount of overbank flow exiting the Salmon Creek channel system and flowing out to the terminal end of Hookton Slough during periods of moderate flooding. It could also increase the freshwater flow onto the HBNWR and through the proposed estuary enhancement project area. There are several potential limitations for this enhancement activity: (1) it could only benefit the reach between Hookton Road and the HBNWR. Significant flooding occurs upstream of this reach and there is no guarantee that the proposed setback levee wouldn’t be flanked itself upstream of Hookton Road. (2) During larger rainfall events and high tides the setback levee could essentially be bypassed or flooded on all sides making it considerably less effective at transmitting flow from Salmon Creek into the estuary on the HBNWR. (3) There is no obvious location to end the levee system at its upstream or downstream end. This would be particularly problematic if the proposed channel on the HBNWR had less capacity than the upstream channel system. (4) Finally, increased confined flow through the upstream channel reach could increase erosion of the material in the existing channel bed and banks; this could result in undermining the bridge on Hookton Road.

5.1.2 Enlarging the Channel

Enlarging the existing channel through the upstream private property essentially has similar benefits and drawbacks as constructing the setback levee system. In addition, it would require removal of the riparian vegetation that currently exists on the channel banks. Deepening or widening the channel to increase its flow capacity would need to be performed only after hydraulic analyses had been conducted to ensure than the channel’s hydraulic efficiency was not compromised. Although riparian vegetation could be replanted and would likely flourish in a new location, this vegetation appears to play a key role in stabilizing the banks of the existing channel and in providing habitat for various wildlife species.

5.1.3 Allowing a controlled headcut to propagate upstream

Allowing a controlled headcut to propagate upstream from the upper extent of the LSCEEP is also a viable alternative for increasing the flow capacity of the upstream channel reach. This could be accomplished by slow removal of the grade control structures and monitoring the upstream effects. The existing material comprising the channel sediments appear to lend themselves to this approach as they are mostly sands and silts and exhibit little to no cohesiveness. There are several drawbacks to this approach but if conducted in small conservative increments the effects of these drawbacks could be minimized. The first and most significant effect of this alternative would be the potential undermining of the bridge abutments on the Hookton road bridge. Although it is not clear if a headcut would propagate all the way to the bridge, the result of compromising the bridge integrity would be costly and potentially litigious. Second, downcutting of the existing channel would increase the height of the existing channel banks, it is uncertain if the banks could remain stable if their height was increased.

5.2 Subsurface stratigraphy and project constraints where the existing Salmon Creek channel will transition to the proposed, newly constructed channel on HBNWR

5.2.1 Vulnerability of existing channel sediment to headcut erosion

Our characterization of the subsurface geologic substrate in the existing channel verifies the TAC's assumption that the channel could rapidly headcut if no measures are undertaken to establish grade control in the upstream segment of the LSCEEP on the HBNWR. The channel bed and near surface substrate is composed of unconsolidated silts underlain by unconsolidated gravely sands. These units would offer little resistance to headcutting and channel incision. If no actions are undertaken to establish grade control through the oversteepened section on the HBNWR, several negative impacts could result: (1) the channel could establish a migrating headcut that propagates onto the private property upstream of the HBNWR. (2) If a vertical headcut developed and persisted because it was "hung up" on an unknown resistant subsurface layer, or on tree roots, it could temporarily inhibit juvenile fish passage during lower flows. (3) The head cut and associated channel incision could result in some lowering of the channel through the private property reach, resulting in increased bank collapse and increased downstream sedimentation. (4) The headcut could migrate upstream and undermine the abutments on the Hookton Road Bridge. (5) If the channel on the private property reach is lowered enough it could be encompassed by the tidal inundation and subjected to salt water inundation; this could in turn have deleterious affects on the existing riparian vegetation.

The vulnerability of the existing channel sediments to headcut erosion and channel incision has been reviewed with the project engineer and grade control structures will likely be incorporated into the project design of the oversteepened channel reach on the HBNWR property.

5.2.2 Project constraints related to channel design and alignment

A subsurface investigation near the boundary where the proposed channel will transition to the existing channel of Salmon Creek was conducted to characterize the geologic materials likely to be encountered during construction of the LSCEEP. Substrate exposed in the trench suggests there are several geologic units which may be encountered during excavation of the upstream reaches of the proposed estuary channel on HBNWR. Three general units were identified during the trenching: (1) The bulk of the trench contained massive silty clay deposits which we suggest are tidal mud flat deposits, (2) Channelized within these deposits are silty gravely sand deposits which we interpret as the historic channel of Salmon Creek, and (3) Clay-sand silt deposits that overlay all the other units which we interpret as more recent overbank deposits from Salmon Creek and/or anthropogenic deposits from previous land management activities. (Map 5).

Because the alignment of the proposed channel will occupy the historic channel of Salmon Creek in its uppermost reach, there are several geologic constraints that will need to be addressed during the design phase of the project as well as potential unanticipated constraints throughout the upper reach of the LSCEEP. These include: (1) the silty-gravely sand unit that comprises the historic channel of Salmon Creek lacks cohesion and is saturated. If the proposed channel has smaller dimensions than the historic channel, the sideslopes will be at least partly comprised of the silty-gravely sand unit; this unit may not support steep channel sideslopes. (2) Similarly, the clay-sand-silt unit (Qcsm) that likely caps all the other units in reaches 1 and 2 also lacks cohesion and may not support steep channel sideslopes, although observations from the upstream reach suggests dense riparian vegetation can allow similar deposits to hold up to 12' vertical channel sideslopes. (3) Based on observations during trenching activities, the historic channel of Salmon Creek is essentially acting like an underground reservoir; the material comprising this buried channel feature is very porous and permeable and capable of delivering significant amounts of water to the project excavation. During instances when the proposed channel will cross or re-occupy this historic channel potentially hundreds to thousands of gallons of water could be expected to drain to the proposed work site. (4) Given the dynamic nature of deltaic areas and the recent history of routing water through the HBNWR it is likely that unanticipated tidal channels, filled ditches, or other uncharacterized natural or anthropogenic materials may be encountered during excavation of the proposed channel. These could pose problems during channel excavation work and might require on-site design changes because of their properties or configuration.

5.2.3 Project constraints related to grade control structures

Based on the observations of the geologic substrate at the confluence of the proposed and existing channel, and the potential consequences of allowing a headcut to migrate off the property, grade control structures will likely be incorporated into the proposed final design. There area two obvious geologic constraints related to the proposed grade control structures: (1) Because of frequent flooding in the area, the flat deltaic topography, and the erodible geologic substrate in the project area there is a chance one or more of the grade control structures could get flanked during flood events, with stream flow diverting across the adjacent pasture lands. (2) The geologic substrate that the rock grade control structures will foot into may not provide adequate basal support for the structures. This could result in any one of the grade control structures sinking or differentially settling into the excavated channel if channel downcutting occurs or in response to ground shaking during a seismic event, or even simply from exceeding the bearing capacity of the material.

5.3 Other potential project constraints

There are several general geologic constraints that are important to discuss as they relate to this project. Assuming a design life of 50 years, not all of these pose an immediate risk to the project. However, given the uncertainty in the timing and frequency of these processes or events it is prudent to discuss their impacts or the potential constraints they may impose on the project.

Several of the potential project constraints are phenomena related to future earthquakes. The timing and magnitude of expected future earthquakes in the South Bay is not completely clear as there are several fault systems which could affect the area. Of the potential seismic sources, the Cascadia subduction zone (Csz) probably poses the largest threat due to its potential to generate great (>mag. 8) earthquakes and its estimated recurrence interval. Recent space-time diagrams based on earthquake generated turbidites in northern California and Southern Oregon and coastal archives from southern Oregon suggest the Cascadia Subduction zone ruptures in along its entire length as well as in segments (Goldfinger et al, 2008; Goldfinger et al, in press; Satake et al., 1996, 2003; Kelsey et al., 2002; Witter et al., 2003). From the turbidite data a total of 38 events define a Holocene recurrence for the southern Cascadia margin of ~260 years. Probabilities for segmented ruptures range from 7-9% in 50 years for full margin ruptures, to ~30% in 50 years for a southern segment rupture (Goldfinger et al, 2008; Goldfinger et al, in press). The most recent documented large subduction earthquake was in 1700 AD. This suggests the project area may undergo significant subsidence during the assumed design life of the project. This would be in addition to expected eustatic sea-level rise. The magnitude of expected coseismic subsidence is likely between 0.9 - 3.1m/event based on work by Patton and Witter (2004). A better understanding of the timing and magnitude of pre-historic relative sea-level changes as well as projecting estimates of eustatic sea-level rise is critical to reducing the uncertainty related to design parameters for future engineering projects.

5.3.1 Surface fault rupture

The most likely source of surface fault rupture is from the Little Salmon Fault. This fault is the most active of the thrust faults comprising the on-land fold and thrust belt of the southern Cascadia subduction zone (Map 1). The western trace of the fault projects to the north of the proposed project area but there may be undocumented splays that pose a direct threat to the project. The western trace as mapped by Witter et al. (2002) projects directly toward the HBNWR headquarters. Although this may not be a direct threat to the proposed project, it could cause significant disruption to the channel or its grade control structures and downstream tide gates.

5.3.2 Hard ground shaking

The project area has experienced seismic activity with strong ground motion during past earthquakes and it is likely that strong earthquakes causing seismic shaking will occur in this area in the assumed design life of the project. Hard ground shaking is one of the most likely catastrophic geologic phenomena that the project will be subjected to. Table 1 shows the most likely sources of hard ground shaking in the region. CGS estimates of ground acceleration suggest there is a 10% chance the project area will be subjected to 0.8g during the assumed design life of the project. This level of ground shaking has the potential to produce significant deleterious effects on the project including: settlement or differential settlement of hardened channel structures, increased sediment supply from upstream landslides, bank collapse, and liquefaction.

5.3.3 Liquefaction

During strong earthquakes, loose, saturated, cohesionless soils can experience a temporary loss of shear strength and act as a fluid. This phenomenon is known as liquefaction. Liquefaction is dependent on depth to water, grain size distribution, relative density of soils, degree of saturation, and intensity and duration of the earthquake. The potential hazard associated with liquefaction is seismically induced settlement, collapse of channel banks, or lateral spreading.

The likelihood of liquefaction at a given site is highly dependent on peak ground velocities and horizontal ground vibration frequencies (Kostadinov and Towhata, 2002). Because these two phenomena tend to attenuate as the distance from the earthquake source increases, only those earthquakes with appropriate magnitude-distance combinations are capable of inducing liquefaction at a given site (Beroya and Aydin, 2008). Studies conducted utilizing both laboratory and empirical data suggest that liquefaction is likely to take place when peak ground velocities (PGV) exceeds 0.10 m/s and that the upper bound of horizontal ground vibration frequency after liquefaction occurrence is 1.3–2.3 Hz (Kostadinov and Towhata, 2002). These parameters could easily be exceeded by most of the ground shaking sources listed in Table 1.

Historically there have been several documented cases of liquefaction affecting lowland deltaic areas in the Humboldt Bay region. The 1906 earthquake on the San Andreas fault caused over 40 acres of deltaic lands in the Eel River estuary to "have been entirely ruined" with multiple 2'-6' fissures. From the same earthquake, reports from the Fields Landing area include a 6' deep 500' fissure opening up (Lawson, 1908). More recently, the 1992 Petrolia earthquake resulted in several anecdotal accounts of "sand volcanoes" and other features commonly related to liquefaction reported throughout the Humboldt Bay region.

The color change noted in the top of the clay unit (Qch, Figure 5) is likely due to the location of the groundwater table, where sediments above the groundwater are oxidized and sediments below the groundwater are reduced. This would indicate that the average groundwater table is around 1.75 meters below the ground surface and is within the Qch unit. This groundwater elevation is likely to change seasonally and may be higher (within the Qcsm unit) or lower within the Qch unit. Nonetheless on average it is around 1.75m below the ground surface.

Given the high ground water, several sources of hard ground shaking, and interstratified cohesionless and cohesive soils found in the project area we consider this area likely to experience liquefaction-related phenomena within the assumed design life of the project. The consequences of hard ground shaking and subsequent liquefaction within the project area could include settlement of the grade control structures, collapse of the channel margins into the excavated channel, or lateral spreading.

5.3.4 Relative sea-level changes

Relative sea-level changes are a hotly debated issue in coastal areas throughout the world and there is significant uncertainty regarding the recurrence interval and magnitude of the expected changes over the next several decades. This is particularly true in the Humboldt Bay region where relative sea-level changes are driven by coseismic land level changes as much or more than they are by eustatic sea-level changes. There is significant debate as to whether coseismic land-level changes in the Humboldt Bay area are due to faulting events on upper plate faults within the accretionary prism of the Cascadia subduction zone, from the rupture of the subducting mega-thrust itself, or a combination of the two. Most scientists agree that mega-thrust earthquakes on the Cascadia subduction zone do cause significant relative sea-level changes and are likely the primary reason for the observations of buried wetland soils in Humboldt Bay. Nonetheless, the repeated, rapid submergence of coastal areas within Humboldt Bay from coseismic subsidence is unequivocal.

During the trenching investigation two buried wetland soils were observed in the subsurface stratigraphy (Map 5). The buried soils consisted of peat layers interstratified with mud deposits.

The upper contact of the peat layers with the mud appeared very sharp, suggesting rapid change of depositional environments. In several other areas around Humboldt Bay these types of lithostratigraphic contacts are interpreted as earthquake induced subsidence event horizons where a vegetated marsh is submerged into a depositional environment dominated by mud flats. This interpretation is supported by other local observations (Patton and Witter, 2006) suggesting that the project area has undergone rapid coseismic subsidence during the Late Holocene. Since the peat layers are undated and have not been tested for evidence that supports an interpretation of earthquake induced subsidence, the interpretation that the peat layers are a result of earthquake induced subsidence remains equivocal. Even if the peat layers represent subsidence events, one cannot use the elevation difference between events to quantitatively estimate the amount of pre-historic subsidence, nor can it be used to estimate expected future subsidence. To answer these questions would entail a considerable amount of work outside the scope of this project. Regardless, Southern Humboldt Bay has been subjected to repeated coseismic subsidence and past observations of subduction zones around the world suggests that longer intersiesmic intervals result in larger subsidence events.

5.3.5 Tsunami inundation

Several recent studies have documented tsunami inundation within and around the project area (Carver et al., 1993; Patton and Witter, 2006; Li, 1992; Leroy, 2006). Furthermore, observations of sand layers overlaying buried wetland soils, exposed within the trench dug in this study, have characteristics similar to tsunami deposits found in Hookton Slough by Patton and Witter (2004). Recent modeling by CGS shows the entire project area well within the limits of tsunami inundation from a large (Csz) event. Current tsunami run-up estimates are limited to modeling and observations of geomorphic features in the dune field on the North Spit of Humboldt Bay, these suggest tsunami wave heights along the open coast may be between 4 and 7 meters. Wave heights in the Hookton slough area would be significantly lower as the waves are expected to attenuate as they move inland.

5.3.6 Extreme flooding and sedimentation

As mentioned above, the Salmon Creek Delta has historically been an area of coastal sediment deposition, dynamic geomorphic processes, and frequent flooding. The geologic materials comprising the bulk of the watershed upstream of the project area mostly consist of highly erodible sandstones and siltstones of the Wildcat Formation (Ogle, 1953; McLaughlin et al., 2000). Several studies of the upstream watershed demonstrate accelerated sedimentation from anthropogenic activities as well as high rates of natural background sedimentation (PWA, 1999). Given the vulnerability of the watershed to erosion, extreme rainfall events could overwhelm the estuary enhancement project with more sediment than could be routed by the proposed self-sustaining estuarine system envisioned for the LSCEEP. This could result in unintended infilling of the proposed tidal channel and catastrophic re-routing of the channel system within the Salmon Creek Delta. Even if it was feasible to restore the project after such an event, extensive excavation and maintenance of the channel would be required to return it to a functioning system.

6 RECOMMENDATIONS

6.1 Recommendations for the upstream reach between the Refuge and Hookton Road Bridge

There are a number of considerations involved in executing any modifications to the upstream reach between the HBNWR and the Hookton Road Bridge. These include: landowner participation; projected land use of the area; the desired measurable results of any project; legal issues regarding maintenance of project components; and anticipating negative results and preparing for adaptive management strategies. These issues are outside the scope of this project, but the recommendations outlined for this area can be considered a starting point to develop future plans. The two primary options for reducing the likelihood of the project area being flanked during flooding are:

1. Enlarge the existing private property channel to accommodate larger runoff events and reduce the frequency of Salmon Creek diverting overland to Hookton Slough.
2. Construct a set back levee to accommodate larger runoff events and reduce the frequency of Salmon Creek diverting to Hookton Slough.

6.2 Recommendations for the Proposed Enhancement Activities within the Upstream Reach on the HBNWR

Recommendations to facilitate the channel enhancement project are as follows:

1. Prior to construction, the historic channel of Salmon Creek should be delineated and marked in the field. The areas where the proposed channel will exit or cross the historic channel should be identified. At this location A dewatering strategy that takes into consideration the potential for water to pipe from the unexcavated historic channel into the construction site should be established.

2. Dewatering pits should be installed in the historic channel, throughout the areas where the proposed channel will re-occupy or cross it, and water should be pumped away from the construction site to prevent flooding into the project during construction. These pumps will likely be needed several days prior to construction.

Several of the recommendations regard the stability of the bed and banks of the proposed channel where it crosses or re-occupies the historic channel of Salmon Creek. In our opinion a design that does not attempt to re-occupy the historic channel is a better option as it reduces the uncertainty of success involved in stabilizing the channel margins. The typical overbank sediments found in the area provide a more stable substrate from which to construct a new channel as compared to the sandy, unstable sediments of the old channel system.

3. If the proposed channel is going to cross or re-occupy the historic channel of Salmon Creek, then the design channel should include actions to reduce the likelihood of bank collapse due to the characteristics of the sandy sediment filling the channel and to handle the significant volumes of water currently confined within the abandoned channel sediments. Options could include:

   a. Consider alternatives that avoid occupying the historic channel of Salmon Creek. If various constraints make this infeasible; The number of times the proposed channel crosses, enters, or exits the existing channel should be minimized.

b. If the proposed channel will re-occupy the historic channel, the proposed channel needs to be similar or larger in dimensions than the historic channel to avoid having channel margins composed of the silty-gravely sand material currently filling the channel.

c. If the proposed channel needs to be smaller in dimensions than the historic channel, the silty-gravely sand material should be excavated and replaced with a more cohesive, less permeable and less porous substrate better suited for channel margin material. If this action is infeasible or not cost-effective the channel margins could be layed back to 3H-1V and heavily planted with riparian trees. The second alternative would need to include a strict monitoring and adaptive management plan as well as coordination with the HBNWR as this section of the project may be the most vulnerable to unanticipated adjustments.

d. If the proposed channel is simply going to cross the historic channel of Salmon Creek, then A dewatering strategy that takes into consideration the potential for water to pipe from the unexcavated historic channel into the construction site should be established.

4. Geo-fabric should be included in the design specifications for each grade control structure to provide both lateral and basal support. This will reduce load-causing settlement as well as reduce the structures vulnerability to liquefaction and seismically-induced settlement.
5. The most upstream grade control structure should be set 50-100m onto HBNWR property so there is room to conduct adaptive management activities if the grade control structures are flanked or are defeated in other ways
6. Consider designing the last grade control structure so the footing is deep enough to handle all grade changes and design and construct it such that it can be modified to raise or lower the grade if needed.
7. If uncertainty persists in the design specifications of the grade control structures then laboratory tests should be conducted on the various geologic substrates to better determine the geologic characteristics of the material.
8. Side slopes of the proposed channel within the reoccupied reach of Salmon Creek should be 3:1 and planted with riparian trees and other vegetation to reduce the likelihood of liquefaction and bank collapse.
9. The project and the surrounding area should be inspected after every moderate ground shaking event.
10. Expect areas of unstable geologic substrate throughout the proposed channel construction area and plan adaptive management strategies to address these potential issues. Have additional funding for rock armor, large woody debris, and additional excavation measures to support unstable areas exposed during excavation (this may be most pertinent where the new channel crosses unidentified channels or ditches)

7 SOURCES OF UNCERTAINTY

We recognize several sources of uncertainty associated with this project, some of which could be resolved with further analysis, but some of which may not be currently resolvable. The primary sources of uncertainty include:

1. The stratigraphy documented in the core may not reflect the stratigraphy throughout the entire reach of the channel upstream of the HBNWR. Any change in the stratigraphic units

could influence the substrates vulnerability to headcut erosion.

2. The stratigraphy documented in the trench may not reflect the stratigraphy throughout the entire upper refuge. There are likely a number of historic and prehistoric buried channels in the project area that were not identified in the limited subsurface sampling that was conducted. Similarly, historic aerial imagery suggests there are several drainage canals throughout the upper refuge. These canals no longer exhibit any topographic expression so they are likely filled in, but the geologic substrate filling the canals has not been documented.
3. The geologic units encountered in the trench were described in the field but were not subjected to laboratory analysis. Tests may need to be conducted on the samples to determine design parameters for the grade control structures.
4. There is significant uncertainty in how the geologic constraints such as surface fault rupture, hard ground shaking, liquefaction and tsunami inundation will affect the project in the future. This is exacerbated by the fact that no engineering design life has been explicitly stated for the project.
5. There is also significant uncertainty in the projections of relative sea-level change that may affect the LSCEEP in the future. This uncertainty can be divided into two areas of research: A) eustatic sea-level changes - This is the projected rise in sea-level from global warming and ocean water volume expansion. Estimates have been attempted globally but this phenomenon is variable on a regional scale. B) Relative sea-level change from local tectonic activity. This phenomenon has been well documented in the Humboldt Bay region but it needs more research before it can be fully utilized in engineering designs with any certainty of the frequency and magnitude.

8 CONCLUSIONS

This report presents the findings of PWA's geological evaluation of the upper portion of the Salmon Creek Estuary Enhancement Project. The purpose of the investigation was to compile geologic background material and evaluate potential geologic constraints as they relate to the proposed estuary enhancement activities proposed in Design Alternative B in the 2003 study entitled *Lower Salmon Creek Delta Salmonid Habitat Enhancement Opportunities* (PCFWWRA, 2003). Our project included documentation of the extent and conditions of the levee along the upstream reach between the HBNWR and the Hookton Road Bridge, and a characterization of subsurface geologic units at the area where the proposed project channel will transition to the existing Salmon Creek Channel.

Field observations of the upstream reach between the HBNWR and the Hookton Road Bridge indicate only the southwestern portion of the channel is bordered by a levee. Geometric characteristics suggest the levee may have been constructed in two phases (Section A and Section B; Table 2 and Map 4). Section A was likely constructed when an original channel section of Salmon Creek was bypassed or shortly thereafter. It appears much more robust than Section B but exhibits several erosional features on its inside edge. Section B of the levee is generally thinner and lower in geometry than Section A and appears to be constructed with a level of effort significantly less than Section A. An alternative explanation is that the levee in Section A has been more recently upgraded as some anecdotal evidence suggests.

Two localities were chosen to characterize the subsurface stratigraphy in the area where the existing channel will transition to the proposed channel. The first was within the margins of the existing channel, close to where it currently enters the ditched channel on the HBNWR, this area was investigated utilizing a gouge core. The second was on the HBNWR roughly 60m north of the location where the channel currently transitions to the ditched channel (Map 5). This area was trenched with a hydraulic excavator. These locations were chosen because they were likely to represent the suite of geologic substrates expected to be encountered in the existing channel and during the excavation of the proposed channel in the upper refuge.

Generally, the geologic substrate in the transition area is composed of clay-sand silt deposits overlaying thick bay mud deposits. The historic channel of Salmon Creek was identified in the trench and is observed as a generally trapezoidal shaped feature inset into the bay mud deposits and overlain by the clay-sand silt deposits. The channel deposits consist primarily of poorly sorted sand with secondary gravel and fine grained material.

Several project constraints were evaluated and recommendations were developed to mitigate for them. Primary constraints considered include: the potential for the project to be flanked due to upstream channel conditions and the existing topographic configuration, the vulnerability of existing channel sediment to headcut erosion, project constraints related to channel design and alignment, project constraints related to grade control structures, and other geologic project constraints such as: surface fault rupture, hard ground shaking, liquefaction, relative sea-level changes, tsunami inundation, and extreme flooding and sedimentation.

9 CERTIFICATION AND LIMITATIONS

This report entitled "*Geologic Evaluation of the Upstream Portion of the Salmon Creek Estuary Enhancement Project, Humboldt County, California*" was prepared by a licensed professional geologist at Pacific Watershed Associates (PWA), and all information therein is based on data and information collected by PWA staff. The summary of background geologic data, collection of data and analysis, evaluation of geologic constraints, and all recommendations were similarly conducted by a California licensed professional geologist at PWA.

The interpretations and conclusions presented in this report are based on a study of inherently limited scope. Observations are qualitative, or semi-quantitative, and confined to surface and subsurface expressions of limited extent. Interpretations of problematic geologic and geomorphic features and geomorphic processes are based on the information available at the time of the study and on the nature and distribution of existing features.

The conclusions and recommendations contained in this report are professional opinions derived in accordance with current standards of professional practice, and are valid as of the submittal date. No other warranty, expressed or implied, is made. PWA is not responsible for changes in the conditions of the property with the passage of time, whether due to natural processes or to the works of man, or changing conditions on adjacent areas. Furthermore, to be consistent with existing conditions, information contained in the report should be re-evaluated after a period of no more than one year, and it is the responsibility of the landowner to ensure that all recommendations in the report are reviewed and implemented according to the conditions existing at the time of construction. Finally, PWA is not responsible for changes in applicable or appropriate standards beyond our control, such as those arising from changes in legislation, regulations, or the broadening of knowledge which may invalidate any of our findings.

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10 REFERENCES

California Geologic Survey, interactive map of potential ground accelerations in California. (http://www.conservation.ca.gov/cgs/rghm/psha/PublishingImages/pga.jpg).

Carver, G.A., and Burke, R.M., 1987, Late Pleistocene and Holocene paleoseismicity of Little Salmon and Mad River thrust systems, northwestern California--implications to the seismic potential of the Cascadia subduction zone [abs.]: Geological Society of America Abstracts with Programs, v. 19, p. 614.

Clarke, S. H., 1987, Geology of the California continental margin north of Cape Mendocino, in D. W. Scholl, A. Grantz, and J. G. Vedder, eds., Geology and resource potential of the continental margin of western North America and adjacent ocean basins - Beaufort Sea to Baja California, Circum-Pacific Council for Energy and Mineral Resources, Earth Science Series, p. 15A1-15A8.

Carver, G. A., Abramson, H. A., Garrison-Laney, C. E., and Leroy, T. H., 1998, paleotsunami evidence of Subduction earthquakes for northern California: Final report for Pacific Gas and Electric Company., 164p., plus appendicies.

Clarke, S.H., Jr., and Carver, G.A., 1992, Late Holocene tectonics and paleoseismicity, southern Cascadia subduction zone: Science, v. 255, p. 188-192.

Dengler, L, A., McPherson, R. C., and Carver, G. A., 1992, Historic Seismicity and Potential Source Areas of Large Earthquakes in North Coast California: in Burke, R.M., and Carver. G.A., eds., A look at the southern end of the Cascadia Subduction Zone and the Mendocino Triple Junction: Pacific Cell, Friends of the Pleistocene field trip guidebook, p. 112-119.

Geomatrix Consultants, 1994, Seismic Ground Motion Study for Humboldt Bay Bridges on Route 255, unpublished consultants report for the California Department of Transportation.

Goldfinger, C., Kelly Grijalva, Roland Bürgmann, Ann E. Morey, Joel E. Johnson, C. Hans Nelson, Julia Gutiérrez-Pastor, Andrew Ericsson,* Eugene Karabanov,† Jason D. Chaytor,‡ Jason Patton, and Eulàlia Gràcia, 2008, Late Holocene Rupture of the Northern San Andreas Fault and Possible Stress Linkage to the Cascadia Subduction Zone. Bulletin of the Seismological Society of America, Vol. 98, No. 2, pp. 861–889, April 2008, doi: 10.1785/0120060411

Goldfinger, C., C. Hans Nelson, Joel E. Johnson, Ann E. Morey, Julia Gutiérrez-Pastor†, Eugene Karabanov, Andrew T. Eriksson, Eulàlia Gràcia, Gita Dunhill, Jason Patton, Randy Enkin, Audrey Dallimore, Tracy Vallier, and the Shipboard Scientific Parties, in press. Turbidite Event History: Methods and Implications for Holocene Paleoseismicity of the Cascadia Subduction Zone. USGS Special Report, in press.

Jacoby, G., Carver, G., A., Wagner, W., 1995. Trees and herbs killed by an earthquake 300 years ago at Humboldt Bay, California, Geology, vol. 23: 77-80

Kelsey, H.M., and Carver, G.A., 1989, Late Neogene and Quaternary tectonics associated with northward growth of the San Andreas transform fault, northern California: Journal of Geophysical Research, v. 93, no. B5, p. 4,797-4,819.

Kelsey, H.M., Witter, R.C., and Hemphill-Haley, E., 2002, Plate-boundary earthquakes and tsunamis of the past 5500 yr, Sixes River estuary, southern Oregon: Geological Society of America Bulletin, v. 114, p. 298–314.

Kilbourne, R.T., 1985, DMG Open-File Report 85-04, Geology and Geomorphic Features Related to Landsliding, Fields Landing 7.5' Quadrangle, Humboldt County, California Scale 1:24,000

Lawson, A.C., 1908, ed., The California earthquake of April 18, 1906: Report of the State Earthquake Investigations Commission: Washington, D.C., Carnegie Institution of Washington, Pub. no. 87, v. I and II, reprinted 1969. Available from: http://www.carnegieinstitution.org/editorial_offices.html

Leroy, T.H., 2006, Coastal sand dune stratigraphy and geomorphology of the North Spit of Humboldt Bay: in Hemphill-Haley, M., Leroy, T.H., McPherson, R.M., Patton, J.R., Stallman, J., Sutherland, D., Williams, T., eds., Signatures of Quaternary crustal deformation and landscape evolution in the Mendocino deformation zone, NW California: Pacific Cell, Friends of the Pleistocene field trip guidebook.

Li, Wen-Hao, 1992, Evidence for late Holocene coseismic subsidence in the lower Eel River valley, Humboldt County, Northern California: M.S. Thesis, Arcata California, Humboldt State University, Department of Geology, 87p.

McCrory, P. A., 1996, Evaluation of fault hazards, Northern Coastal California. U.S. Geological Survey open file report 96-656

McCrory, P. A., 2000, Upper plate contraction north of the migrating Mendocino triple junction, northern California: Implications for partitioning of strain, Tectonics, vol. 19, no. 6, pages 1144-1160

McLaughlin R.J., Ellen, S.D., Blake, M.C. Jr., Jayko, A.S., Irwin, W.P., Aalto, K.R., Carver, G.A., Clarke, S.H. Jr., 2000, Geology of the Cape Mendocino, Eureka, Garberville, and Southwestern part of the Hayfork 30 X 60 minute quadrangles and adjacent offshore area, northern California: U.S. Geological Survey Miscellaneous Field Studies MF-2336. Available from: http://wrgis.wr.usgs.gov/map-mf/mf2336/

Ogle, B.A., 1953, Geology of the Eel River Valley area, Humboldt County, California: Sacramento, CA, California Department of Conservation, Division of Mines Bulletin 164, 128 p.

Pacific Coast Fish, Wildlife and Wetlands Restoration Association, 2003, Lower Salmon Creek Delta Salmonid Habitat Enhancement Opportunities. Report for the California Department of Fish and Game and the Humboldt Bay National Wildlife Refuge.

Patton, J., 2004, Late Holocene coseismic subsidence and coinicident tsunamis, southern Cascadia subduction zone, Hookton Slough, Humboldt Bay, California: M.S. thesis, Arcata, California, Humboldt State University, 71 p.

Patton, J.R., and Witter, R., 2006, Late Holocene coseismic subsidence and coincident tsunami, southern Cascadia Subduction zone, Hookton slough, Wigi (Humboldt Bay), California: in Hemphill-Haley, M., Leroy, T.H., McPherson, R.M., Patton, J.R., Stallman, J., Sutherland, D., Williams, T., eds., Signatures of Quaternary crustal deformation and landscape evolution in the Mendocino deformation zone, NW California: Pacific Cell, Friends of the Pleistocene field trip guidebook.

Pacific Watershed Associates, 1999, Watershed Assessment and Erosion Prevention Planning Project, Salmon Creek Watershed, Humboldt County, California: Report prepared for the California Department of Fish and Game.

Satake, K., Shimazaki, K., Tsuji, Y., and Ueda, K., 1996, Time and size of a giant earthquake in Cascadia inferred from Japanese tsunami records of January 1700: Nature, v. 379, p. 246–249.

Satake, K., Wang, K., and Atwater, B.F., 2003, Fault slip and seismic moment of the 1700 Cascadia earthquake inferred from Japanese tsunami descriptions: Journal of Geophysical Research, v. 108.

Vadurro, G.A., 2006, Amount and rate of deformation across the Little Salmon fault and Table Bluff anticline within the on-land portion of the southern Cascadia Subduction zone fold and thrust belt, NW California: in Hemphill-Haley, M., Leroy, T.H., McPherson, R.M., Patton, J.R., Stallman, J., Sutherland, D., Williams, T., eds., Signatures of Quaternary crustal deformation and landscape evolution in the Mendocino deformation zone, NW California: Pacific Cell, Friends of the Pleistocene field trip guidebook.

Vadurro, G.A., Bickner, F., Lindberg, D., Manhart, G., Watt, C., 2006, Fault surface rupture and fold hazard evaluation of the Little Salmon fault at the College of the Redwoods, Eureka campus, southern Cascadia subduction zone fold and thrust belt, NW California: in Hemphill-Haley, M., Leroy, T.H., McPherson, R.M., Patton, J.R., Stallman, J., Sutherland, D., Williams, T., eds., Signatures of Quaternary crustal deformation and landscape evolution in the Mendocino deformation zone, NW California: Pacific Cell, Friends of the Pleistocene field trip guidebook.

Valentine, D. W., 1992, Late Holocene stratigraphy as evidence for late Holocene paleoseismicity of the southern Cascadia subduction zone, Humboldt Bay, California: M.S. thesis, Arcata, California, Humboldt State University, 84 p.

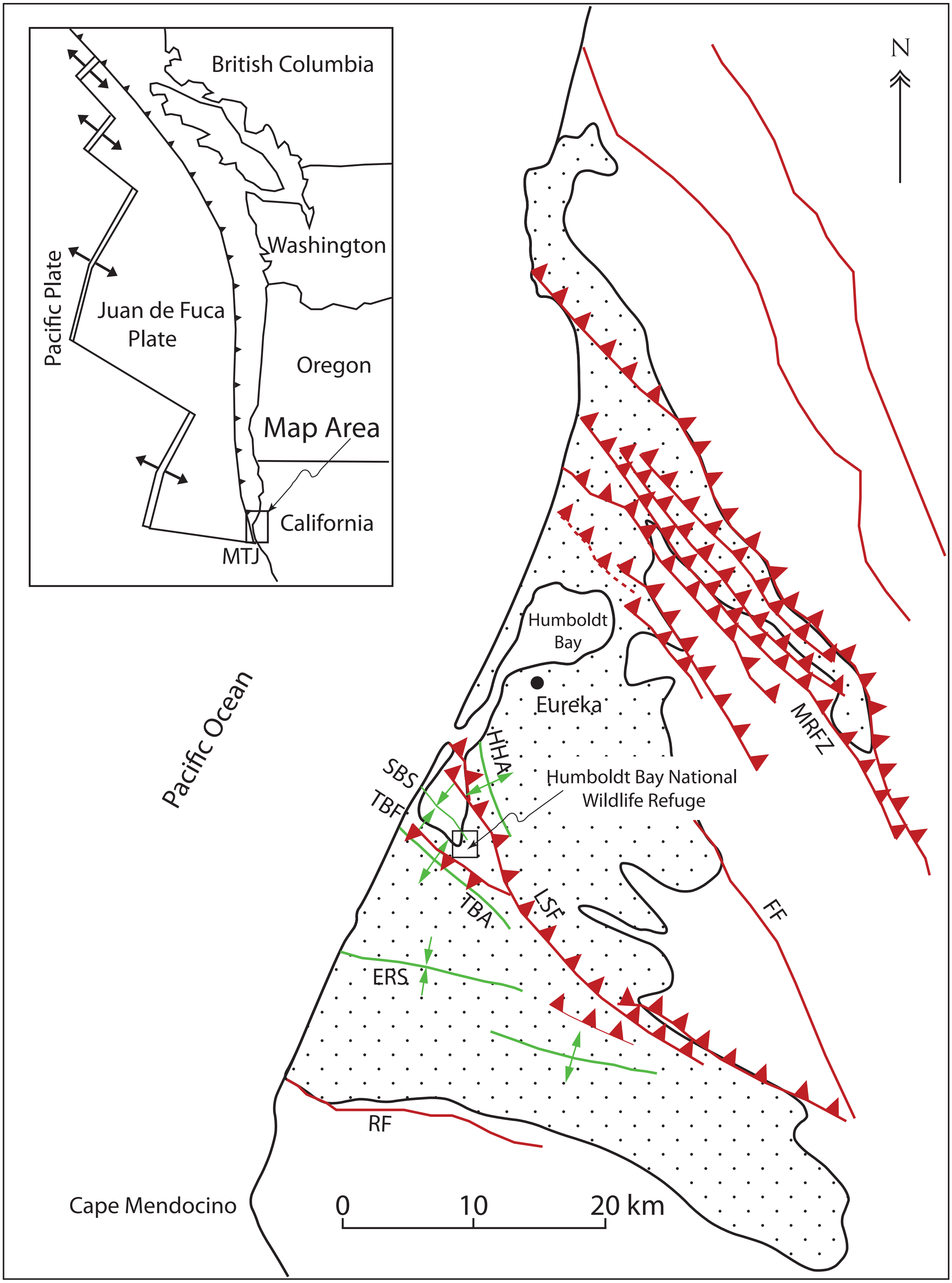
Vick, G. S., 1988, Late Holocene paleoseismicity and relative sea level changes of the Mad River Slough, northern Humboldt Bay, California: M.S. thesis, Arcata, California, Humboldt State University, 87 p.

Williams, T. B., 2003, The geodetic signature of modern deformation (1993-2002) within the southern Cascadia Subduction zone, Northwestern California: M.S. thesis, Arcata California, Humboldt State University, 88p.

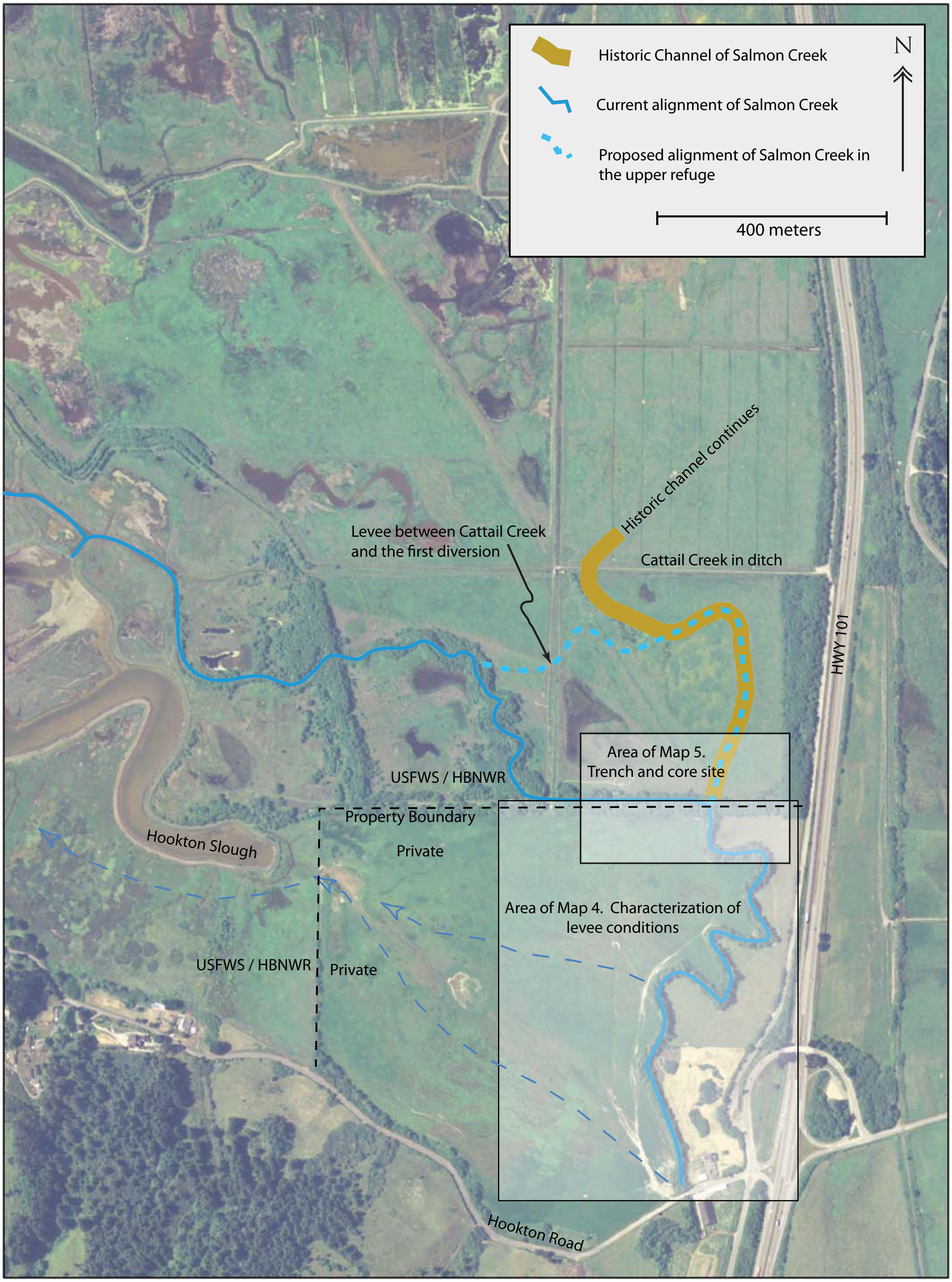
Witter, R. C., Patton, J. R., Carver. G. A., Kelsey, H. M., Garrison-Laney, C., Koehler, R. D., and Hemphill-Haley, E., 2002, Upper-plate earthquakes on the western Little Salmon Fault and contemporaneous subsidence of the southern Humboldt Bay over the last 3,600 years, Northwestern California. Final technical report for the U.S. Geological Survey National Earthquake Hazards Reduction Program Award No. 01HQGR0125.

Witter, R.C., Kelsey, H.M., and Hemphill-Haley, E., 2003, Great Cascadia earthquakes and tsunamis of the past 6700 years, Coquille River estuary, southern coastal Oregon: Geological Society of America Bulletin, v. 115, p. 1289–1306.

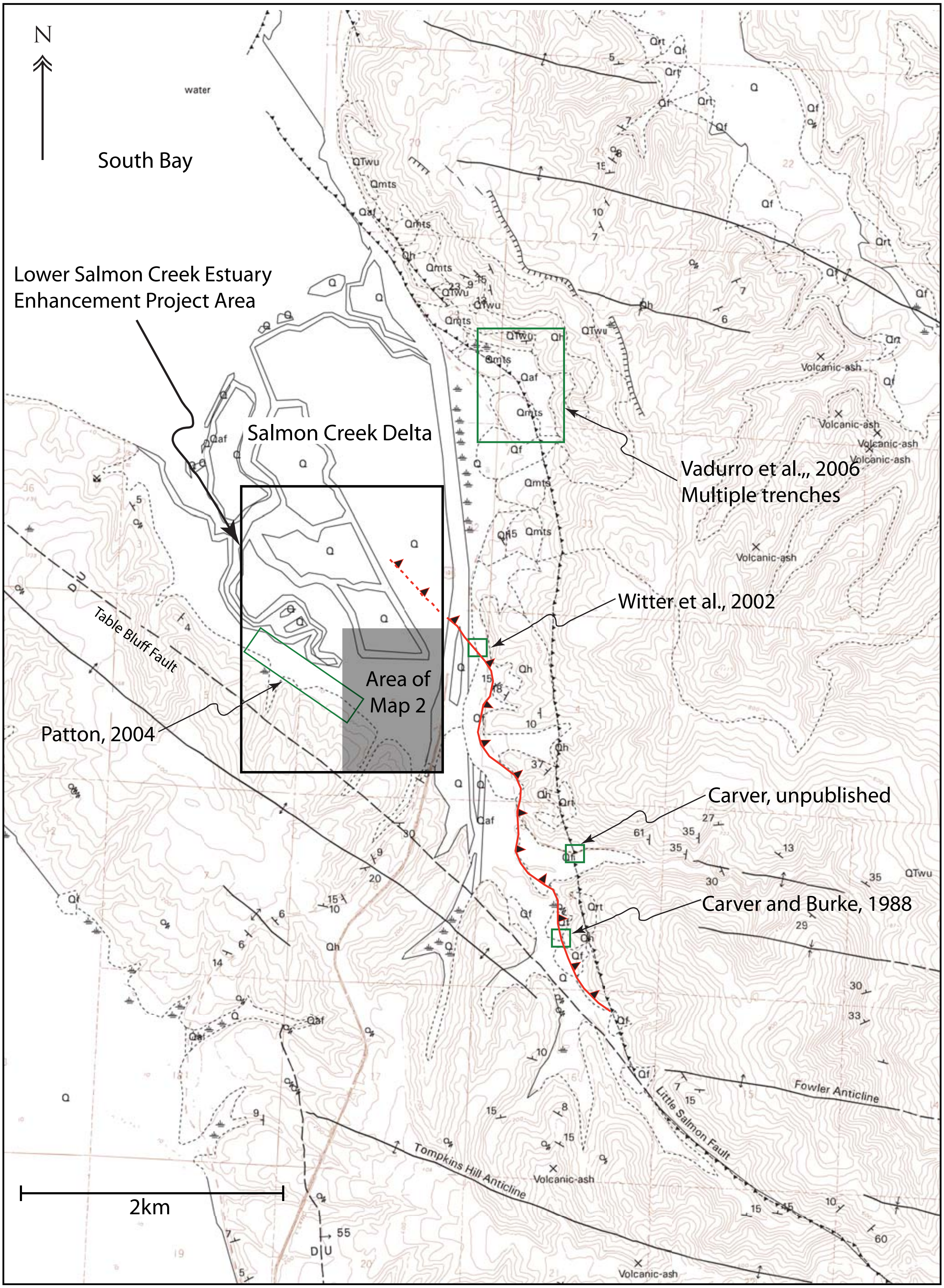
Woodward-Clyde Consultants, 1980, Evaluation of the potential for resolving the geologic and seismic issues at the Humboldt Bay Power Plant unit no. 3: Oakland, CA, URS Corp. (formerly Woodward-Clyde Consultants), Report for Pacific Gas and Electric Co.



Map 1. Project location and tectonic map of the Lower Salmon Creek Estuary Enhancement Project. Dotted area delineates the Neogene Wildcat Group, Falor Formation, and Pleistocene Marine terraces (After Kelsey and Carver, 1988 and Witter and others, 2002). MRFZ, Mad River Fault Zone; HHA, Humboldt Hill Anticline; SBS, South Bay Syncline; LSF, Little Salmon Fault; TBF, Table Bluff Fault; TBA, Table Bluff Anticline; FF, Freshwater Fault; ERS, Eel River Syncline; RF, Russ Fault.

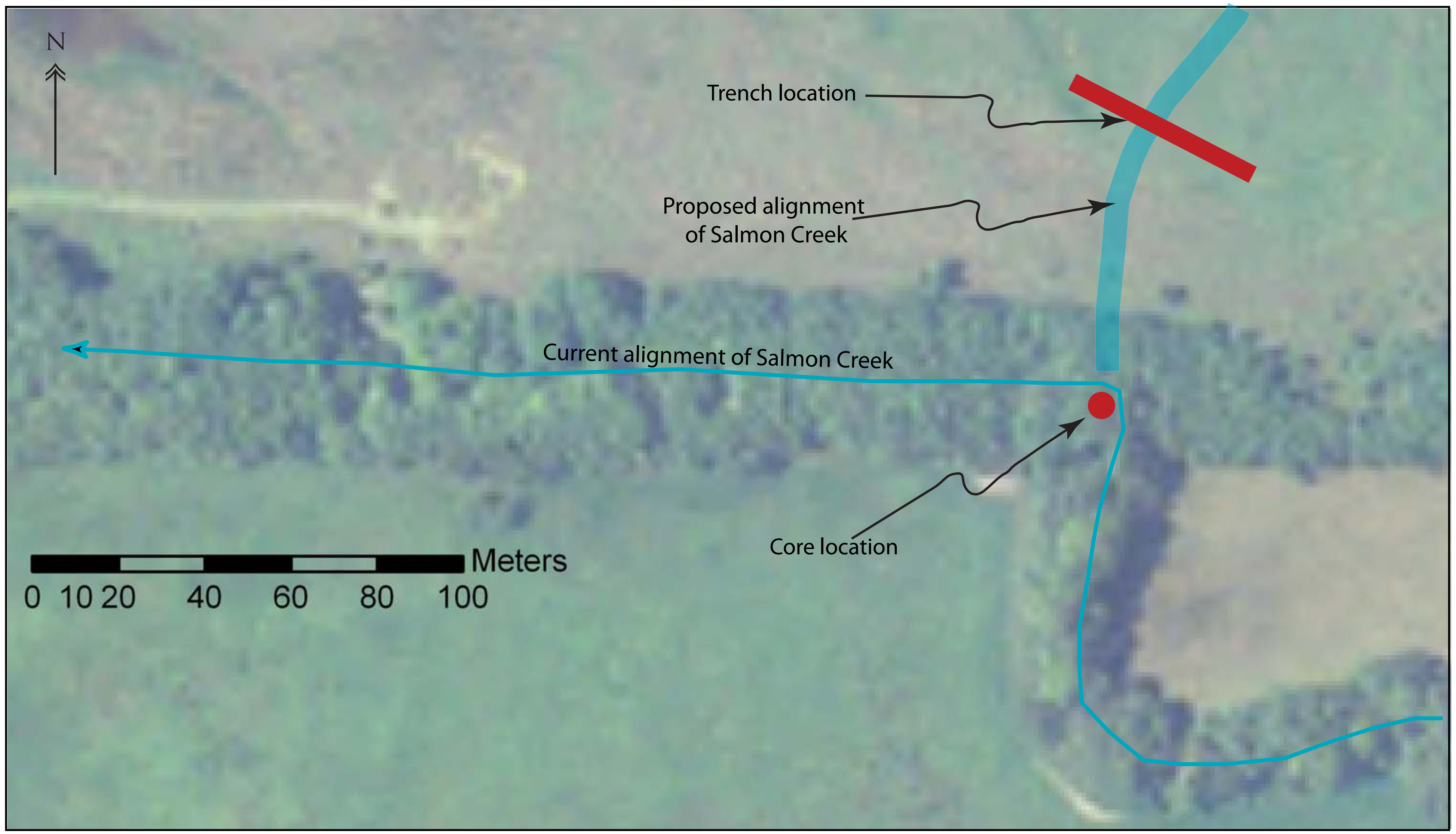


Map 2. Location map showing the primary areas of the focus of this investigation and points of interest. Dashed lines with arrowheads indicate directions of recently observed overbank flow routes of Salmon Creek on the private property upstream of the HBNWR. Flow routes modified from PCFWWRA, 2003.



Map 3. Geologic map of the Lower Salmon Creek Estuary Enhancement Project area. Map modified from Kilbourne, 1985. Green boxes indicate areas of recent paleoseismic investigations. Red fault is recently mapped western trace of the Little Salmon Fault. Shaded block within the project area is the focus of this project.

Map 4. Extent and classification of the levee system on the private property directly upstream of the Humboldt Bay National Wildlife Refuge, Humboldt County, California.



Qml — Clay-sand **Silt**- Medium brown Clay and sand rich silt , very loosely consolidated and highly saturated (essentially muck), no roots but likely partly composed of organic matter. This material essentially liquefied during core extraction, it is probably composed of bank slough and recent channel deposits.

Qsm — Silty **Sand**- Blue-grey, silt rich sand. Sand is moderately sorted, fine to course and unconsolidated. There are occasional herbaceous plant fragments scattered throughout the unit. This material is highly saturated and has no cohesive properties.

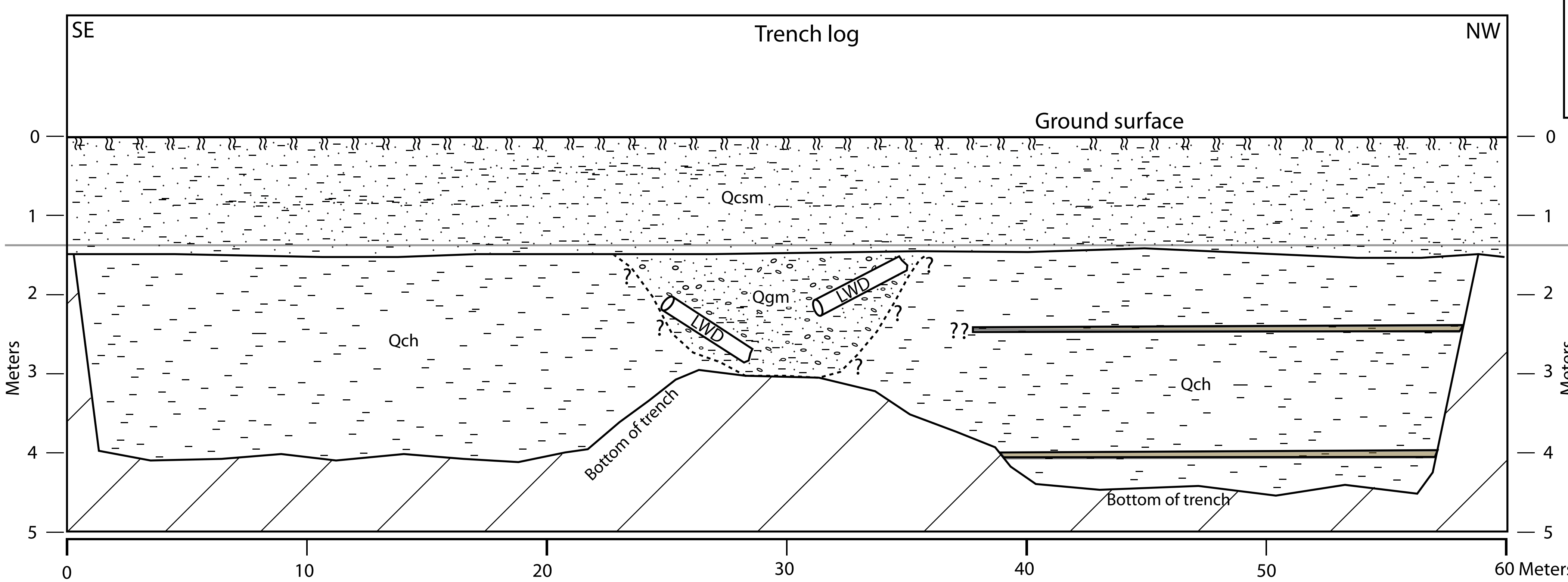
Qcsm — Clay-sand- **Silt**- Reddish brown, clay rich silt with very minor traces of fine sand. The material is not homogenous and contains discontinuous layers of clay rich material ranging in thickness from 5-20cm. It also contains discontinuous layers of horizontal oxidized banding ranging from 2-25cm in thickness. There is minor soil development in this unit at the ground surface (see description below). There are abundant 1-5mm diameter roots throughout the unit increasing in density toward the top. This material exhibits minimal cohesive properties

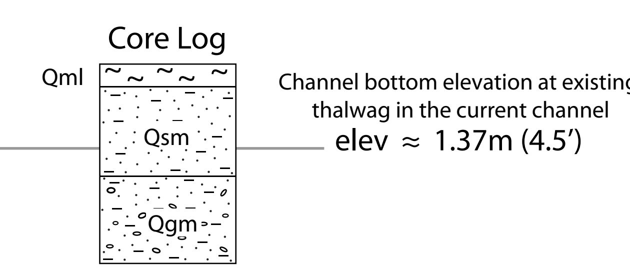
Qch — Silty **Clay**- Massive, medium grey, silt rich clay with trace amounts of fine sand throughout the unit. Freshly excavated material is blue-grey in color but quickly turns to a medium grey. The Upper 0.3m of the unit is medium brown in color and grades to the medium grey clay over a 0.15m distance. roots are very rare and are all smaller than 2mm in diameter. There is occasional large woody debris randomly scattered throughout the unit mostly consisting of redwood logs and root fragments. The clay is very cohesive and holds relatively steep trench walls compared to other units in the trench. The clay has a medium consistency and can be penetrated several inches by ones thumb with moderate effort. This consistency roughly coensides with an unconfined compressive strength of 0.5-1.0 tsf.

Qgm — Silt-gravel- **Sand**- Medium blue-grey sand with minor silt and gravel. The sand is poorly sorted, fine to course, highly saturated material. The silts are mixed throughout the unit and make up a small portion of the overall matrix. The gravel makes up roughly 5% of the unit and consists of well rounded, 1-5cm clasts fully supported by the matrix. The unit is highly saturated and exhibits characteristics suggestive of high porosity and high permiability. Abundant large woody debris consisting of sawed off redwood trees up to 0.75m diameter and 3m long can be found throughout the unit.

Soil- Minor soil development at current ground surface. Soil is essentially an oxidized C horizon with slightly blocky structure and abundant roots ranging in diameter from 1-3mm.

Buried wetland soil- Wetland soil consisting of fibrous peat and abundant roots. Peat is brown and has many preserved plant parts some of which are rooted down into the underlying clay unit. Some samples were observed to have multiple .5-1cm sand layers overlying the peat. The upper contact of the peat units with the overlying clay unit is quite sharp (1-2mm) .





Map 5. Locations and logs of the trench and core taken from the area where the existing channel of Salmon Creek will transition into the proposed channel. The grey line through both the core and trench log represents the current elevation of the channel in the existing thalweg.

Appendix E
Implementation Cost Estimate

Opinon of Probable Construction Costs for 90% Design Submittal
Salmon Creek Phase 2 Habitat Enhancement Project

Michael Love & Associates
Hydrologic Solutions
PO Box 4477 • Arcata, CA 95518 • (707) 476-8938

DATE: 1/14/10

Item		Estimated Quantity	Unit Measure	Unit Price	Total Amount
	General				
1	Mobilization	1	LS	$20,000	$20,000
2	Fish Relocation*	5	Day	$2,000	$10,000
3	Maintenance of Traffic/C.A.R	1	LS	$5,000	$5,000
4	Cultural Resource Monitoring	20	hrs.	$120	$2,400
	Materials to be Furnished*				
5	Engineered Streambed Material Rock for Reach 1 Rock Weirs	510	Ton	$35	$17,850
6	Rock for Anchoring Log Structures	140	Ton	$31	$4,340
8	Geotextile for Rock Weirs	1,300	SY	$4	$5,200
9	Soil Stabilization Matting	1,200	SY	$2	$2,400
10	1"x3" Stone for Construction Access Road Upgrades	2,600	Ton	$37	$96,200
	Construction				
11	Excavation (Includes salvaging and stockpiling clay and topsoil)	48,135	CY	$5	$240,675
12	Install Compacted salvaged clay bankfull (Cattail Creek Berm, Log Step Pool Channel Bottom)	3,100	CY	$10	$31,000
13	Hauling and Installation of Excavated Material in Overflow or as Directed by Refuge	45,035	CY	$10	$450,350
14	Install Rock Weirs and Geotextile	510	Ton	$62	$31,620
15	Install 1"x3" Stone for Construction Access Road Upgrades*	2,600	Ton	$5	$13,000
16	Install Pond Log Habitat Structures, Log Step Pools, Log Jam, and Log Vanes with anchor hardware	60	EA	$500	$30,000
17	Install Rock Anchors for Log Structures	140	Ton	$78	$10,850
19	Install Soil Stabilization Matting	1,200	SY	$3	$3,600
20	Collect and Install Riparian revegetation (4' willow cuttings @ 2'OC)	5,600	EA	$2	$8,400
21	Collect and Install Willow Brush mattress	200	SY	$10	$2,000
22	Permanent Seeding and Mulching	203,862	SY	$0.50	$101,931
23	Clearing and Grubbing	3	Acre	$1,000	$3,000
24	Install and Remove Temporary Ford at Diversion Ditch	1	EA	$5,000	$5,000
25	Temporary Erosion & Sediment Control	1	LS	$10,000	$10,000
26	Furnish & Install Temporary Sheet Piling	1,500	SF	$20	$30,000
27	Water Management	1	LS	$45,000	$45,000
	Subtotal Construciton				**$1,179,816**
	15% Contingency				$176,972
	Total Construction				**$1,356,788**

** Items that may be provided by USFWS*

Note:
Cost estimate does not include preparing final PS&E (100% submital), Project Mangament, Water Management/Fish Passage structureBidding Services, and Construction Management & Inspection.