PROJECT CONCEPTUAL DESIGN REPORT ◦ DECEMBER 31, 2014

Redwood Creek Estuary Restoration and Levee Rehabilitation Conceptual Design Project Orick, Humboldt County, California

PREPARED FOR

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Overview

A large-scale, multiple-objective project is needed to restore the Redwood Creek estuary and rehabilitate the Redwood Creek Flood Control Project near the community of Orick in northern Humboldt County. Restoration of hydraulic, sediment transport, and floodplain processes is needed to help the estuary regain some of its former form, function, resiliency, and productivity. Rehabilitation of the Flood Control Project is needed to address design deficiencies and provide acceptable, sustainable flood protection. Humboldt County consulted with adjacent landowners and a Peer Review Committee to develop conceptual designs for a multiple-objective project with the primary goals of achieving estuary restoration and levee rehabilitation and being compatible with adjacent agricultural land use. Substantial contributions from this planning study included facilitating stakeholder dialogue and improving the understanding of natural processes, desired conditions, and potentially feasible project concepts. Primary funding for this planning study was provided by the California Department of Fish and Wildlife (formerly Department of Fish and Game) through the Fisheries Restoration Grant Program.

Background

The Redwood Creek Flood Control Project consists of a system of two earthen embankment levees and associated infrastructure along approximately 3.4 miles of lower Redwood Creek, extending into the Redwood Creek estuary. Construction of the Flood Control Project by the U.S. Army Corps of Engineers from 1966 to 1968 included excavation and enlargement of the channel to a target geometry and placement of earthen embankments along each bank. The Flood Control Project is currently operated and maintained by Humboldt County.

Construction of the Flood Control Project caused major physical changes to the lower reach of Redwood Creek and its estuary, which includes North Slough, lower Sand Cache Creek, Middle Slough, South Slough, and lower Strawberry Creek. As a result, estuary volume has been reduced by over one-half of its pre-levee size due to sediment deposition, and fish habitat and water quality have been severely impaired. The net result has been a reduction in the ecological function of the estuary in terms of productivity and survival of fish and other aquatic species. Desired ecological conditions include increased low and high flow habitat capacity; increased duration of suitable water quality conditions; increased winter rearing habitat; and improved growth rates and productivity. Restoration of the Redwood Creek estuary would provide substantial benefit for the recovery of estuarine fish species including three salmonid species (coho salmon, Chinook salmon, and steelhead) listed as threatened under the federal Endangered Species Act, in addition to other estuarine dependent species.

The Flood Control Project is impaired by the deposition of large volumes of sediment, which has reduced the project's flood capacity from the level of protection specified by Congress (77,000 cubic feet per second with three feet of freeboard). Current flood capacity is highest at the upstream extent of the levee system and decreases progressively downstream. The lower 2,300 feet of the Flood Control Project has a capacity of approximately 53,000 cubic feet per second, which corresponds to a 2-percent annual-chance flood (50-year recurrence interval flood). Fundamental design flaws, rather than lack of maintenance, are the root cause of the sediment impairment. A trapezoidal channel excavated several feet below the equilibrium bed elevation was not a stable, sustainable geometry for an alluvial channel with ongoing sediment supply. Construction of the levees also reduced the ability of North and South Sloughs to flush sediment, which contributes to flooding of adjacent privately owned pastures and public roads. In addition, recent studies have identified localized areas on the levee that do not meet current standards for seepage, underseepage, and slope stability. A fundamental rehabilitation of the Flood Control Project is needed to accommodate sediment inflow and achieve an acceptable level of flood protection that can be sustained with normal maintenance. Improvements are needed to regain active status in the Corps of Engineers Rehabilitation and Inspection Program and achieve certification and accreditation on the FEMA Flood Insurance Rate Map.

The lower Redwood Creek valley contains privately owned agricultural land adjacent to the Flood Control Project. Conceptual designs were developed with the goal of maintaining agricultural productivity and limiting the net loss of agricultural land use to the greatest extent possible while meeting other project goals. It is assumed that affected private landowners would be fairly compensated for impacts associated with levee modifications. In addition, the project would need to be consistent with the resource protection and preservation responsibilities of the National Park Service for affected federal land in Redwood National Park.

Historical Conditions and Processes

Historically, Redwood Creek flowed through its last downstream meander in the feature currently designated as South Slough. Historical estuary conditions were dependent on the interaction between coastal processes, river and floodplain flows, and sediment dynamics. The configuration of the estuary was dynamic year to year and depended on the relative energy delivered by the ocean and river, and fluvial and marine sediment supplies. Annually, the estuary was shaped by sediment deposition from coastal processes and river transport and sediment removal by tidal and high Redwood Creek flows. High river flows were likely the dominant mechanism that flushed marine-derived sediments from the estuary, through multiple flow paths: interaction between Redwood Creek (flowing through South Slough) and the north headland; overbank flooding into Middle Slough; and floodplain flows into North Slough.

Historical aerial photographs (1936-1968) show a system that was resilient to flood events and associated riverine sediment deposition. Large floods would typically deposit sediment into the estuary, but the estuary would persistently maintain its general planform and the slough channels would remain connected to the embayment. Subsequent moderate to high river flows would help flush fluvial sediment from the estuary and slough channels into the ocean.

The physical changes caused by construction of the Flood Control Project resulted in alteration of water circulation and sediment transport processes, which had the effect of altering sediment-flushing flows, changing sedimentation patterns, reducing the geomorphic complexity of the estuary, stagnating water circulation, and reducing the volume of tidal exchange. One of the most significant consequences was loss of the physical processes that functioned to flush out marine-derived sediment transported into the estuary. The last meander bend (South Slough) was cut off and the channel was straightened. The Flood Control Project disconnected Redwood Creek from its floodplains, preventing overbank flows to the floodplains and eliminating the multiple flow paths that maintained the size and complexity of the estuary prior to the levee construction. Overbank flows could no longer enter the heads of Middle and North Sloughs and scour the marine-derived sediment from the slough channels. Understanding the role of historical physical processes provides the basis for developing restoration design concepts.

Conceptual Designs

A broad range of potential design concepts was identified in an effort to achieve the desired future conditions, processes, and functions. Initial concepts were presented to the affected landowners and a Peer Review Committee for discussion and feedback, and refinements were made in an effort to optimize estuary and levee benefits while achieving alternatives that are most likely to be feasible. A total of seven alternatives, designated A1 through A7, are presented in this report. Landowners have not committed to any alternative. All alternatives are conceptual in nature, and additional modifications and refinements will be needed based on consultations with affected private and public landowners; consultations with funders and regulatory agencies; the results of further technical studies; and further design efforts to optimize the desired conditions and processes. The range of alternatives represents a mix of performance in terms of potential feasibility for landowner support, optimization of estuary ecological restoration, and improvement of levee performance. Feasibility will ultimately be determined by a suite of factors but first and foremost requires private landowner cooperation and agreement.

The Flood Control Project has benefited privately owned agricultural land by preventing bank erosion, eliminating inundation from Redwood Creek (except for backwater flooding from North Slough and South Slough), and eliminating deposition of debris and coarse sediment. Conversely, the levees have eliminated the replenishment of fine sediment onto the floodplain pastures and created localized areas with poor drainage. Pasture drainage north of the estuary is currently impaired due to blockage caused by marine-derived sediment and wood in North Slough, while pasture drainage on the south side is currently considered adequate. Drainage will likely become an increasing problem due to land subsidence and sea level rise.

Modification of the levee system would be a significant change from existing conditions, where agricultural operations have benefited from flood protection provided by the levee for over 35 years. The Arcata Bottoms, Eel River Bottoms, and other local areas demonstrate that intermittent flooding can be compatible with agricultural land use; however, potential impacts will need to be carefully evaluated and addressed. Appropriate compensation for any flooding impacts, and for any conversion of private land to non-agricultural use, will be a pre-requisite to moving forward on a levee modification project.

Alternative A1 involves relocating the lower portion of the north levee to coincide with the county road and relocating the lower portion of the south levee along a new alignment that ties in to the nearest point along Highway 101. This alternative allows Redwood Creek to re-occupy South Slough and re-establishes the creek-headland interaction on the north side of the estuary. This alternative also restores overbank flooding into North Slough to allow scour of sediment and wood. This alternative allows reconnecting Redwood Creek to the southern wetland near the National Park Service visitor center and increases riparian and floodplain areas. Portions of the adjacent agricultural lands are restored as floodplain but retained as pasture for grazing, and portions are converted to floodplain with riparian vegetation.

Alternative A2 is a refinement of Alternative A1, with the same design on the north side and a different alignment for the setback levee on the south side. The setback levee hinge point is situated further upstream, opposite the hinge point for the setback levee on the north side. In common with Alternative A1, Alternative A2 re-occupies South Slough, re-establishes the creek-headland interaction, restores overbank flooding on the north side, re-connects the southern wetland, increases riparian areas, and retains areas for grazing. Alternative A2 is different from Alternative A1 by providing additional floodplain connectivity between South Slough and the new south levee. This additional floodplain provides more high-flow habitat, more floodplain fine sediment deposition, and allows the sediment transition zone to occur further upstream from the estuary than Alternative A1.

Alternative A3 has the same design on the north side as Alternatives A1 and A2 but takes a different approach on the south side, to provide an alternative that does not involve constructing a new levee in close proximity to the estuary. The lower portion of the south levee would be removed up to the approximate location of the South Slough gated culverts, which would also be removed. The remaining portion of the south levee would remain in place to protect the adjacent agricultural land, and a relatively shorter new setback levee would be constructed to protect structures against flooding. The portion of the existing south levee left in place would continue to be maintained but not to the level of achieving FEMA certification standards. The new setback levee would be maintained to FEMA certification standards. Redwood Creek would not be rerouted into South Slough, but would remain in its current alignment. The left bank along Middle Island would be lowered so that overbank flows could enter the head of South Slough, similar to overbank flows entering North Slough. More detailed information regarding expected backwater flooding conditions on the adjacent pasture and levee maintenance would be needed to evaluate the feasibility of Alternative A3.

Alternative A4 reflects a slight modification of Alternative A2 with respect to the alignment of the setback levee on the south side.

Alternatives A1, and potentially A2 and A4, represent the alternatives most likely to be feasible in terms of landowner acceptance. The estimated cost for these alternatives is approximately $27 million to $28 million. Preliminary hydraulic and sediment analysis indicate that these alternatives would likely achieve the minimum objectives for the Flood Control Project; however their adequacy for achieving the objectives for estuary restoration remains undetermined.

Alternative A5 reflects a concept for a culvert through the levee on the north side of the Flood Control Project. The feasibility of this concept for scouring sediment and maintaining drainage within North Slough is questionable. In addition to concerns for long-term maintenance and performance, this concept does not substantially contribute to the overall project goals for the estuary and Flood Control Project.

Alternatives A6 and A7 involve concepts for levee removal over large areas on both the north and south sides. These alternatives would affect multiple ownerships including owners who were not involved in the outreach efforts for this planning study due to time and funding constraints. These alternatives were developed primarily as reference points for comparison with Alternatives A1 through A4. On the north side, Alternatives A6 and A7 would allow overbank flows to access additional floodplain area and help flush sediment from the North Slough and multiple slough channel alignments. On the south side, these alternatives would allow overbank flows from Redwood Creek to access a large floodplain area and join Strawberry Creek. The majority of the affected adjacent land could continue to be used for grazing, but this land would no longer be protected by the Flood Control Project. These alternatives propose a new road on the north side of the valley leading up to two residential properties; however, the feasibility of this new road is unknown.

The estimated cost for Alternatives A6 and A7 ranges from $33 million to $35 million. Alternatives A6 and A7 would benefit the Flood Protection Project by substantially increasing the overall levee capacity for the central residential and commercial area of Orick. This additional freeboard capacity would help offset future in-channel sedimentation and vegetation affects within the channel. These alternatives would provide the greatest potential for sediment scour and maintaining slough channel size and capacity in North Slough. These alternatives would have the greatest ecological benefit based on providing high-flow refugia and sediment reduction and maximizing the likelihood of resilience and persistence for estuary processes.

Alternatives A6 and A7 are not considered feasible at this time due to the extent of the affected areas involving private landowners, lack of private landowner agreement, and the uncertainty in associated risks.

Next Steps

Discussions with adjacent private landowners along lower Redwood Creek were constructive and the opportunity exists to continue those discussions into the future and work toward agreement on the footprint for a proposed project with appropriate terms, conditions, and compensation. Levee modifications will ultimately be needed on both the north and south sides to achieve the overall goals and objectives; however, work could be implemented in phases.

This planning study identified that Alternative A1, and potentially Alternatives A2 or A4, are more likely to be feasible in terms of acceptability from the affected private landowners. The fundamental question that must be addressed is whether one of these alternatives is sufficient to restore physical processes and ecological conditions and provide resiliency for future conditions (sediment loading and sea level rise) to justify the substantial investment.

Recommended next steps include continued stakeholder dialogue; additional data collection and technical studies to evaluate the effectiveness of the conceptual alternatives identified in this report; and continued efforts to obtain a Congressional appropriation for the Corps of Engineers to perform a General Investigation Study.

2 BACKGROUND

2.1 Funding

Humboldt County was awarded a grant in 2012 from the California Department of Fish and Wildlife (formerly Department of Fish and Game) through the Fisheries Restoration Grant Program to develop conceptual designs for a multiple-objective project on lower Redwood Creek and estuary that would achieve estuary restoration and levee rehabilitation and be compatible with adjacent agricultural land use. Additional funding and/or cost-share contributions were provided by Humboldt County; NOAA-National Marine Fisheries Service; National Park Service; Federal Emergency Management Agency; Pacific Coast Fish, Wildlife and Wetlands Restoration Association; Stillwater Sciences; Northern Hydrology and Engineering; and the North Coast Regional Land Trust.

2.2 Statement of Work

The statement of work from the grant agreement with the Department of Fish and Wildlife is provided in Attachment A. The statement of work includes the following provisions:

- Humboldt County will develop conceptual design alternatives that achieve the optimum estuary function resulting in improved salmonid survival and productivity while also rehabilitating the levee system to meet flood protection requirements of the Federal Emergency Management Agency and the United States Army Corps of Engineers. The feasibility of these design alternatives will be determined by whether they meet the needs of the adjacent landowners as well as meeting the criteria of regulatory agencies.

- To improve salmonid production, the estuary restoration design element must at a minimum contain the objectives of: (1) improving channel connectivity and circulation with adjacent wetlands and sloughs; (2) increasing channel depth, diversity, and complexity including instream cover; and (3) identifying off-channel rearing opportunities.

- The final report will summarize information in terms of adjacent landowner needs, regulatory requirements, community concerns, affected species, critical life history stages, physical processes of concern, and any conflicts in species needs, community needs and flood control requirements.

- The final report will contain at least three viable conceptual design options for the multi-objective project that incorporate considerations for global climate change and sea level rise.

2.3 Study Area

Redwood Creek is located within the North Coast Ranges of California, entirely within the northern portion of Humboldt County. The Redwood Creek watershed (Figure 2-1) drains an area of approximately 285 square miles (mi^2), including Prairie Creek, prior to flowing into the Pacific Ocean about 50 miles south of the California-Oregon border (RNSP, 1997). Prior to entering the ocean, Redwood Creek flows through the unincorporated community of Orick, California (Figure 2-2). The Redwood Creek estuary is a small bar-built estuary/lagoon located about two miles below Orick, and is partially incorporated into the lower end of the Redwood

Creek Flood Control Project (Figure 2-2). Land in the vicinity of the lower Redwood Creek and estuary includes privately owned agricultural land and a portion of Redwood National Park managed by the National Park Service (NPS).

2.4 Redwood Creek Flood Control Project

The Redwood Creek Flood Control Project (Flood Control Project) consists of a system of two earthen embankment levees and associated infrastructure. Construction of the Flood Control Project included excavation and enlargement of the channel to a target geometry and placement of earthen embankments along each bank. The levee system confines approximately 3.4 miles of lower Redwood Creek.

The Flood Control Project was constructed by the U.S. Army Corps of Engineers (Corps of Engineers) from 1966 to 1968 to protect the community of Orick from floodwaters, in response to a series of flood events that occurred in 1950, 1953, 1955 and 1964. The Flood Control Project was authorized by Congress through the Flood Control Act of 1962, with a design flow (standard project flood) of 77,000 cubic feet per second (cfs) with three feet of freeboard (U.S. Congress, 1962a and 1962b; Corps of Engineers, 1961, 1966, 1968, 1969). Humboldt County (County) was the local sponsor for the Flood Control Project and agreed to accept responsibility for operation and maintenance following construction.

The levee system protects residences, businesses, a school, agricultural operations, community rodeo grounds, Redwood National Park South Operations Center, public and private roads and U.S. Highway 101. Approximately 300 people live within the floodplain immediately behind the levee system in the middle and upper sections, while the lower section is adjacent to agricultural land. Orick is considered a severely disadvantaged community based on median income.

2.5 Adverse Effects of Flood Control Project on Estuary

Construction of the Flood Control Project caused major physical changes to the lower reach of Redwood Creek and its estuary, which includes North Slough, lower Sand Cache Creek, Middle Slough, South Slough, and lower Strawberry Creek. One of the most significant consequences was loss of the physical processes that functioned to flush out marine-derived sediment transported into the estuary. As a result, the estuary volume has been reduced by over one-half of its pre-levee size due to sediment deposition, and fish habitat and water quality have been severely impaired. The net result has been a reduction in the ecological function of the estuary in terms of productivity and survival of fish and other aquatic species.

Restoration of the Redwood Creek estuary would provide substantial benefit for the recovery of estuarine fish species including three salmonid species (coho salmon, Chinook salmon, and steelhead) that are listed as threatened under the federal Endangered Species Act in addition to other estuarine dependent species. Estuary restoration would also complement other large-scale restoration efforts conducted by the National Park Service within Redwood National Park, which occupies most of the lower one-third of the watershed.

2.6 Levee Deficiencies

2.6.1 Capacity

The Flood Control Project is impaired by the deposition of large volumes of sediment each winter, which has reduced the project's flood capacity from its intended level of protection

(77,000 cfs). Sediment impairment occurred the first winter after construction, and recent technical studies demonstrate fundamental design flaws as the root cause of the problem (NHE, 2010a). The most recent analysis indicates that the flood capacity ranges from 53,000 to 68,000 cubic feet per second, with the lowest capacity in the lowermost segment (NHE, 2009 and 2010b). Construction of the levees also reduced the ability of North and South Sloughs to flush sediment, which contributes to flooding conditions in these areas.

The Flood Control Project was not designed to depend on large-scale sediment removal, and such activity was not specified in the Operation and Maintenance Manual. The County has implemented a program to remove relatively small amounts of excess sediment, to the extent feasible, in an effort to regain some capacity and increase the level of protection. However, such activity provides very limited and short-term capacity gains and diverts the County's limited funds from other maintenance needs. Gravel removal and vegetation treatments within the channel are highly regulated by federal and state environmental laws and regulations due to the presence of listed species, their designated critical habitat, and environmentally sensitive habitat areas. Review and processing times by the permitting agencies can take three to five years and the permits come with many restrictions and conditions.

The scale and persistence of this problem requires a fundamental rehabilitation of the Flood Control Project to accommodate sediment inflow and achieve an acceptable level of flood protection that can be sustained with normal maintenance.

2.6.2 Structural Stability

A geotechnical investigation study was completed in 2011 to assess whether the Flood Control Project meets current performance standards for potential failure modes including seepage, underseepage, slope instability, settlement, seismic deformation, seismic settlement, and liquefaction (CGI, 2011). The investigation results indicate that several locations along the levee system do not meet performance criteria for seepage, underseepage, slope instability, and liquefaction using the standard conservative assumption of steady-state river stage conditions. A majority of these non-compliant locations meet the performance criteria if non-steady (transient) river stage conditions are assumed. Additional discussion is provided in Section 5.5.3.

2.7 Federal Levee and Floodplain Management Programs

2.7.1 U.S. Army Corps of Engineers

The Corps of Engineers implements the Civil Emergency Management Program under the authority of Public Law (PL) 84-99, in accordance with Engineer Regulation ER 500-1-1. This program includes the Rehabilitation and Inspection Program for federal flood control projects. Eligibility in the Rehabilitation and Inspection Program is contingent upon periodic inspections of a levee by the Corps of Engineers and a determination that the levee is adequately maintained. Levees that have active status within this program are eligible for federal assistance following a flood damage event, whereby the Corps of Engineers is authorized to repair damages back to pre-flood conditions (if the work is economically justifiable with a benefit-cost ratio greater than unity).

In January 2007, the Corps of Engineers placed the Redwood Creek levee system on a national list of 122 levees with maintenance deficiencies that present an increased risk to the public due to the overall loss of capacity. In March 2008, the Corps of Engineers placed the Redwood Creek levee on inactive status under the Rehabilitation and Inspection Program. According to correspondence from the Corps of Engineers, the action to de-activate the Flood Control Project from the Rehabilitation and Inspection Program was based on the levee system not meeting the Congressional intent for capacity (77,000 cfs). Each annual inspection report since 2008 has contained an overall rating for the levee system of "Unacceptable."

2.7.2 Federal Emergency Management Agency

The Federal Emergency Management Agency (FEMA) develops flood hazard data including Flood Insurance Rate Maps ("FEMA flood maps") and Flood Insurance Studies under the National Flood Insurance Program. FEMA flood maps provide information on flood risk and are used as a basis for implementing flood insurance requirements and regulating floodplain development. Properties located within a designated Special Flood Hazard Area on the effective FEMA flood map are subject to mandatory flood insurance requirements if there is a federally backed mortgage loan, and are subject to flood damage prevention ordinances which contain standards for new construction and substantial improvements on existing structures.

The Special Flood Hazard Area is defined as the horizontal extent of the floodplain for the 1-percent annual-chance flood (100-year recurrence interval flood), also called the base flood. A levee can be recognized as providing protection for the base flood on the FEMA flood map if there is evidence and documentation that the levee meets the design standards contained at 44 CFR Section 55.10. FEMA will accredit a levee on the flood map if the levee owner submits the required evidence and documentation and certifies that the levee meets the applicable standards. These standards address freeboard (minimum distance between the top of the levee and the base flood), structural stability, interior drainage, and operational and maintenance. Levees must provide a minimum freeboard of three feet above the water surface level of the base flood.

The Redwood Creek Flood Control Project was accredited on the first FEMA flood map, prepared in 1982, with the Flood Control Project providing protection for the 1-percent-annual-chance flood. This map continues to be the effective flood map, subject to future update as described below. In 2009, FEMA released for public review a preliminary updated flood map which was prepared based on technical studies performed by the Corps of Engineers (COE, 2009 and 2010a). NHE (2009) provided a technical review of the 2009 Corps of Engineers studies. The 2009 preliminary flood map was not made effective, and FEMA subsequently awarded a grant to the County to update the supporting technical studies for the updated flood map. These studies included topographic data acquisition, hydrologic and hydraulic analyses, and floodplain mapping (NHE and Manhard, 2013a and 2013b). Concurrent with the County's development of these technical studies, FEMA revised its policies and guidelines for addressing levees on FEMA flood maps (FEMA, 2013).

In its current condition, the Redwood Creek Flood Control Project cannot be certified as complying with the FEMA accreditation standards primarily due to localized freeboard and structural stability deficiencies. However, FEMA has developed a new process called "seclusion mapping" that allows for deferral of flood hazard zone changes behind certain non-accredited levees. As a result, FEMA plans to release draft updated flood maps for Orick in January 2015 that do not change the flood hazard zone for land behind the Flood Control Project. These maps are expected to become effective in Fall 2016. FEMA's "seclusion mapping" process is intended to be temporary and flood hazard zone designations behind the Flood Control Project are subject to change in the future if the levee deficiencies are not remedied.

2.8 Previous Planning and Design Efforts

This project built on previous work including Moffatt & Nichol Engineers (2003) and Redwood National and State Parks (RNSP) (2005). The 2003 Moffatt & Nichol project was a hydraulic study to assess six alternatives for levee modifications. This study provided useful technical information and analysis of hydraulic and geomorphic considerations, but was not successful in moving project planning forward. The 2005 RNSP draft report provided important background information for the estuary and general considerations for project design, but did not formulate specific design elements and was not brought to completion.

2.9 Assumptions and Approach

A large-scale, multiple-objective water resources project is needed in order to achieve a sustainable solution for threatened and endangered species recovery, ecosystem restoration, and flood protection in the Redwood Creek watershed. Based on current understandings of the levee and estuary, it is assumed that the project will require modification and re-configuration of a portion of the levee system. A fundamental premise is that any involvement of adjacent private lands will depend on the landowner's willingness to participate based on fair compensation and consideration of their interests and needs.

The County applied an approach consistent with the Redwood Creek Integrated Watershed Strategy (2006). This approach included acknowledging multiple values and interests, soliciting stakeholder input, utilizing the best available data and information, being adaptive, and working toward consensus. During the initial phase there was an emphasis on trying to understand the physical processes that created and maintained the form and ecological functions of the estuary prior to construction of the Flood Control Project. Key steps included the following:

- The County consulted with adjacent landowners.
- The National Park Service compiled and provided digital copies of its photographic archive and estuary documents.
- The County retained Northern Hydrology and Engineering and Stillwater Sciences to provide technical assistance on evaluating estuary and levee needs and developing conceptual designs.
- The County retained HDR Engineering, Inc. to provide consultation on Corps of Engineers and FEMA programs.
- The County consulted with the Corps of Engineers to discuss potential administrative and programmatic options to achieve the goals and objectives.
- A Peer Review Committee was convened to provide technical input on restoration needs, physical processes, and restoration design concepts. Participants included representatives from the following organizations:
    - National Park Service
    - NOAA-National Marine Fisheries
    - NOAA-National Weather Service
    - U.S. Fish & Wildlife Service
    - U.S. Geologic Survey
    - U.S. Army Corps of Engineers
    - California Department of Fish & Wildlife
    - California Coastal Commission
    - State Coastal Conservancy
    - North Coast Regional Land Trust

- CalTrout
- Pacific Coast Fish, Wildlife and Wetlands Restoration Association

Meetings of the Peer Review Committee were held on:

- January 23, 2013
- May 1, 2013
- August 12, 2013
- March 17, 2014
- December 1, 2014

Comments on the draft report from members of the Peer Review Committee are provided in Appendix B.

2.10 Project Goals

The overall goals for the conceptual design planning project include the following:

<u>Estuary:</u>

1. Restore the hydrologic, morphologic, and ecologic processes necessary to develop and maintain functional, self-sustaining estuarine habitat, especially for the recovery of threatened salmonid species including Southern Oregon/Northern California Coast coho salmon, California Coastal Chinook salmon, and Northern California steelhead.

<u>Flood Control Project:</u>

1. Accommodate sediment inflow, remedy structural deficiencies, and achieve an acceptable level of flood protection that can be sustained with normal maintenance.

2. Regain active status in the Corps of Engineers Rehabilitation and Inspection Program and achieve certification and accreditation on the FEMA Flood Insurance Rate Map.

<u>Adjacent Land:</u>

1. Maintain agricultural productivity within the lower Redwood Creek valley and limit the net loss of agricultural land use to the greatest extent possible while meeting other project goals.

2. Fairly compensate affected private landowners for impacts associated with levee modifications.

3. Be consistent with the resource protection and preservation responsibilities of the National Park Service for affected federal land in Redwood National Park.

Objectives and indicators associated with these goals are presented in Section 8.

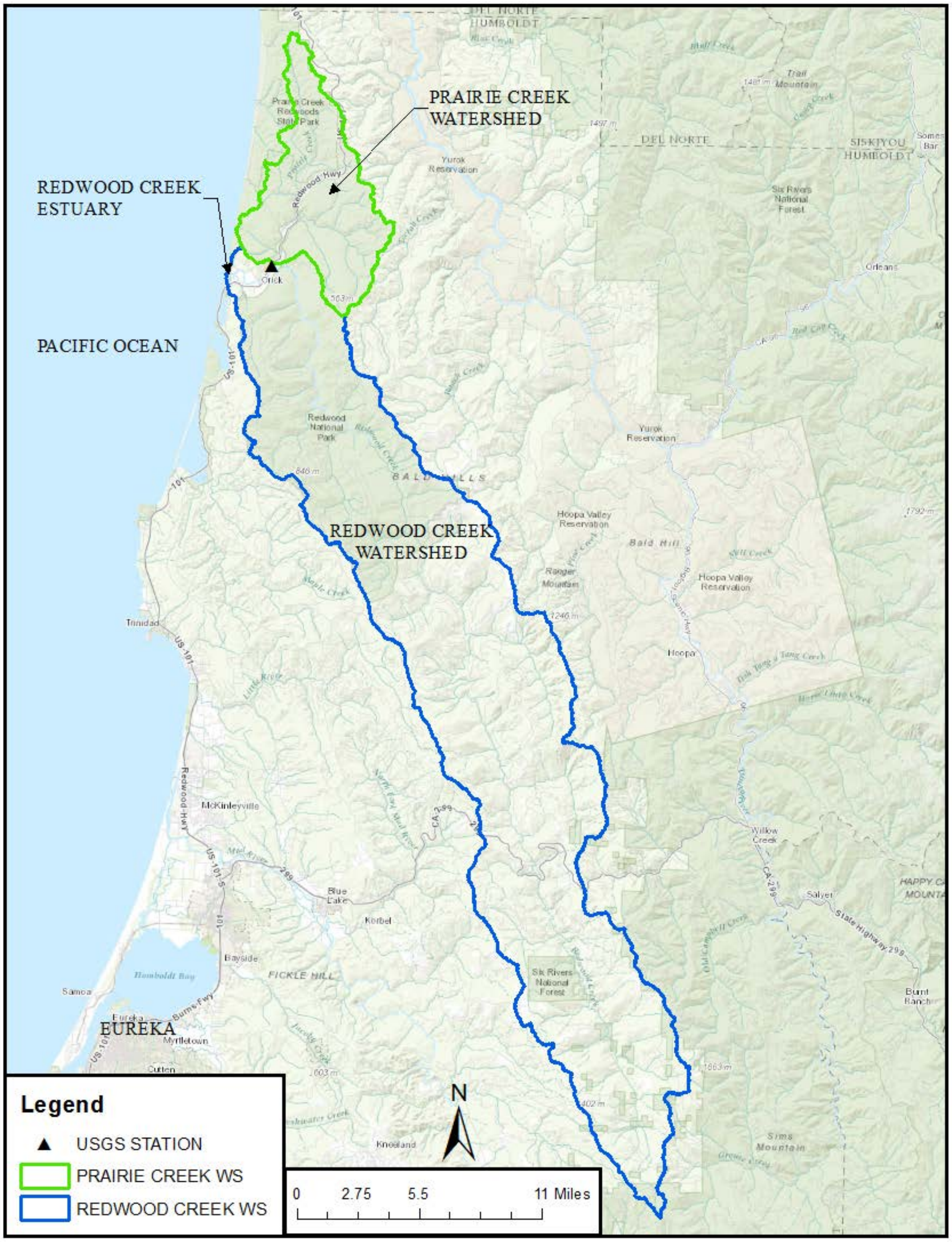


Figure 2-1. Redwood Creek and Prairie Creek drainage basins.

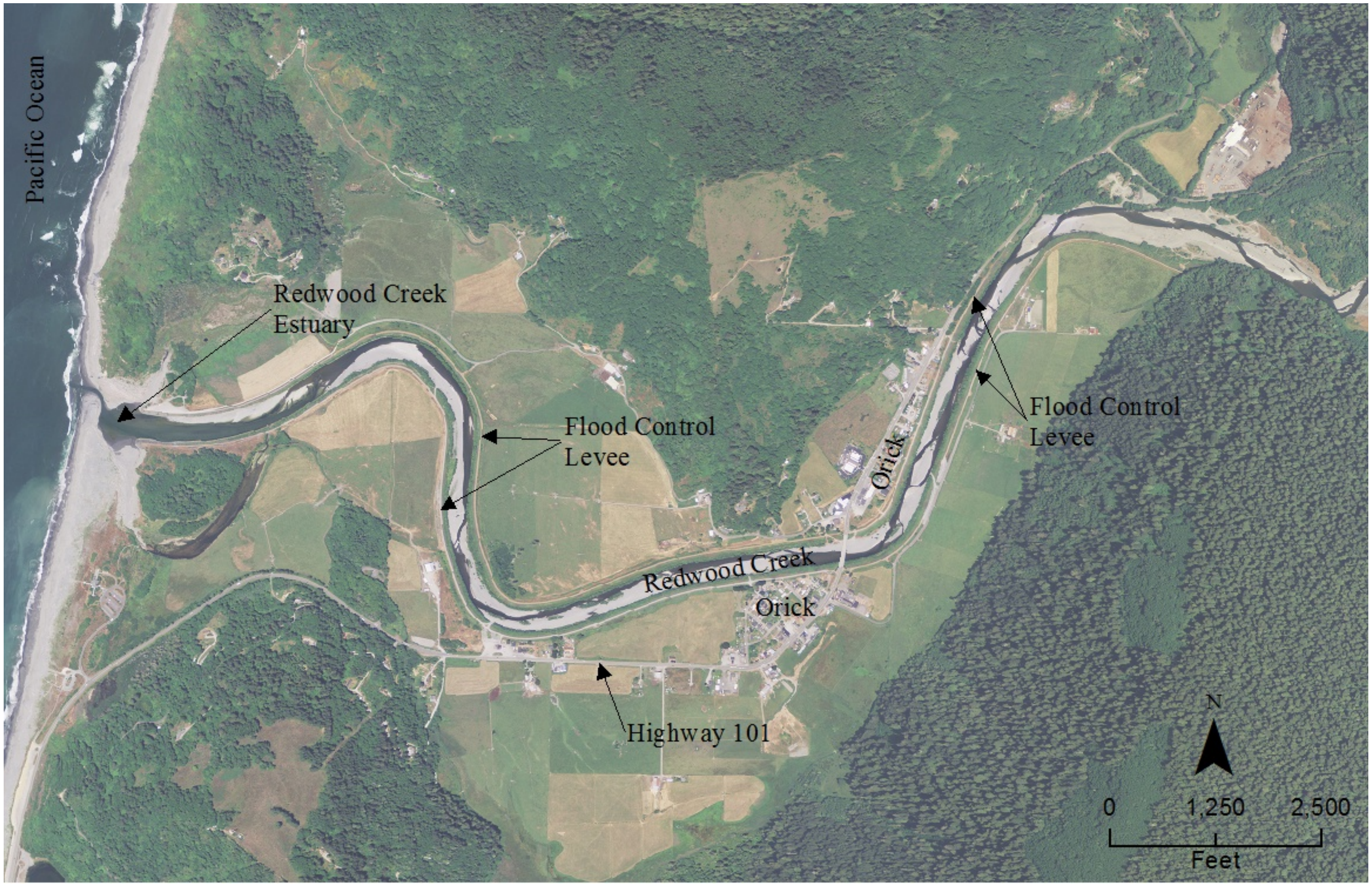


Figure 2-2. Map of Lower Redwood Creek and the Redwood Creek Estuary, the Community of Orick, California, and the extent of the Redwood Creek Flood Control Project (July 6, 2009, USDA-NAIP).

3 PURPOSE AND NEED

3.1 Purpose

The purpose of the Redwood Creek Estuary Restoration and Levee Rehabilitation Conceptual Design Project (Project) is to restore the ecological function of the Redwood Creek estuary and rehabilitate the Redwood Creek Flood Control Project in a manner that achieves desired flood capacity and is compatible with adjacent agricultural land use. The project envisions a dynamic, ecologically healthy, self-sustaining and resilient estuary, and a Flood Control Project that provides an acceptable level of flood protection independent of sedimentation.

3.2 Need

3.2.1 Estuary

Construction of the Flood Control Project in the late 1960s caused major physical changes to the lower reach of Redwood Creek and its estuary. These changes included confining the creek channel within the levees, loss of riparian vegetation, bypassing the last downstream meander of the creek (South Slough), loss of connectivity to off-channel features, and re-structuring of the estuary. The changes resulted in alteration of water circulation patterns and sediment transport processes, which had the effect of altering sediment-flushing flows, diminishing sediment storage and scour, reducing the geomorphic complexity of the estuary, stagnating water circulation, and reducing the volume of tidal exchange. Loss of overbank flood flows resulted in reduced sediment flushing and exacerbated accumulation of marine-derived wood and sediment in North Slough, and marine sediment in South Slough. The accumulation of wood and sediment decreased water circulation, which resulted in poor water quality, limited fish access, and decreased overland drainage causing flooding of pastures and roads in the North Slough and Sand Cache Creek area.

One study estimates that the estuary volume has been reduced by approximately one-half of its pre-levee size due to sediment deposition (Ricks, 1995); however, this estimate may actually be low since significant sediment deposition has occurred since 1995. The changes caused a reduction in deep areas and reduced connectivity to off-channel features and other rearing habitat areas for fish. Limited water circulation and tidal exchange in the estuary is associated with diminished summer/fall water quality in the form of reduced oxygen concentrations and elevated water temperatures (RNSP, 2005; Fuller, 2011). The net result has been impairment of the estuary's physical and biologic function, which reduced the capacity of the estuary/lagoon to support salmonids and other aquatic species (Cannata et al., 2006).

Restoration of some or all of these processes would help the estuary and lower Redwood Creek regain some of its former form, function, resiliency, and productivity.

3.2.2 Flood Control Project

Inherent design deficiencies are the root cause for the diminished Flood Control Project performance (NHE, 2010a). The original levee design was based on the assumptions of static bed elevations and fixed trapezoidal cross-section geometry, which are fundamentally inconsistent with alluvial rivers. In addition, the levee design set the bed elevation at three to four feet below the pre-levee channel, a condition that is highly unstable due to sedimentation. Historical channel survey data demonstrate a repeated pattern of the channel elevations returning to pre-levee bed elevations within a few years following large-scale sediment removal. The levee was not designed to adequately accommodate the episodic high sediment loads and bedforms that are typical of north-coast alluvial rivers.

In December 2008, the Corps of Engineers issued a technical report analyzing the capacity of the Redwood Creek levee system, assessing the relative contribution of gravel and vegetation to capacity reduction, and estimating the quantity of gravel that would need to be removed to achieve certain thresholds. According to this report, capacity is highest at the upstream extent of the levee system and decreases progressively downstream. The Corps of Engineers analysis indicated that a total of 178,000 cubic yards of gravel would need to be removed to achieve a protection level for the 100-year flood throughout the levee system, and a total of 430,000 cubic yards of gravel would need to be removed to restore the entire system to design conditions. Due to the annual influx of sediment to the levee system, it is likely that similar quantities would need to be removed on a nearly annual basis to maintain capacity. In concept, removal of 430,000 cubic yards would cost approximately $4.4 million; however, permits and approvals for such an action would not be obtainable due to the environmental impacts. Massive gravel excavation to maintain levee capacity as indicated in the December 2008 Corps of Engineers report was not envisioned when the levee was constructed by the Corps of Engineers in the 1960s. Periodic gravel excavation was not identified as a work element of the Operation and Maintenance Manual prepared by the Corps of Engineers in 1968.

The Flood Control Project requires rehabilitation to address the freeboard and structural deficiencies. Freeboard can be addressed through horizontal re-alignment of the levee embankments, raising the vertical grade of the embankments, or a combination of both. Structural deficiencies can be addressed by a variety of mitigation measures. Rehabilitation of the Flood Control Project should lead to (1) restoration of active status within the Corps of Engineers Rehabilitation and Inspection Program, and (2) compliance with the FEMA design standards at 44 CFR 55.10.

The minimum acceptable level of protection for the Flood Control Project is capacity for a 100-year-flood (1%-annual-chance-flow) with three feet of freeboard that can be sustained with expected future bed elevations and does not depend on sediment or vegetation removal from the channel. While a majority of the Flood Control Project meets this protection level, the entire levee system does not (analysis results provided in Section 5.5.2). Due to the uncertainties associated with sediment transport, climate change, and a relatively limited hydrologic record, an appropriate safety factor will need to be incorporated into the new design capacity. Restoration of the design capacity of 77,000 cfs is not economically feasible. Therefore, the Congressional intent for the Flood Control Project will need to be modified to a realistic, sustainable, and acceptable protection level. In addition, Congressional action will likely be needed re-define the limits of the Flood Control Project if the levee embankments are re-aligned and the area of protection changes.

3.2.3 Road and Pasture Drainage

The impaired estuary condition creates poor drainage conditions for portions of Hufford Road which leads to intermittent flooding. There are also poor drainage conditions for the adjacent pastures, especially adjacent to North Slough, which diminishes grass productivity and limits winter access.

4 HISTORICAL ESTUARY CONDITIONS AND PROCESSES

This section describes the historical conditions of the Redwood Creek estuary, along with the dominant physical and biological processes and ecosystem functions, to provide the basis for developing restoration actions and/or elements.

Current conditions of the estuary and the effects that the Flood Control Project levees have had on the estuary condition, physical and biological processes, biological communities and the ecosystem have been studied and documented in various reports by Redwood National and State Parks and others. However, information on historical estuary processes and function prior to the Flood Control Project is not as well documented. Most of the available documentation pertains to the apparent condition of the estuary from historical photographs and anecdotal accounts beginning around 1873. Estuary and watershed disturbances were already underway prior to the first aerial photography flight in the 1930's.

To provide a description of the physical processes controlling estuary function and maintenance we relied on interpretation of the historical photographs, review of available literature on the Redwood Creek estuary, other literature, professional judgment and interpretation.

4.1 Historical Estuary Condition

Figure 4-1 highlights key historical Redwood Creek features that will be discussed below. Prior to the construction of the Flood Control Project levees in 1968, historical photographs, maps and aerial images between approximately 1905 and 1948 reveal a relatively large bar-built estuary with an extensive riparian woodland along the upstream estuary boundary and slough channels (Figures 4-1 to 4-7). Current estuary conditions and processes have been highly altered compared to historical conditions due to the construction of the Flood Control Project levees and channelization of Redwood Creek in 1968 (Ricks 1995). However, a number of other anthropogenic changes to the Redwood Creek watershed have affected the estuary. Some of the other key disturbances affecting long-term estuary function include:

- Large flood events in 1860s, 1890, 1927, 1950s and 1960s
- Extensive logging and associated large landslides within the watershed (beginning in the 1950s)
- Large sediment loading associated with 1950s and 1960s floods, particularly 1964 event (Figure 4-8)
- Channel widening and aggradation beginning in the mid-1950s and continuing through levee construction (Ricks 1995)
- Conversion of the dense spruce forest surrounding the Lower Redwood Creek channel and estuary to agriculture land use beginning in the early 1900s (Ricks 1995; NPS 2005) (Figure 4-9)
- Filling of the barrier beach and associated wetlands during California-Pacific Mill construction in 1951 (Ricks 1995) (Figure 4-9)
- Stabilization (armoring) of the large southerly meander to prevent channel migration near the Mill site (NPS 2005) (Figure 4-10)
- Major vegetation disturbance during either the late 1860s or 1890s flood events (Ricks 1995).

All of these non-levee disturbances resulted in incremental changes to the estuary form and function. However, it appears that the estuary was able to maintain enough fundamental physical and biological processes and resiliency to remain highly productive until construction of the Flood Control Project from 1966 to 1968 (Figure 4-10).

4.2 Interpretation of Historical Estuary Physical Processes

Function and maintenance of historical estuary conditions were dependent on the interaction between coastal processes, river and floodplain flows, and sediment dynamics. The configuration of the estuary during any given year depended on the relative energy delivered by the ocean and river, and fluvial and marine sediment supplies. The dominant processes operating within the Redwood Creek estuary can be lumped into the following categories:

- Barrier beach breaching and closure and creek mouth migration
- Slough channel formation and evolution
- Riverine and coastal sediment erosion/deposition patterns
- Circulation and water quality

Annually, the estuary was shaped by sediment deposition from coastal processes (ocean supplied) and river transport (fluvial supplied), and sediment removal by tidal and high Redwood Creek flows. Water levels and depths within the estuary were controlled by river and floodplain flows, tide levels, barrier beach breaching and closure, seasonal sedimentation and erosion patterns and the location of the river mouth outlet along the beach. Flood flows would often scour the north slough and remove coastal sediment deposited at the mouth annually, creating a persistent 20 foot deep pool along the cliffs of the north headland from Dorrance Creek to the west (Ferrana and Ricks 1981, as referenced by NPS 2005). Although described as separate processes, they interacted to maintain estuary form, function and resilience prior to construction of the Flood Control Project levees.

4.2.1 Barrier beach breaching and closure and creek mouth migration

The Redwood Creek estuary can be classified as a bar-built estuary (Kraus et al. 2008; Corps of Engineers, 1991) where long-term sedimentation has kept pace with inundation (e.g. sea level rise). A common characteristic of bar-built estuaries is the long, narrow sand or gravel bar or barrier beach that forms across the estuary, lagoon or river mouth and is aligned parallel with the coast (Kraus et al. 2008). Bar-built estuaries along California that have tidal inlets through the barrier beach can be classified as always, never, rarely or periodically open (Kraus et al. 2008). Tidal inlet morphology is a dynamic balance between sediment import through tidal and wave-driven processes and sediment export from the scouring action of tidal and river flows (O'Brian 1971, Williams and Cuffe 1994; Kraus et al. 2002 and 2008; Behrens et al. 2013). When these sediment import and export processes are in morphological equilibrium the inlet may vary little spatially and temporally (Ranasinghe and Pattiaratchi 2003; Behrens et al. 2009). However, as noted by Behrens et al. (2013), small inlets with cross sectional areas < 100 m^2 rarely reach dynamic equilibrium as the channel bed friction on these smaller inlets restricts the flushing capacity of the tidal and river flows. The resulting imbalance in the sediment budget (net sediment input) can lead to changes in inlet morphology (shape, area and length), inlet migration and inlet closure. Breaching of the barrier beach, through natural or mechanical means, controls the depth, duration and frequency of flooding in the bar-built estuary/lagoon, as well as the tidal exchange, circulation and water quality (Kraus et al. 2008).

As described by Kraus et al. (2002), the longshore barrier beaches enclosing the lagoons (e.g. Big Lagoon, Stone Lagoon, Dry Lagoon, and Freshwater Lagoon) in northern Humboldt County, which includes the Redwood Creek barrier, are spits situated between headlands and are composed of medium sand, gravel and cobbles carried by longshore transport. Kraus et al. (2002) also noted that these headland to headland barrier beaches are remarkably straight and near-constant width, indicating that surge and tidal processes, which can cause spit re-curving, overwash and breaching, are weak compared to longshore processes.

The configuration of the Redwood Creek estuary actively eroded and reworked the barrier beach from the north headlands to the approximate location of the historical California-Pacific Mill site (current location of the Thomas J. Kuchel Visitor Center) (Figures 4-4, 4-7, 4-11, and 4-12). High winter flows scoured and narrowed the estuary side of the barrier beach, storm berm and overwash slope (Ricks 1995). The flood of 1964 completely removed the barrier beach from the California-Pacific Mill site to the headlands warping the beach to the north-west, creating a large offshore ebb shoal, and moved the Redwood Creek mouth well north of the headland (Figure 4-8). High creek flows would have also actively eroded the tidally deposited and wave overwash sediments and fluvial deposited sediments from the estuary (Figure 4-12).

Historically, the breaching and closure of the Redwood Creek mouth (inlet) was likely dependent on the interplay between the coastal and fluvial processes. The inlet would remain open if tidal flows and/or Redwood Creek flows were high enough to erode the depositing coastal sediments. Inlet closure occurs when the transport of sediment into the inlet by tidal action and longshore and/or cross-shore transport is not be adequately scoured by tidal and river flows, ultimately closing off the inlet.

Redwood Creek flows are generally high enough in winter and spring to keep the inlet open to the ocean by eroding accumulated sediments, allowing sea water to be mixed with the estuary during tidal cycles. The historical location of the winter/spring inlet appears to be highly dynamic and likely occurred all along the active barrier beach (Figure 4-2, Figure 4-6, Figure 4-7, Figure 4-9 and Figure 4-10) depending on the location of the initial fall or winter breach. During the summer and fall dry season, river flow decreases significantly and the combined tidal prism and river flow were typically not large enough to keep the inlet open (Ricks 1995). These patterns describe the general year-to-year seasonal inlet conditions. However, drought conditions, large winter storms, large wave events and El-Niño events could alter the typical seasonal pattern (Behrens et al. 2013). For example, drought conditions could lead to a longer inlet closure period. Likewise, large waves during a relatively low winter flow period could temporally close the inlet, which would then allow the estuary to fill and ultimately breach.

Historical inlet closure processes of the Redwood creek mouth are probably similar to the contemporary processes described by Ricks (1995). As river flow decreases in the late spring and summer the mouth becomes narrower as tidal and coastal transport deposit sediment into the inlet forming a sill. Coastal streams like Redwood Creek with low summer discharges (0.1 to 10 cms (< ~ 350 cfs)) typically migrate alongshore (Clifton et al. 1973), and the limited sediment flushing capacity of smaller inlets (< 100 m^2 (< 1076 ft^2) cross sectional area) due to increased bed friction can lead to changes in inlet morphology, migration and closure (Behrens et al. 2013). With the dominant north-northwest wind and wave environment during the spring and summer (Ricks 1995), the inlet channel typically migrates to the south, and channel migration can occur rapidly and episodically when high seas coincide with high tides. Due to the morphology of the barrier beach (Kraus et al. 2002), wave-driven longshore sediment transport is probably the dominant inlet closure process. Immediately following a breach event cross-shore transport of the breach ebb shoal can also move sediment into the inlet (Kraus, 2008; Behrens et al., 2013), however, the ebb shoal is an ephemeral feature as waves disperse the sediment originally deposited from the breach event (Kraus et al. 2002).

Natural breaching of barrier beaches in California commonly occurs from the lagoon or estuary side by two mechanisms (Kraus et al. 2008). The first is when the closed lagoon or estuary fills with a combination of groundwater, river flows and direct precipitation that eventually overflows and scours the barrier beach at its lowest point. The second mechanism is when seepage through the barrier beach caused by the head difference between the lagoon and ocean liquefies the sediment-water mixture, allowing a large quantity of material to be transported from the breach. It is not necessary for the lagoon level to reach the top of the beach barrier for seepage failure (Kraus et al. 2002). Kraus et al. (2008) stated that the dominant natural breaching process in Northern California is when the lagoon fills then breaches by overflow and scour through the barrier beach at their lowest and/or narrowest section. Kraus et al. (2002) also noted that seepage may locally lower the barrier beach initiating overflow and scour. Winter wave overwash along the historically longer barrier beach (Figure 3-1) may also have provided transient low points along the entire length of the barrier beach where the breaches would occur.

Natural and manmade breaching of the Redwood Creek barrier beach occurred prior to construction of the levees. Local resident, Beeb White, said that the mouth was usually left alone since there was enough filtration through the beach to keep lagoon water levels low (Ferrana and Rick 1981). However, Don and Alice Tipton and Savina Barlow mentioned that people would breach the barrier beach whenever the pastures would flood for long periods of time (Ferrana and Rick 1981). Wave overwash also occurred, which enabled fresh seawater and adult salmonids to enter prior to full breaching of the bar. Pinky Zuber said that salmon would occasionally enter the lagoon during wave overwash prior to breaching (Ferrana and Rick 1981).

The historical timing of natural breaches was variable. The Arcata Union (l8 January l902) reported that "The mouth of the creek has been closed for the past ten days. The Indians say that it is the first time the creek has been closed at this time of year that they know of" (Van Kirk 1994). The Arcata Union (26 November l904) reported that "The mouth of the river broke open last Thursday and let in another lot of salmon" (Van Kirk 1994). The Arcata Union (18 July 1912) noted that "Redwood Creek, which has been closed for several weeks, broke out a few days ago and fishing conditions will improve there now" (Van Kirk 1994).

Based on heavy-mineral analysis in the mouth of Redwood Creek, the sediments in the beach and nearshore environment near the mouth of Redwood Creek are a mixture of Klamath River and Redwood Creek sources (Ricks 1995). Historically sediments carried by Redwood Creek probably did not accumulate in the estuary as these sediments were periodically flushed through the mouth during high river flows (Ricks 1995). Any fluvial sediment deposited in the nearshore would be subject to cross-shore transport and onshore deposition prior to wave dispersal. As noted earlier, the dominant source of sediments to the historical Redwood Creek estuary is probably from net southerly longshore transport.

Scouring of deposited coastal and fluvial sediments within the estuary would have been dependent on high river flows and the location of the Redwood Creek mouth. The winter location of the Redwood Creek mouth and inlet migration during the spring and summer would increase sediment scour and could have locally deepened the estuary near the location of the inlet. Sediment depositional patterns within the estuary were also likely dependent on the location of the mouth. For example, when the winter river mouth was located to the south (near the historical California-Pacific mill site, Figure 4-2 and Figure 4-6) increased sediment deposition from both coastal and fluvial sources would have occurred in the isolated estuary areas to the north. These sediments would have been subject to scour when river and/or floodplain flows entered the north and middle sloughs. When the winter river mouth was located to the north near the headland more of the estuary would be subject to sediment scour during high river flows.

Seepage rates through the barrier beach depend on lagoon and ocean levels, texture of the barrier material, length of the barrier beach from lagoon to ocean, and length of the barrier beach in contact with the estuary (Clifton et al. 1973, as cited in Ricks 1995). The historical active barrier beach, which is longer and smaller than current conditions, probably allowed for increased seepage from the lagoon to the ocean when the inlet was closed. This would allow the lagoon to stabilize at lower levels during periods of low flow and inlet closure when river flows were near seepage rates, perhaps allowing the lagoon to remain closed longer prior to natural breaching by overtopping and scour. During the inlet closure process in the spring/summer periods, increased seepage rates would have also decreased inlet flows likely accelerating the timeframe of the inlet migration and closure process. Increased seepage from the ocean to the estuary during high tides could have allowed cold salt water to enter the estuary, potentially decreasing temperature and increasing density mixing and circulation in the estuary. As noted by Ferrana and Ricks (1981) there was enough filtration through the beach to keep lagoon levels low; however, that was in the "early days" according to Beeb White who said that clay has since plugged up the beach.

4.2.2 Slough channel formation and evolution

We hypothesize that the historical North Slough and Middle Slough were maintained primarily by overbank flooding from Redwood Creek. In addition, the size and configuration of these channels as depicted in pre-levee aerial photographs may have been associated with former mainstem Redwood creek channel alignments and/or former or existing tributary alignments (e.g. Sand Cache Creek, Strawberry Creek). This hypothesis is inferred from geomorphic features depicted on historical (pre-levee) aerial photographs, personal accounts, and changes documented by post-levee aerial photographs (Section 5.6.1).

The 1941 aerial photograph (Figure 4-1) shows a complex system of interconnected slough channels, tributaries, backwater areas (wetlands), high flow scour channels across floodplains, and potential barrier beach breaching locations. Above the estuary, Strawberry Creek and the network of floodplain channels on the southern floodplain would concentrate high flows. These concentrated flows would help to keep the floodplain channels and creek mouth scoured, and direct flood flows to the head of Middle Slough during large flood events. The configuration of the North Slough branches would capture and concentrate right bank overbank flows from Redwood Creek. The most northerly branch of North Slough is the current alignment of Sand Cache Creek. It's unlikely that the size of this branch of the slough could be attributed to Sand Cache Creek flows alone. This indicates that both branches of North Slough may have been former mainstem Redwood Creek or Sand Cache Creek channels, or have evolved and been maintained as high flow channels from floodplain flows, tidal action, or a combination of these. Middle Slough may also have been a former Redwood Creek channel alignment, or former alignment of Strawberry Creek, that was ultimately bisected as Redwood Creek migrated to the south. Middle Slough clearly connects to mainstem Redwood Creek during high river flows or high estuary levels during barrier closure (Figures 4-1 and 4-10).

As noted in an interview with Francis "Beeb" White on 29 May 1981 and supplemented with information from Thelma Hufford (14 September 1980) by Ferrana and Ricks (1981):

> "Most of the time when Redwood Creek flooded, the water came through the Hendriksen's fields and into the North Slough. There was a large hole where the

> county road bridge crosses the north slough. The bridge was an old railroad car that had been placed there. After the Hendriksen's put their dike in, the North Slough was not affected by floods so it started to fill up with sediment."

The likely dominant process that scoured accumulated coastal and fluvial sediments to maintain the size and capacity of North and Middle Sloughs (and help maintain the 20 foot deep pool at the north headland) was the capturing and concentrating of overbank flows. North Slough was maintained through overbank floodplain flows along the northern portion of the Orick Valley, while Middle Slough was maintained through overbank flows directly from the Redwood Creek channel.

The rate of sediment accretion (infilling) in the sloughs would have been affected and/or controlled by the following processes:

- frequency of overbank flows from main channel;
- volume of floodplain flows routed through slough channels;
- tributary flows;
- tidal exchange and circulation;
- sediment grain size and loads from the mainstem and tributaries; and
- vegetation as it relates to sediment deposition on floodplains, root strength along banks, and concentrating flow (flow convergence) in channels.

4.2.3 Sediment erosion and depositional patterns (sediment transport)

As discussed above, the historical sediment erosion and depositional patterns within the Redwood Creek estuary were driven by coastal and fluvial processes. Marine-derived sediments were likely delivered to the estuary through a combination of tidal currents, wave overwash and diffracted wave energy around the barrier beach (Klein 1991; Ricks 1995). Fluvial sediments would have been flushed from the embayment and slough channels during high river flows. High river flows were likely the dominant mechanism that flushed marine-derived sediments from the estuary, through multiple flow paths: interaction between Redwood Creek (flowing through South Slough) and the north headland; overbank flooding into Middle Slough; and floodplain flows into North Slough.

Historically, the mainstem of Redwood Creek flowed through its last downstream meander in the feature currently designated as South Slough (Figure 4-1, Figure 4-2, Figure 4-3 and Figure 4-5), which was subsequently cut off by construction of the Flood Control Project. During high winter flows and when the mouth was to the north, the main flow was directed in a southeast to northwest direction along the inside of the barrier beach and toward the headland on the north side of the estuary. This flow pattern allowed for a scouring of the accumulated marine sediment in the embayment and narrowing and lowering of the barrier beach between the estuary and ocean (Figure 4-7 and Figure 4-12).

We assume that the sediment input and output (sediment budget) to the Redwood Creek estuary interacted over time to maintain the general estuary configuration. The dominant processes controlling sediment inputs to the estuary were:

- transport capacity of coarse sediment decreased toward ocean (fluvial sediment);
- overbank flows to forested floodplain reduced fine sediment delivery (fluvial sediment);
- riparian vegetation on channel margin provided bank strength limiting bank erosion;

- tidal (flood tide), cross-shore, and longshore transport (coastal sediment); and,
- wave overwash from ocean (coastal sediment).

The dominant processes controlling sediment outputs from the estuary were:

- tidal scour (ebb tide),
- overbank flows contribute to a net export of sediment through slough channels (circulation change),
- high river flows flushed coastal and fluvial sediments through mouth (inlet) into ocean, and
- high river flows eroded landward edge of storm berm and barrier beach.

The historical photographs in Figures 4-11 and 4-12 illustrate the interaction of these processes. Winter waves overwashed into the estuary and south wetland area, as captured in the photograph in Figure 4-11, to deposit coastal sediments into the estuary and build the storm berm. Subsequent higher river flows remove the overwashed sediments and scour the storm berm and barrier beach (Figure 4-12).

The 1964 flood deposited a tremendous amount of sediment on the floodplains of the Orick valley. The general sedimentation patterns, thickness, and type of the 1964 floodplain deposits were recorded by McLaughlin and Harradine (1965) and presented in Ricks (1995) (Figure 4-13). Generally, silt was deposited on the left (southern) bank floodplain, while sands were deposited on the right (northern) bank floodplain. This depositional pattern indicates that higher floodplain velocities and probably flows occurred on the right bank than on the left bank, due to the right bank sand deposits. This pattern also shows that higher velocity flows likely entered North Slough and were probably the dominant reason why North Slough appears to have remained relatively scoured compared to Middle Slough following the 1964 flood (Figure 4-10).

The historical aerial photographs from 1936 to 1968 (Figures 4-1, 4-2, 4-9 and 4-10) show an estuary system that was resilient to large flood events (e.g. 1955 and 1964) and associated sediment deposition. These large floods would typically deposit large amounts of sediment into the estuary, but the channels and estuary would maintain its general planform. Subsequent moderate to high river flows would help flush these fluvial sediments from the estuary and slough channels into the ocean (Figure 4-10).

4.2.4 Circulation and Water Quality

The historical circulation patterns within the Redwood Creek estuary were controlled by complex transport and mixing processes that can be isolated into three specific spatial areas within the estuary. The first area includes the interconnected sloughs, main channel, embayment and wetlands (Figure 4-1), which includes the following transport and mixing processes:

- tidal exchange when the inlet (mouth) is open;
- backwatering when the inlet is closed;
- wind mixing when the lagoon is open, filling or full;
- density currents from salinity and temperature gradients when the lagoon is open, filling or full; and,
- interaction between slough, main channel, embayment and wetlands during high lagoon stages and flood flows.

An isolated circulation area within the estuary system are the slough channels (e.g., North and Middle Sloughs) that receive winter overbank flows from floodplain flows (e.g., North Sloughs) and direct tributary flows (e.g., Strawberry and Sand Cache Creeks). A final isolated circulation area is the embayment and main channel and includes the following transport and mixing processes:

- continuous river flow, and,
- wave overwash.

Historical water quality condition in the estuary prior to the construction of the Flood Control Project is not documented. However, the circulation patterns of the historical estuary configuration likely maintained relatively good year-round water quality conditions. This included greater estuary depths due to localized scouring of marine and fluvial sediment (e.g., north headland), greater tidal exchange of cold marine water and tidal prism volume (facilitated by a narrower and more dynamic barrier beach bar), increased localized shading from mature riparian and floodplain forests, greater interaction of floodplain, groundwater, and hyperheic flow, and bathymetry that supported mixing currents within the main estuary embayment (Figures 4-6 and 4-7).

4.3 Interpretation of Historical Ecological and Biological Conditions

Redwood Creek historically contained robust salmonid populations including coho and Chinook salmon, steelhead, and coastal cutthroat trout (Van Kirk 1994, Anderson et al. 1997). Pacific lamprey were also present as were large runs of eulachon, in addition to other smelt and estuarine adapted species such as tidewater goby and starry flounder (Van Kirk 1994, Anderson et al. 1997). These populations of salmon, steelhead, Pacific lamprey, and eulachon supported a sustainable tribal fishery that transitioned in modern times into a popular sport and subsistence fishery.

A key to the productivity of historical fish populations in Redwood Creek, in particular salmonids, was its large and complex estuary and associated floodplain habitats. While the carrying capacity of the historical estuary is not known, it was sufficient to support large runs of steelhead and coho and Chinook salmon. The historical estuary was characterized by mixed mature Sitka spruce riparian forests and patchy grasslands with numerous wetlands, distributary channels and sloughs, and complex shorelines with large woody debris and vegetation (Figures 4-1 to 4-5). The connectivity between Redwood Creek, its floodplain distributary channels, and estuary allowed juvenile salmonids to escape winter floods and the associated high velocity and turbidity of the mainstem channel. Access to protected off-channel habitats significantly increases winter survival of juvenile salmonids (Peterson 1982, Swales et al. 1986, Brown and Hartman 1988, Pollock et al. 2004, Lestelle 2007). These habitats have been shown to be especially important to over-wintering juvenile coho salmon, and to a lesser extent, to over-wintering juvenile steelhead (Beechie et al. 1994, Solazzi et al. 2000).

One notable habitat feature in the historical estuary that provided exceptional over-wintering and spring growth habitat was the large seasonal wetland and off-channel lake between the estuary and Freshwater Lagoon (Figure 4-4 top). This grassy and herbaceous wetland dried out during the height of summer (Figure 4-4 bottom), although it retained a wetted stream channel year-round. This stream channel provided upstream and downstream access to juvenile salmonids and appeared to be naturally configured so as to minimize the risk of stranding, which can be a problem for off-channel habitats that are only intermittently accessible (Brown and Hartman 1988). During the winter it filled with water, likely from multiple sources, creating a mix of open water, flooded herbaceous and wetland plants, and mature Sitka spruce forest in the surrounding riparian and floodplain areas. This inundation apparently persisted through the spring and into the summer. Open, shallow areas of floodplains and wetlands that let sun light penetrate the water column and reach the substrate have been shown to provide rich food resources for salmonids by increasing primary production and subsequent secondary production in the form of zooplankton, which are a high quality prey for juvenile salmonids (Ahern et al. 2006).

In general, access to complex floodplain and estuarine habitats allows juvenile salmonids to utilize additional food supplies and more favorable rearing areas, which allowed them to grow at a more rapid rate during all seasons as compared to mainstem habitats and be larger upon ocean entry (Swales and Levings 1989, Sommer et al. 2001, Lestelle 2007, Hayes et al. 2008). Larger size at ocean entry improves marine survival rates (Ward and Slaney 1988, Holtby et al. 1990, Bond et al. 2008) and eventual adult escapement. The rich food resources of the historical estuary and its associated floodplain and wetland habitats were a major factor contributing to its greater capacity and survival probabilities for juvenile salmonids compared to current conditions. The rich historical food resources were facilitated primarily by the following processes: 1) inputs of detritus and terrestrial insects from mature riparian forests and grasslands (Junk et al. 1989, Allan et al. 2003); 2) increased primary (phytoplankton) and secondary (zooplankton and aquatic macro-inveterate) production from open and shallow areas of seasonally flooded wetlands and tidal sloughs (Healey 1980, Levy and Northcote 1982, Ahern et al. 2006); 3) mixing of salt and freshwater and the increased productivity associated with the thermo-halocline, nutrient coupling and cycling, and flocculation chemistry (Kemp and Boynton 1984); and, 4) the greater total length of convoluted channel margins, resulting in high shoreline development values (Matthews 1998) and greater complex diversity of riparian vegetation with open and closed canopy.

The historical water circulation patterns likely resulted in the good water quality conditions that enabled juvenile salmonids, primarily Chinook salmon and steelhead, to not only survive, but thrive in the estuary during the summer months (Healey 1980, Levy and Northcote 1982, Bond et al. 2008, Hayes et al. 2008, Volk et al. 2010, Fuller 2011).

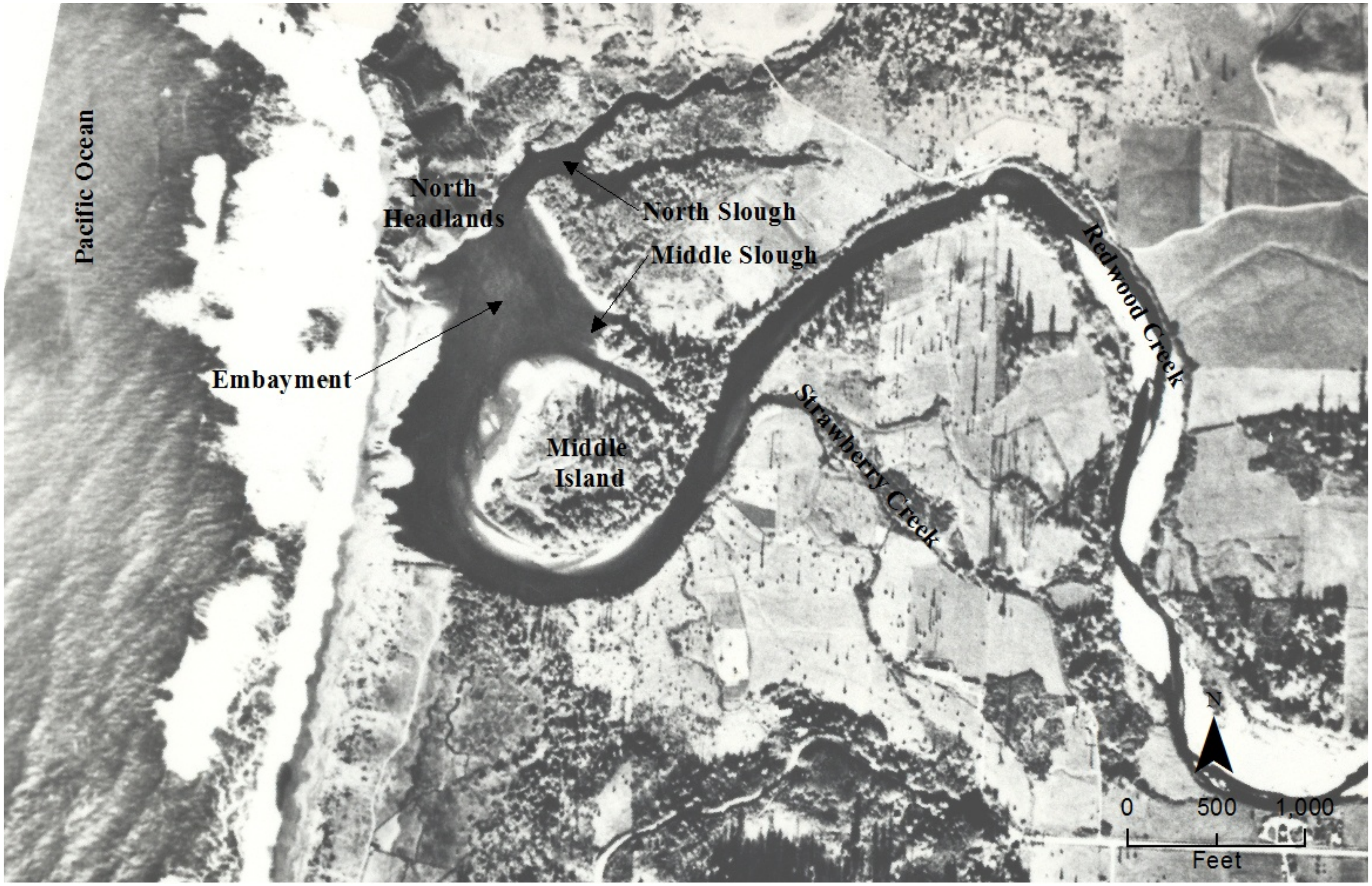


Figure 4-1. Redwood Creek estuary historical configuration and key features (11 June 1941, Redwood National Park collection). Note barrier beach is closed and estuary appears relatively full.

Figure 4-2. Earliest aerial image of the Redwood Creek estuary (29 June 1936, Redwood National Park collection). Note creek mouth is on the south end of barrier beach. North Slough, Middle Slough and Redwood Creek mouth appear to be scoured deeper than embayment. The easterly edge of the estuary still appears to be heavily forested.

Figure 4-3. Yurok fish camp (top) and person in dugout canoe (bottom) in Redwood Creek estuary (circa 1900's, UC, Berkeley). Note forested estuary margin and large woody debris along water edge in bottom photo.

Figure 4-4. Redwood Creek estuary looking north from southerly bluffs: top photo circa 1905 (Albert L. Kroeber, UC Berkeley, Hearst Museum of Anthropology), bottom photo dated 1928 (Thomas T. Waterman, UC Berkeley, Hearst Museum of Anthropology). Note flooded wetland area in foreground with open grassy areas, and extent of woodland area surrounding easterly edge of estuary.

Figure 4-5. Photo (top) looking west towards ocean showing densely wooded North Slough area of the Redwood Creek estuary (circa 1910-1915, Russ Pinto photo, Western Rivers); photo (bottom) of Redwood Creek looking downstream from Highway 101 Bridge showing forested channel banks (1910, Robert and Alma Davison photo, Feranna and Ricks, 1981).

Figure 4-6. Redwood Creek estuary oblique (7 September 1948, US Army Corps of Engineers photo). Image shows creek mouth towards south end of barrier beach. Note tidal flow and/or wave action into estuary.

Figure 4-7. Redwood Creek estuary oblique (29 December 1947, Shuster collection, HSU Library). Image shows creek mouth on north end of barrier beach. Note low profile of active barrier beach from the southerly edge of the last meander north to the headlands.

Figure 4-8. Aerial image of Redwood Creek estuary (13 January 1965, Redwood National Park collection) following the December 1964 flood event. Note amount of sediment deposition in the estuary and in the fields on both sides of the creek channel. Barrier beach was scoured and warped to the northwest, and creek mouth was deflected well north of the headlands.

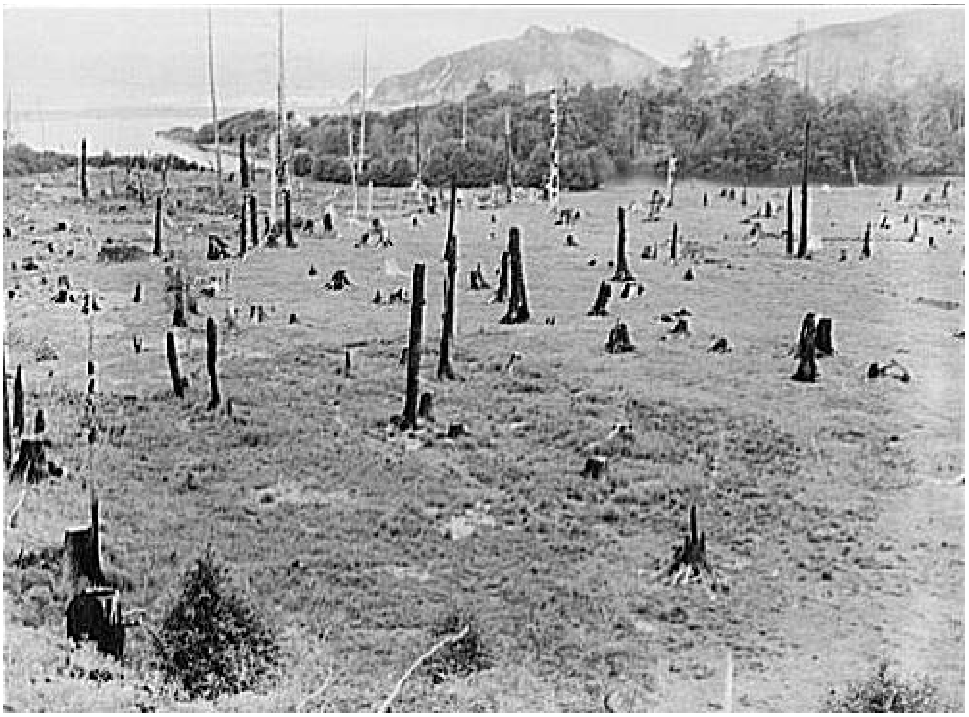


Figure 4-9. Photo (top) looking west towards ocean and overlooks last meander showing removal of forest and conversion to agricultural land use (1939, Dorothea Lang photo); and photo (bottom) looking north showing realigned Highway 101 and California-Pacific Mill (28 June 1948, Caltrans photo, Don Tuttle, Humboldt County Public Works). Note extent of wetland fill at Mill site in lower photo.

Figure 4-10. Aerial image of Redwood Creek estuary (2 May 1967, Redwood National Park collection) which is approximately 1.5 years after December 1964 flood. Despite large sediment loads from 1964 flood the Middle and North Sloughs are still connected to the estuary embayment. Creek mouth is located in approximate middle of the barrier beach. Note what appears to be channel armoring along the left bank of the last meander just upstream of the California-Pacific Mill site.

Figure 4-11. Redwood Creek estuary looking north towards mouth (February 1939, Gloria and Albert Zuber photo, Feranna and Ricks, 1981) with large winter waves overtopping barrier beach and flowing into the estuary, and overtopping low vegetated beach dune and flowing into flooded south wetland area.

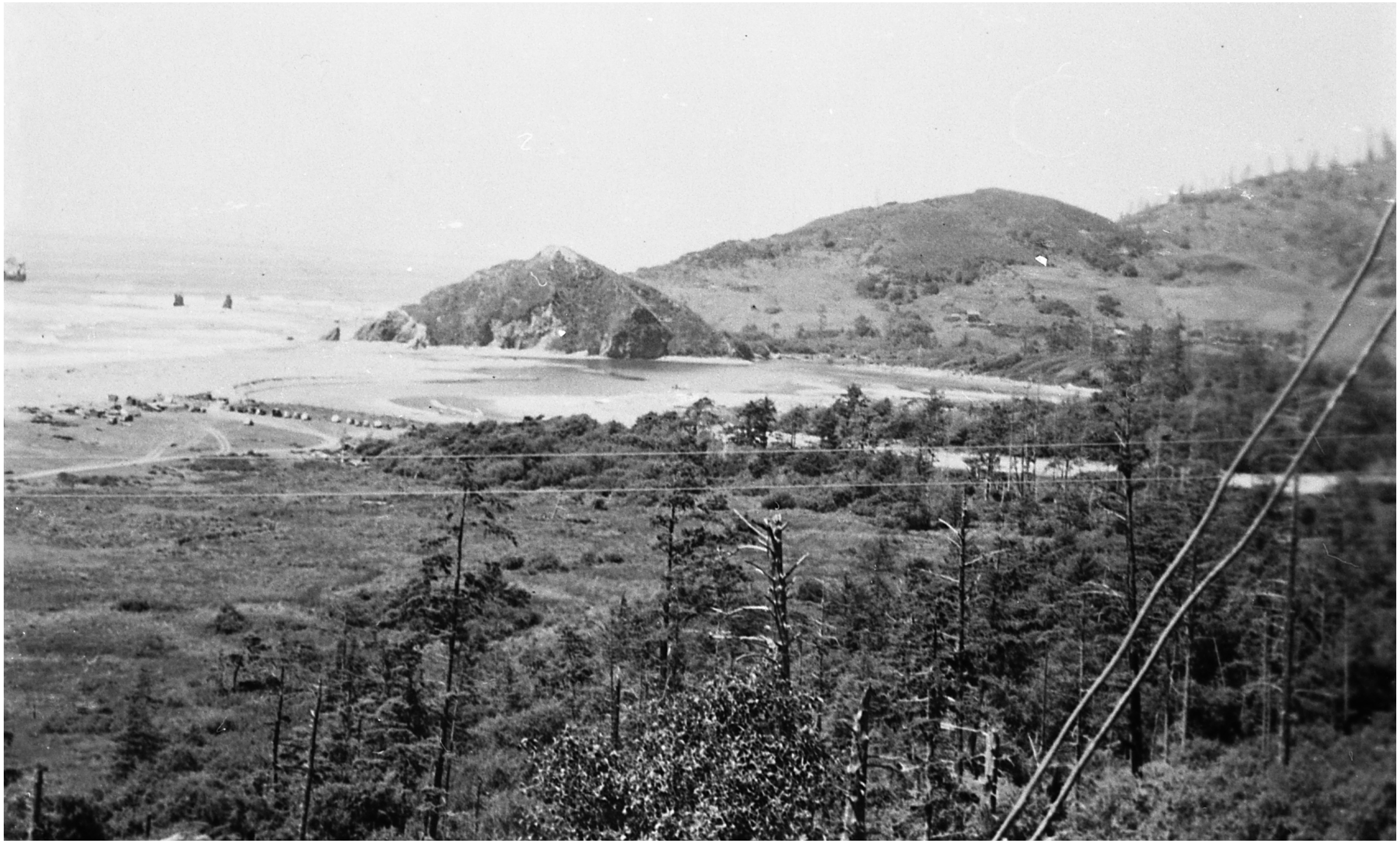


Figure 4-12. Redwood Creek estuary looking north towards mouth (Early 1940s, Gloria and Albert Zuber photo, Feranna and Ricks, 1981) during period when barrier beach is open and estuary water levels are low. Note the escarpment along creek side of the barrier beach (north of the cars) likely indicating scour from high creek flows.

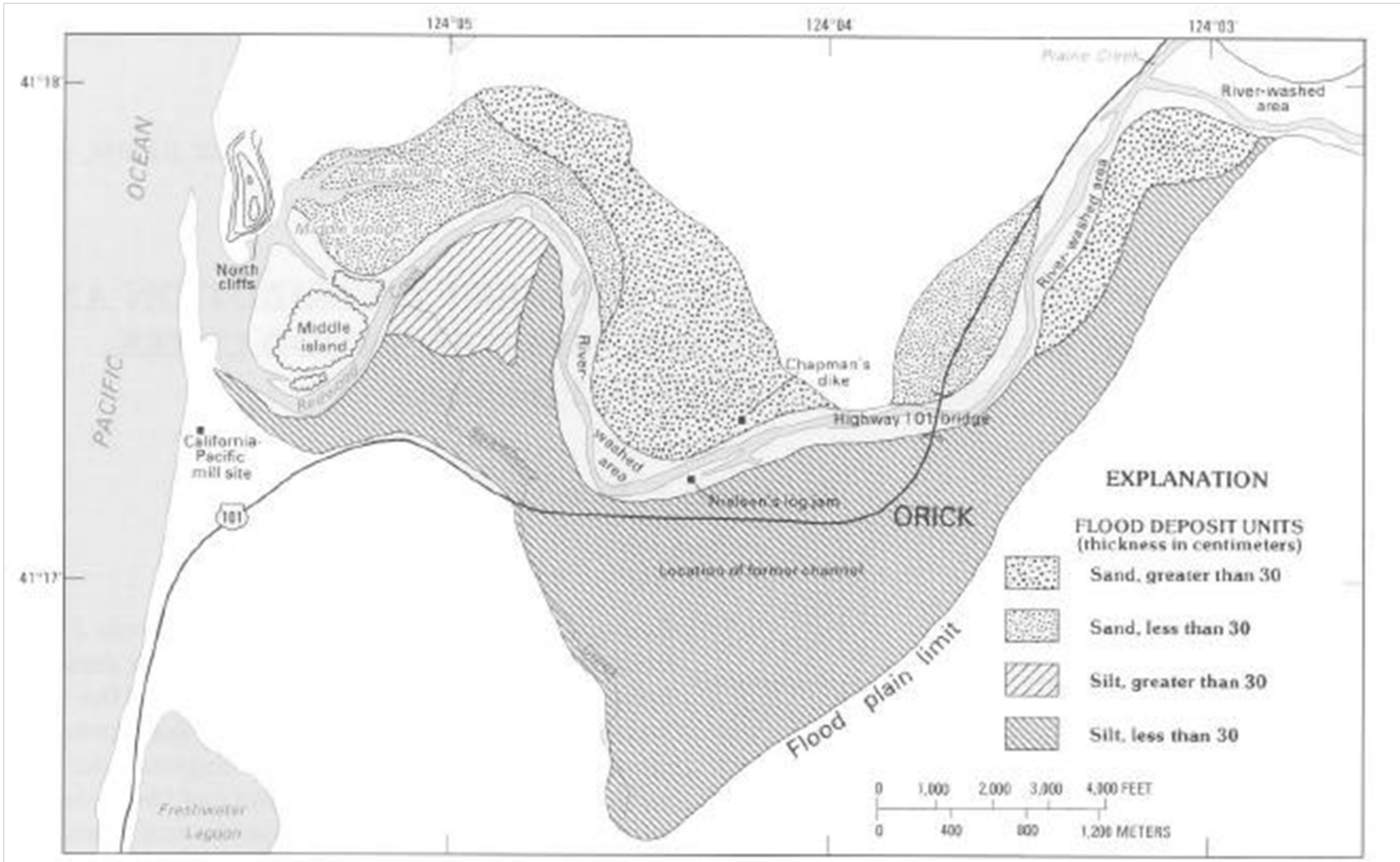


Figure 4-13. Redwood Creek flood plain showing 1964 flood deposits and selected historical cultural features [source of map is Ricks (1995), flood deposit units are from McLaughlin and Harradine (1965)].

5 EXISTING CONDITIONS AND PROCESSES

The Redwood Creek basin has been studied extensively since the 1970s, owing in part to the creation of Redwood National Park in 1968 and expansion of the park in 1978 due to concerns over erosion and sediment delivery originating on upstream and upslope private timberlands (Nolan et al., 1995). Section 5 provides a brief overview of existing conditions of the Redwood Creek watershed, climate and geology, the current hydrology, channel hydraulics and sedimentation within lower Redwood Creek, and concludes with a summary of current estuary condition and processes.

5.1 Watershed Characteristics and Climate

The Redwood Creek watershed (Figure 2-1) is within the wooded and steep North Coast Ranges of California. Most of the 285 mi^2 drainage basin is elongated in a north-northwest direction and is approximately 65 miles long and 4.5 to 6.5 miles wide, with a basin elongation ratio of 0.34 (Janda et al., 1975). Basin elevations range from sea level to 5,300 feet. Prior to entering the ocean, the creek flows through the small bar-built Redwood Creek estuary located about 2 miles below the town of Orick.

The climate of the Redwood Creek basin can be described as Mediterranean with mild, wet winters, and warm, dry summers (Janda et al., 1975). Mean annual basin wide precipitation is approximately 60 inches, with most of the rainfall falling between the months of November through March (Klein and Anderson, 2012). Precipitation generally falls as rain, with snow fall at the higher basin elevations. Snow melt has only a minor impact on runoff since less than 25 percent of the Redwood Creek basin is high enough to have significant snow pack (Janda et al., 1975). However, rain-on-snow events can increase peaks flows as occurred during the 1964 Redwood Creek flood (RNSP, 1997).

The Redwood Creek basin is underlain by metamorphic and sedimentary rocks of the Franciscan assemblage and by shallow marine and sedimentary deposits (Cashmen et al., 1995). Geologic structure in the basin is governed by a series of north-northwest trending faults (Janda et al., 1975; Hardin et al., 1982), with Redwood Creek generally following the Grogan fault (Cashmen et al., 1995). The basins Franciscan assemblage rocks are highly fractured and deformed and susceptible to landslides (Nolan et al., 1995), and the basin has recently experienced high tectonic uplift rates. The effects of weak rock units, rapid tectonic uplift and intense winter precipitation results in naturally high rates of erosion in the Redwood Creek basin (Janda et al., 1975; Nolan et al., 1995). The naturally high rates of erosion have been accelerated by past timber harvest and associated road building practices throughout the basin (Janda et al., 1975; Nolan et al., 1995).

Best (1995) documents the post-World War II acceleration of logging in Redwood Creek when few regulations were in place to moderate effects on erosion and sediment delivery. With passage of the Z'berg-Nejedly Forest Practice Act of 1973 the size of individual harvest areas in California was reduced along with other rules to limit damage to hillslopes and streams. In Redwood Creek logging rates fell abruptly after park expansion in 1978 excluded the downstream one-third of the watershed from commercial timber harvest.

In accordance with Redwood National Park expansion legislation in 1978, a restoration program was initiated on Redwood Creek parklands focusing on the 434 miles of logging roads that existed in 1978 (Klein and Anderson, 2012). To date, about 300 miles (69%) of logging roads have been decommissioned (obliterated) such that their potential to deliver sediment has been greatly reduced. Road decommissioning has also occurred elsewhere in Redwood Creek on private timberlands, along with upgrading of logging roads to reduce their likelihood of sediment delivery.

5.2 Hydrology

Klein (1991) notes that the hydrology of the lower 2.5 miles of Redwood Creek, including the estuary, is affected by tidal action and streamflow (Figure 2-2). Tides are mixed semidiurnal with a mean range of 4.99 feet, a diurnal range of 6.87 feet, and a mean sea level elevation of 3.33 feet (NAVD88) based on the National Oceanic and Atmospheric Administration (NOAA) Crescent City Tide Station (NOAA ID: 9419750). Besides Redwood Creek, two small streams (Strawberry Creek and Sand Cache Creek) flow into the estuary, along with unnamed tributaries (Figure 2-2).

5.2.1 Flood-Flows

The U.S. Geological Survey (USGS) has operated a stream gaging station on Redwood Creek at Orick, California (station no. 11482500), and streamflow has continuously been monitored since October 1953. The Redwood Creek at Orick gaging station is located just below the confluence with Prairie Creek (Figure 2-2), and has a basin area of 277 mi^2 above the gage. The flood of record is 50,500 cubic feet per second (cfs) on December 22, 1964, with similar flows in 1953 (50,000 cfs), 1955 (50,000 cfs), 1972 (49,700 cfs), and 1975 (50,200 cfs). Since 1975, the highest flow was 40,300 cfs in 1997.

As part of the County's technical studies to support FEMA's floodplain mapping for Redwood Creek and the community of Orick, NHE and Manhard (2013a) conducted a detailed flood-frequency analysis for Redwood Creek at the Orick station. Flood-frequency estimates were determined using the 65-year record of annual-peak discharges. The flood-frequency estimates listed in Table 5-1 are based on a log-Pearson Type III (LP3) distribution (Figure 5-1) following Bulletin 17B procedures (IACWD, 1982).

The smaller streams (e.g., Strawberry Creek and Sand Cache Creek) that flow into the estuary have not been gaged or consistently monitored for streamflow. Flood-flow estimates for the 2-year to 500-year events were determined for Strawberry Creek and Sand Cache Creek using the regional flood-frequency equations for California (Gotvald et al., 2012). The more frequent flood-flows (1.1-year to 1.5-year) were based on an approach for extending flood-frequency analysis developed by NHE based on a LP3 distribution and least-squares optimization. Regional-equation parameters were determined from the USGS online StreamStats program (http://water.usgs.gov/osw/streamstats/), and the LP3 skew value used in extending the flood-frequency analysis was based on the regional skew model for California (Parrett et al., 2011). Table 5-2 lists various watershed/hydrology parameters for Strawberry and Sand Cache Creeks. Results of the flood-frequency analysis for Strawberry and Sand Cache Creeks are listed in Table 5-1, and shown on Figure 5-1.

Table 5-1. Summary of flood-frequency estimates for Redwood Creek at Orick, CA (NHE and Manhard, 2013a), and Strawberry Creek and Sand Cache Creek based on regional flood-frequency equations (Gotvald et al., 2012).

Chance Exceedance (Return Interval)	Flood-frequency estimates (cfs) by drainage basin		
	Redwood Creek at Orick, CA	Strawberry Creek[1]	Sand Cache Creek[1]
90-% (1.11-yr)	8,900	52	14
80-% (1.25-yr)	12,100	83	23
67-% (1.5-yr)	15,800	122	34
50-% (2-yr)	20,500	180	50
20-% (5-yr)	31,900	340	100
10-% (10-yr)	39,000	450	130
4-% (25-yr)	47,100	600	180
2-% (50-yr)	52,600	720	210
1-% (100-yr)	57,700	840	250
0.2-% (500-yr)	68,000	1,100	330
Not Determined	77,000	n/a	n/a

1. Strawberry Creek and Sand Cache Creek 67-% (1.5-yr), 90-% (1.11-yr) and 80-% (1.25-yr) flood-flow estimates based on a flood-frequency analysis extension technique developed by NHE.

Table 5-2. Estimated Strawberry Creek and Sand Cache Creek watershed and hydrology parameters.

Parameter	Unit	Strawberry Creek	Sand Cache Creek
Basin area	mi^2	2.0	0.5
Annual Precipitation	in	56.8	55.8
Mean basin elevation	ft	403	284
Log-Pearson III skew		-0.615	-0.618
Q_2 ratio with Redwood Creek at Orick (Table 4-1)		0.00878	0.00244

5.2.2 Daily Flows

Flow duration curves (FDC) were determined for Water Year (WY) 1953 to 2012 Redwood Creek at Orick annual and seasonal mean daily flows (Figure 5-2). Redwood Creek monthly exceedance flows are summarized in Table 5-3. Results indicate that annual mean daily flow (MDF) exceeds 8,900 cfs very infrequently (less than 1 percent of the time), where 8,900 cfs equates to an approximate 1.11-year peak-flood event (Table 5-1). Seasonally Redwood Creek flows are high in the fall/winter (November to January) and winter/spring (February to April) periods, decrease in spring/summer (May to July) months, and significantly decrease in the summer/fall period (August to October) (Figure 5-2).

MLA (2008) reports that streamflow in Strawberry Creek was measured at 1.5 cfs in June 1988 and estimated at 0.25 cfs in August 1988. To provide a continuous streamflow record, MDF estimates for Strawberry and Sand Cache Creeks were estimated using the Q_2 ratio method (Corps of Engineers, 2001). The Q_2 ratio method uses the ratio of the 2-year peak flow (Q_2) between a gaged and ungaged site. Scaling estimates between Redwood Creek at Orick, and Strawberry and Sand Cache Creeks are listed in Table 5-2. Scaled annual and seasonal FDC for Strawberry Creek (Figure 5-3) and Sand Cache Creek (Figure 5-4) were determined using the estimated MDF. Table 5-4 and Table 5-5 provide monthly exceedance flow estimates for Strawberry and Sand Cache Creeks.

The MDF and FDC for Redwood Creek can be useful for fisheries habitat evaluations. The MDF and FDC estimates for Strawberry and Sand Cache Creeks can be used to help assess the importance of these ungaged flows to the Redwood Creek estuary, and their potential to provide year-round or seasonal fisheries habitat.

Table 5-3. Summary of Redwood Creek at Orick, CA mean daily flow by percent time equaled or exceeded.

Percent Equaled or Exceeded	Mean daily flow (cfs) by month											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
5	503	4,195	7,400	7,815	6,188	4,950	3,335	1,725	641	174	73	82
10	227	2,557	5,040	5,600	4,554	3,890	2,440	1,205	449	144	63	51
15	137	1,704	3,988	4,425	3,759	3,219	2,017	972	345	125	56	41
20	100	1,179	3,265	3,580	3,105	2,770	1,758	829	292	112	52	34
25	80	856	2,643	3,006	2,665	2,455	1,566	707	259	104	48	31
30	61	641	2,190	2,577	2,323	2,143	1,402	626	238	98	44	28
35	51	461	1,881	2,238	2,046	1,962	1,252	556	220	92	42	26
40	42	366	1,597	1,950	1,803	1,768	1,119	500	206	87	39	24
45	36	300	1,339	1,694	1,581	1,591	1,024	462	193	81	36	23
50	30	238	1,106	1,492	1,398	1,436	936	428	182	76	34	21
55	26	181	890	1,294	1,254	1,307	838	395	170	71	32	20
60	23	136	753	1,104	1,126	1,209	763	365	158	67	30	19
65	21	105	650	941	1,013	1,107	693	339	147	62	28	17
70	19	84	525	774	911	998	605	315	138	57	25	16
75	16	68	420	662	820	889	532	288	129	53	23	14
80	13	54	305	532	732	784	474	263	118	48	21	13
85	11	43	206	411	644	673	423	236	108	44	19	11
90	9	33	127	315	510	562	374	207	98	39	17	8
95	4	25	71	222	349	438	308	179	83	33	12	5

Table 5-4. Mean daily flow by percent time equaled or exceeded for Strawberry Creek estimated from Q_2 ratio method with Redwood Creek at Orick flows.

Percent Equaled or Exceeded	Mean daily flow (cfs) by month											
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
5	4.4	37	65	69	54	43	29	15	5.6	1.5	0.64	0.72
10	2.0	22	44	49	40	34	21	11	3.9	1.3	0.56	0.45
30	0.54	5.6	19.2	22.6	20.4	18.8	12.3	5.5	2.1	0.86	0.39	0.25
50	0.26	2.1	9.7	13.1	12.3	12.6	8.2	3.8	1.6	0.67	0.30	0.19
70	0.17	0.74	4.6	6.8	8.0	8.8	5.3	2.8	1.2	0.50	0.22	0.14
90	0.08	0.29	1.1	2.8	4.5	4.9	3.3	1.8	0.9	0.34	0.15	0.07
95	0.04	0.22	0.62	2.0	3.1	3.8	2.7	1.6	0.7	0.29	0.10	0.05

Table 5-5. Mean daily flow by percent time equaled or exceeded for Sand Cache Creek estimated from Q_2 ratio method with Redwood Creek at Orick flows.

Percent Equaled or Exceeded	Mean daily flow (cfs) by month											
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
5	1.2	10	18	19	15	12	8	4	1.6	0.4	0.18	0.20
10	0.6	6	12	14	11	9	6	3	1.1	0.4	0.15	0.13
30	0.15	1.6	5.3	6.3	5.7	5.2	3.4	1.5	0.6	0.24	0.11	0.07
50	0.07	0.6	2.7	3.6	3.4	3.5	2.3	1.0	0.4	0.19	0.08	0.05
70	0.05	0.21	1.3	1.9	2.2	2.4	1.5	0.8	0.3	0.14	0.06	0.04
90	0.02	0.08	0.3	0.8	1.2	1.4	0.9	0.5	0.2	0.10	0.04	0.02
95	0.01	0.06	0.17	0.5	0.9	1.1	0.8	0.4	0.2	0.08	0.03	0.01

5.3 Channel Hydraulics within Lower Redwood Creek

Several previous studies have used hydraulic models to estimate water surface elevations within the Redwood Creek Flood Control Project for specified flow rates. Modeling results are highly sensitive to the underlying topographic data due to the continuously changing bed elevations caused by sediment transport, and less sensitive to the assumed friction factors.

Two-dimensional (2D) modeling was conducted in South Slough in 1993 to assess circulation and water quality (McKee, 1993). The Corps of Engineers has developed several one-dimensional (1D) hydraulic models of the Flood Control Project (Corps of Engineers, 1998, 2008, and 2010b). Moffatt and Nichol (2003) conducted 2D hydrodynamic and sediment transport modeling to assess alternate levee configurations for Lower Redwood Creek. These older studies are unlikely to be representative of more current conditions due to sedimentation and topographic changes.

The most current hydraulic analysis for Redwood Creek was developed by NHE and Manhard (2013b) using a 1D hydraulic model for the County's floodplain mapping technical studies to support the update of the FEMA flood map. The NHE and Manhard (2013b) 1D hydraulic model was developed using the Corps of Engineers HEC-RAS modeling system (Corps of Engineers, 2010b). The HEC-RAS model extends from the upper end of the Flood Control Project to the ocean (Figure 5-5), and was developed to provide water surface elevations (WSE) when flows are contained entirely within the levees, or WSE when flows occur in the channel and floodplain assuming levees are nonfunctioning. The HEC-RAS model geometry consisted of field based cross-section surveys in the channel and LiDAR data in the floodplain areas. In 2010 and 2011 the County surveyed a total of 34 cross-sections within the Flood Control Project, and the LiDAR data was collected in 2011 as part of the FEMA work. Vertical elevations are referenced to NAVD88 datum.

For the update of the FEMA flood map, the HEC-RAS model (NHE and Manhard, 2013b) was used to predict WSE for the 10-, 25-, 100-, and 500-year peak flood flows (Table 4-1) in Lower Redwood Creek. However, the HEC-RAS model can be used to predict WSE for other flows of interest in Redwood Creek. Figure 5-6 shows the predicted 1.5-, 10-, 100-, and 500-year peak-flood WSE profiles for Lower Redwood Creek with all flow contained between the levees (levees are functioning).

Results of the NHE and Manhard (2013b) study will be used to provide information regarding existing channel hydraulics within lower Redwood Creek, and the model will be used to evaluate conceptual designs developed in this study.

5.4 Sedimentation

The combined effects of unstable bedrock, rapid tectonic uplift, steep terrain, intense winter precipitation, and land use change (primarily timber harvest practices and associated road construction) in the Redwood Creek basin produces one of the highest annual sediment yields in the conterminous United States for basins of similar sizes, with the exception of areas draining active volcanoes and glaciers (Janda et al., 1975; Janda and Nolan, 1979; Nolan et al., 1987; Nolan and Marron, 1995). A number of large winter storms occurring in 1953, 1955, 1964, 1972 and 1975 caused extensive flooding, landslides, erosion, and channel aggradation and stored sediment volume within the Redwood Creek basin (Janda et al., 1975; Nolan et al., 1995; Nolan and Marron, 1995; Madej, 1995). The most damaging was the 1964 flood, which caused widespread landsliding and massive channel aggradation and change within Redwood Creek (Janda et al., 1975; Nolan et al., 1995; Madej, 1995).

The export of the channel-stored bed sediment in Redwood Creek moves in a wave-like fashion downstream (Madej and Ozaki, 1996). By 1990, peak channel aggradation was approximately five miles below Tall Trees Grove and about four miles above Orick (RNSP, 1997). Madej and Ozaki (2009) documented the export of channel-stored bed sediment from the 1970s to present, and showed channel recovery proceeding in a downstream direction. Recovery of the Redwood Creek channel toward pre-aggradation bed elevations has been slower in the flatter gradient downstream reaches, which could have long-term implications for estuary restoration and rehabilitation and maintenance of the Flood Control Project.

Suspended sediment and bedload measurements have been routinely made at the Highway 101 bridge by the USGS and NPS since about 1971. When combined with water discharge, sediment transport samples at known discharges provide the data for making sediment load estimates. Recent work by Klein and Anderson (2012) estimated suspended sediment and bedload loads for Redwood Creek at Orick using multiple log-linear rating curves at obvious temporal shifts for WY 1954 to 2009. On average, Redwood Creek transports approximately 1,075,000 tons (975,000 Mg/yr) of suspended sediment and 174,000 tons (158,000 Mg/yr) of bedload past the Orick gaging station annually. Sediment loads delivered to the Pacific Ocean by Redwood Creek show large inter-annual and decadal variability (Figure 5-7), with the highest loads during the large 1950s through mid-1970s storm events, and dramatically declining loads for the late 1970s to present (Klein and Anderson, 2012).

Klein and Anderson (2012) assessed temporal trends in Redwood Creek suspended sediment by evaluating the 1) departures from period means of annual suspended sediment loads and peak flows, and 2) trends in flow-adjusted suspended sediment concentration (adjusted for streamflow effects) using the nonparametric Seasonal Kendall test (Helsel and Hirsh, 2002). As part of this Project, departures from period means were determined for Redwood Creek bedload loads. Results from period mean departures indicate that suspended sediment loads in Redwood Creek have declined at a greater degree than peak flows (Figure 5-8), whereas bedload loads have decreased at approximately the same rate as peak flows. Results from the Seasonal Kendall test (Figure 5-9) indicate that suspended sediment concentration significantly declined from 1971 to 2009 for Redwood Creek ($p < 0.0001$), with a resulting 3.5 mg L^{-1} yr^{-1} (4.4 % yr^{-1}) decrease in concentration. A similar temporal decrease in Redwood Creek suspended sediment load and concentration was reported in recent work by Warrick et al. (2013). As a result of the decreasing suspended sediment trend the largest storms of recent decades (WY 1996 and WY 1997) produced far less sediment than would have been expected with similar sized storm flows prior to 1975 (Klein and Anderson, 2012).

Suspended sediment can consist of fine-grained sediment (silts and clays), sand, and in some cases gravel. Collected suspended sediment samples are often reported as percent finer than 0.0625 mm, with 0.0625 mm indicating the break between silt and sand. Thus, the percent finer than 0.0625 mm would indicate the fraction of the suspended sediment load consisting of fine-grained sediment (silt and clay), with the remaining percent indicating the fraction of the suspended load made up of particles sand size or greater. Recent work by NHE (in progress, unpublished data) shows that the composition of suspended sediment appears to have coarsened over time (Figure 5-10). This indicates that the suspended sediment load in the 1970s contained more fine-grained sediments (approximately 90% on average) compared to about 70% today.

Klein and Anderson (2012) concluded that the reduction in Redwood Creek sediment loads since the mid-1970s can probably be contributed to natural watershed recovery processes and watershed restoration programs that have occurred within the Redwood Creek basin, along with strengthened land use regulations. The temporal decrease in Redwood Creek annual sediment load appears to be more associated with a decrease in suspended sediment load rather than bedload. Redwood Creek sediment loads, particularly bedload, still remain relatively high and are a concern for maintaining flood capacity within the Flood Control Project (NHE, 2010a) and could affect long-term estuary restoration and recovery.

5.5 Redwood Creek Flood Control Project

The Redwood Creek Flood Control Project was constructed in 1966 to 1968 and consisted of levees and channelization of approximately 3.4 miles of lower Redwood Creek, including the estuary. The intended design of the Flood Control Project was a constant slope (0.0014), fixed geometry, leveed trapezoidal channel with a bottom width of 250 feet and side-slopes of one vertical to three horizontal, and a design capacity of 77,000 cfs (Corps of Engineers, 1961 and 1966). However, sediment deposition within the Flood Control Project has caused a substantial reduction in flood capacity relative to design conditions (Corps of Engineers, 2008; NHE, 2009; NHE, 2010a). Based on the most recent studies, flood capacity with 3 feet of freeboard is highest at the upstream extent of the levee system (68,000 cfs) and decreases progressively downstream (53,000 cfs), and further suggests that the effects of the levee system's sedimentation problems are progressively worse in the downstream direction (NHE, 2009; NHE, 2010a).

5.5.1 Geomorphic Conditions

In 2010, NHE (2010a) conducted a preliminary design review and geomorphic evaluation of the Redwood Creek Flood Control Project. A major conclusion of the NHE (2010a) evaluation was that fundamental design deficiencies, rather than insufficient maintenance, are the root causes for diminished levee performance and flood capacity. In order to reliably meet target flood capacity, the Flood Control Project design requires long-term: (1) static bed conditions, (2) trapezoidal channel geometry, and (3) constant channel gradient with a base level excavated approximately 4.6 ft below mean sea level (-1.3 feet NAVD88). As documented by NHE (2010a), these three design requirements cannot be achieved within the Redwood Creek Flood Control Project for the following reasons:

- Redwood Creek is an alluvial channel with highly variable discharge and sediment supply, and a static bed condition is not achievable in stream channels that have large, episodic sediment pulses (Nolan and Marron, 1995).
- A trapezoidal channel geometry is not a stable geometry in gravel-bed rivers, which are composed of a bar-pool morphology which vary in density, location, and shape based on sediment supply, bed and bank materials, and stream flow.
- The gradient and bed elevation at the downstream end of lower Redwood Creek is controlled by coastal and fluvial processes, and artificially lowering the channel base level to achieve flood capacity is not sustainable within this dynamic environment (Figure 5-11).

NHE (2010a) further showed through multiple lines of evidence from reports, letters, and a time-series of topographic data between 1968 and 2009 that the Flood Control Project never performed as designed:

- The first winter following construction (1968), three to four feet of sediment deposition was observed at several locations within the Flood Control Project. Topographic surveys in 1980 and aerial photos document the continued accumulation of sediment and by 1987, at least 210,000 cubic yards of sediment had deposited within the Flood Control Project.
- In 1987 and 1988, the channel of the Flood Control Project was re-excavated to near design conditions as part of an aggregate mining project to construct the Highway 101 bypass. Ten years after re-excavation, the average bed elevation throughout the Flood Control Project had increased by 1.9 feet, indicating that reach-scale sedimentation was not an isolated occurrence due to the high flood-flows and sediment loads of the late 1960s and early 1970s.
- Topographic surveys 12 years after the initial project construction (1980 and 1981) and nine years after re-excavation to near design conditions (1997) document the re-development of bars, the typical morphology of a gravel-bed river. This demonstrates that the Flood Control Project design geometry is not self-maintaining and reach-wide adjustments towards pre-project morphology occur in as little as nine years.
- A comparison of pre-project contours and design bed elevations in the lower portion of the Flood Control Project indicates that design bed elevations extend approximately 3.3 feet below the pre-project wetted bed elevation. A time-series of topographic surveys after re-excavation of the Flood Control Project in 1987–88 indicate that the bed elevation is approaching the pre-project bed elevations (Figure 5-12), and further demonstrates that deepening the channel below pre-project bed elevations is not self-maintaining.

NHE (2010a) concluded that the original design for the Flood Control Project is neither stable nor an appropriate equilibrium channel form for lower Redwood Creek, and a major re-evaluation of the levee system is needed to provide adequate, sustainable flood protection for the community of Orick and the Highway 101 corridor. The re-evaluation should consist of a detailed geomorphic and sediment transport study that addresses the relative roles of sediment supply, gravel extraction, levee confinement, and coastal and estuarine processes (or restored processes) that will be effective within this dynamic system in the long-term.

5.5.2 Flood Capacity

Flood capacity of the Flood Control Project varies by location, with the highest capacity at the most upstream extent of the levee system and progressively decreasing capacity in the downstream direction.

The Corps of Engineers (2008) performed a capacity-by-reach analysis by segmenting the channel within the Flood Control Project into three reaches and estimating the flood flow capacity for each reach that could provide three feet of levee freeboard. NHE (2010b) updated the capacity by reach analysis performed by the Corps of Engineers (2008) using an updated HEC-RAS model.

For this current report, the capacity-by-reach analysis was once again updated using the NHE and Manhard (2013b) HEC-RAS model developed for the update of the FEMA flood map. The results of this analysis are provided in Table 5-6 (numerical stationing are based on distances in feet). Based on the reassessment, only the approximate lower 2,300 feet of the Flood Control Project does not provide continuous three feet of levee freeboard at the 100-year flood flow, but does provide three feet of continuous freeboard for the 50-year event.

To expand on the flood capacity analysis, a more detailed assessment was conducted using the updated HEC-RAS model and LiDAR topographic data collected along the top of the levee. Figure 5-13 shows continuous levee freeboard assessment along the length of both levees for the 100-year flood. Results are consistent with the findings in Table 5-6, showing generally that the lower portion of the channel below the last major curve (approximately Station 3125) has freeboard capacity below three feet for the 100-year flow. The more detailed analysis also indicates that small isolated portions of the levees above the last big bend have freeboard capacity between two and three feet.

Based on results of the updated HEC-RAS model, the Redwood Creek Flood Control Project can contain the 500-year event without overtopping the levees (Figure 5-6), although freeboard capacity is near or below approximately one foot for portions of the levee downstream from the Highway 101 bridge (Reach 1 and 2).

Table 5-6. Summary of flood capacity by reach for Redwood Creek Flood Control Project with 3 feet of levee freeboard.

Reach	Reach by Station	Flood Flow (cfs)	Flood Freq. (Year)	Flood Freq. (%-Exceedance)
Reach 3	11881 to 18504	68,000	500	0.2
Reach 2	3125 to 11881	57,700	100	1
Reach 1	860 to 3125	52,600	50	2

Note: Stationing is based on distance in feet from a reference point located near the mouth of Redwood Creek.

5.5.3 Structural Stability

As discussed in Section 2.5.2, the results of a 2011 geotechnical investigation study indicated that the levee system does not meet applicable standards for seepage, underseepage, slope instability, and liquefaction (CGI, 2011). One limitation of the 2011 geotechnical study is the scope was constrained by the available funds, and cross-sections had an average spacing of one per 1,400 feet rather than the Corps of Engineers standard spacing of one per 1,000 feet. The results from the 2011 study were re-evaluated in 2013-2014 to assess the potential for certification on the FEMA flood map (HDR, 2013 and 2014; CGI, 2014).

Excessive seepage forces acting on the landward side of the levee could potentially decrease slope stability as a result of sloughing or internal erosion. Analysis for seepage through the levee embankment assuming steady-state river stage conditions indicated the potential for through-seepage at 11 of the 18 evaluated locations (CGI, 2011). Steady-state conditions represent a worst-case scenario and may not be representative of actual conditions. CGI (2011) conducted further analysis assuming unsteady (transient) conditions based on a synthetic hydrograph prepared to represent the flood of record. No locations indicated a potential for through-seepage based on the unsteady analysis.

Analysis for underseepage (seepage under the levee embankment and through the levee foundation) assuming steady-state river stage conditions indicated that eight out of 18 evaluated locations exceeded the applicable criteria, with three locations having significant exceedances (CGI, 2011). These three locations are situated along the right levee (facing downstream). Further analysis assuming unsteady conditions indicated that two out of the 18 evaluated locations continued to exceed the criteria. These results likely indicate localized areas where the thickness of the low permeability landside blanket layer is relatively thin. Some amount of mitigation may be provided currently by pressure relief wells located in the vicinity. HDR (2014) expressed an opinion that transient underseepage analysis may not be sufficient for certification associated with the FEMA flood map. Options for mitigation include increasing the blanket thickness near the landside toe and installation of cutoff walls.

Analysis for slope stability on the land side during steady-state loading indicated that four of the ten evaluated locations did not meet the applicable criteria (CGI, 2011). All locations met the criteria based on unsteady analysis. Application of an alternative analysis method suggested by HDR (2013) indicated that one location did not meet the applicable criteria (CGI, 2014). Analysis of slope stability on the water side under rapid drawdown conditions indicated that three of the ten evaluated locations did not meet the applicable criteria. Further analysis of rapid drawdown stability based on transient conditions indicated that all locations met the applicable criteria (CGI, 2014). HDR (2014) expressed reservations about relying on transient analysis for slope stability.

The potential for liquefaction-induced settlement is relatively small (maximum of 6.5 inches) and is not considered a significant deficiency warranting mitigation.

In summary, additional geotechnical investigation and mitigation will be required for localized areas not meeting current standards for seepage, underseepage, and slope stability to achieve certification on the FEMA flood map. An outstanding question is whether a licensed engineer would be willing to utilize analysis results based on unsteady conditions for certification.

5.6 Current Redwood Creek Estuary Condition

The Redwood Creek estuary has been highly altered with the construction of the Flood Control Project in 1968 which shortened, channelized and leveed Lower Redwood Creek (Figure 2-2), and has been identified as the primary cause of the loss of estuary size, volume, and habitats (Klein, 1991; Ricks, 1995; RNSP, 2005). Since construction of the Flood Control Project, at least 50 percent of the Redwood Creek estuary has filled with sediment or become isolated from the main channel (Ricks, 1995).

Beginning in the 1980s, the National Park Service has studied the existing estuary and the adverse effects that the Flood Control Project has had on the physical and biological function of the estuary. This section briefly summarizes various National Park Service studies and findings pertaining to the physical, biological and ecological processes currently at work within the estuary. For a more in-depth review of Redwood Creek estuary existing conditions, change, management and restoration reference can be made to a number of National Park Service studies, such as Ricks (1995), Klein (1991), annual estuarine management and research activities reports (Hofstra, 1984 to 1988), and numerous annual Redwood Creek estuary monitoring and management reports by Anderson (1991 to present).

The current configuration of the Redwood Creek estuary is shown in Figure 5-14. The Flood Control Project levees essentially reroutes the lower portion of the Redwood Creek channel through Middle Slough and channelizes a large portion of the embayment, creating a more direct flow path to the ocean (see Figure 4-10 for comparison). The channel relocation bypasses the last downstream meander and shortens the overall length of the historical lower Redwood Creek channel. The levees terminate well into the embayment, and with the placement of excess levee construction spoil material along both sides of the downstream end of the levee (RNSP, 2005), effectively channelized the connections between North Slough and the last downstream meander with the embayment (Figure 5-15). After levee construction the last downstream meander was essentially converted to a backwater channel, which became known as South Slough, and has filled in extensively with sediment.

5.6.1 Current estuary physical processes

As mentioned above, the physical processes currently at work within the Redwood Creek estuary have been highly altered over historical conditions due to the Flood Control Project.

5.6.1.1 Coastal and fluvial processes, barrier beach and sedimentation

In general, the same coastal processes that historically functioned within the estuary, as described in Section 4, still function at some level although over a much smaller footprint. Channelization and reconfiguration of lower Redwood Creek has reduced the size and location of the active barrier beach, and the general location of the creek mouth, to the north immediately west of the downstream extents of the levee (Figure 5-16 to Figure 5-19). Shortly after completion of the Flood Control Project, marine-derived sediments rapidly accumulated across the barrier beach, filled the mouth of South Slough, and created a substantial deposit in the embayment that both filled the deep pool along the north headlands and isolated North Slough from the embayment (Klein, 1991; Ricks, 1995). With the levees effectively isolating the heads of North and South Sloughs, flows that would have normally scoured marine-derived sediments from these areas do not exist, and the sloughs have become sediment traps. Consequently, coastal sediments driven by wave overwash and tidal currents during periods when the barrier beach is breached, continually deposit into the slough mouths and embayment. Wave overwash from large winter storms also creates a large sand storm berm between the barrier beach and South Slough (Ricks, 1995), and with no creek flows to scour the storm berm it still persists and expands today (Figure 5-14, Figure 5-17, Figure 5-18, and Figure 5-21).

Large winter storm waves from the southwest can enter the embayment and subject the North Slough neck to direct wave attack (Klein, 1991). These large waves can also scour the embayment and subaerial deposit of sediment and organic debris and redeposit them into the North Slough neck (Ricks, 1995). The storm berm generally protects South Slough from direct wave attack, but is still subject to waves refracting around the berm. On occasion large waves do overtop the storm berm and can transport large quantities of sand into South Slough (Klein, 1995).

Prior to levee construction high creek flows would have routinely scoured marine-derived sediments from the embayment and sloughs, and maintained a relatively large active barrier beach (see Section 4). Following levee construction, high creek flows have not been able to scour either North or South Sloughs. Also, the extent and location of the levee terminus constricts flow so effectively that only a small portion of the embayment and barrier beach are scoured by high creek flows (Ricks, 1995). For example, the 1964 flood completely scoured and reshaped the entire barrier beach from the California-Pacific Mill site to the North Bluffs (Figure 4-8). In contrast, the 1972 flood (post-levee construction) scoured about 70 percent less of the barrier beach (Figure 5-20) than pre-channelized conditions (Ricks, 1995).

Today's barrier beach breaching and closure process, and creek channel migration is similar to what was described in Section 4 for historical conditions. However, the creek mouth migration and location is generally confined to a much smaller active barrier beach located directly west of the levee end (Figure 5-14, Figure 5-16, Figure 5-17, Figure 5-18 and Figure 5-20). On occasion the creek mouth can still do something unexpected (Figure 5-21), revealing the truly dynamic nature of the coastal and riverine processes in Redwood Creek.

The Flood Control Project levees have reduced channel and floodplain connectivity upstream of the estuary, which has altered velocity and sedimentation patterns. With the loss of channel and floodplain connectivity, sediment deposition cannot occur on the floodplains and has restricted sediment transport to within the leveed creek channel. The configuration of the levee system allows most of the Redwood Creek fluvial sediments to be transported through the mouth to the nearshore environment or beyond during flood flows (Ricks, 1995).

5.6.1.2 Circulation and Water Quality

The Flood Control Project levees were responsible for altering historical water circulation patterns that were critical for the scouring and transport of marine sediments out of the estuary embayment and North Slough, and also affected water quality. After sedimentation of the North and South Slough mouth or inlet channels (e.g. Figure 5-16), water exchange with the embayment became limited (Ricks, 1995). The sloughs and embayment can become connected during periods of high creek discharge (Figure 5-18), high wave action, during periods of large flood tides when water levels exceed the slough inlets (RNSP, 2005), or when the barrier beach is closed (Figure 5-15, Figure 5-19) or the mouth has a favorable configuration (Figure 5-17 and Figure 5-21) and the embayment water levels are high. Discharge from Sand Cache Creek through North Slough and Strawberry Creek via South Slough can be tidally influenced when backwater conditions exist from flood tides or high Redwood Creek flows (Ricks, 1995).

Circulation in North Slough is poor due to the large accumulation of marine-derived sediment and woody debris that blocks flow exchange with the embayment. Sand Cache Creek, which flows into North Slough, is restricted at a road crossing further limiting circulation within the slough (Ricks, 1995). Drainage of adjacent agricultural lands is also affected by the poor circulation and restricted flow conditions of North Slough (RNSP, 2005). The lack of tidal and saltwater exchange between the embayment and North Slough has allowed reed canary grass, an exotic invasive species, to become established in North Slough (Figure 5-14 and Figure 5-19).

Circulation in South Slough is better than North Slough due to unrestricted flow from Strawberry Creek and lower slough inlet elevations (Ricks, 1995). In 1988, the South Slough culvert gates were installed through the levee (Figure 5-13) to improve circulation, water quality and summer rearing for juvenile salmonids in South Slough (RNSP, 2005), by reconnecting flows between Redwood Creek and the head of the slough channel. The culvert gates have improved circulation and water quality in South Slough (RNSP, 2005), but do not generate enough streampower to scour sand from the slough inlet (Klein, 1991).

From 1982 to 1996, the National Park Service monitored 12 sites within the Redwood Creek estuary (embayment and sloughs) for water quality (specific conductivity, temperature, salinity, dissolved oxygen and temperature) to determine limiting conditions for juvenile salmonids. Depending on tide levels, creek flows and barrier beach conditions the estuary embayment can alternate between fresh and brackish water conditions. A salinity layer typically exists in the bottom of the slough channels, and intermittently in the embayment. The following estuary water quality summary is excerpted from RNSP (2005), and examples of estuary water quality conditions in 1991 are provided in Figure 5-22, Figure 5-23, and Figure 5-24.

Salinity levels show that North Slough can be highly stratified (Figure 5-22), which is probably a function of the poor circulation inherent to this slough. North Slough generally has poor water quality for aquatic life (RNSP, 2005), with dissolved oxygen levels near 0 ppm (anoxic conditions) in the lower saline layer and higher dissolved oxygen levels in the thin top freshwater layer early in the summer (Figure 5-22). The top layer dissolved oxygen levels continue to decrease to low levels (~ 2 ppm) throughout summer and into fall. Temperatures are stratified through summer and fall, with lower temperatures (~ 12 to 14 °C) in the bottom saline layer and warmer levels (~17 to 20 °C) in the top freshwater layer.

Salinity levels in South Slough (Figure 5-23) show stratified to moderately stratified conditions which indicate improved circulation conditions over North Slough. Dissolved oxygen levels indicate consistent 12 ppm concentrations with depth in early summer, but oxygen levels decrease to approximately 4 ppm with depth in fall. South Slough temperatures show minor stratification with levels ranging from 16 to 24 °C through the summer/fall period.

Embayment salinity levels (Figure 5-24) show that the embayment can be moderately stratified or completely fresh indicating improved circulation conditions in the embayment over the sloughs. Dissolved oxygen and temperature levels show almost no stratification with depth. Dissolved oxygen concentrations range from 8 to 14 ppm, with the lower oxygen levels occurring during periods when the embayment is brackish or saline. Temperatures range from 14 to 21 °C, and like dissolved oxygen, cooler temperatures occur when the embayment is brackish or saline.

Summer and fall water temperatures in the estuary embayment have been continuously monitored approximately one foot from the bottom since 1997 (RNSP, 2005). Examples of this data (temperatures for 2002 and 2003) are shown in Figure 5-25. Embayment temperatures are influenced by cold water intrusion events, such as tides when the barrier beach is open, high creek flows and wave overwash. When the barrier beach is closed, water temperatures can become elevated. RNSP (2005) reported that the maximum weekly average temperature was 18.7 °C in 2002 and 20.2 °C in 2003.

5.6.2 Current ecological and biological conditions

Current conditions in lower Redwood Creek and its estuary has resulted in significant reductions in the area, volume, and quality of fish habitat during all seasons, reduced access to floodplain and off-channel areas during high flow periods, reduced backwatering, poor water quality during the summer and late fall months, and loss of productivity and reduced survival of juvenile salmonids (i.e., Chinook salmon, coho, steelhead, and cutthroat). All of these factors have contributed to the diminishment of the once abundant anadromous fish populations. In addition, other factors relevant to fish population declines include degradation of upstream spawning and rearing habitats especially from excessive sedimentation, loss of riparian forests, overfishing, conversion of floodplains to agricultural land, and variability in ocean productivity. Some of these impacts largely preceded construction of the levees and alteration of the Redwood Creek estuary.

Currently, the Redwood Creek estuary has lost nearly all off-channel habitats associated with the sloughs (North, Middle, and South) and seasonal wetlands (south wetland/seasonal lake). It has been disconnected from nearly all of its former floodplains, riparian vegetation has become greatly simplified, and the mature Sitka spruce riparian forests are gone. The main embayment of the estuary has filled with a mix of marine and fluvial sediment, resulting in extremely shallow depths and a complete lack of localized scour in the vicinity of the north headland. The shallow depths and loss of connectivity has been exacerbated by the invasive reed canary grass, which chokes wetlands, reduces dissolved oxygen, and captures sediment and detritus. In addition, invasive New Zealand mud snails have been found in the estuary.

In summary, the Redwood Creek estuary has lost the vast majority of off-channel and main channel habitat. What remains is severely impaired for rearing salmonids and other estuarine-dependent fishes. During the winter, high water velocities, excessive turbidity, and lack of off-channel refugia are major problems. High water temperatures, low dissolved oxygen, and limited available rearing habitat limit salmonid production during the summer (RCWG, 2006). While water temperatures and high flows are not a problem during the spring and fall, the lack of habitat and depth in the estuary constrain rearing opportunities and capacity during these seasons as well. All of these changes have combined to degrade the carrying capacity, productivity, and survival for juvenile salmonids and other estuarine fish species year-around (RNSP, 2005; Sparkman, 2008; Anderson, 2010).

5.6.3 Salmonid life history stages and limiting factors

Estuaries are vitally important ecotones for juvenile salmonids. Estuaries provide highly productive, low gradient, complex habitats that can allow fish to achieve rapid growth and avoid predation, thereby compensating for poor growing conditions upstream, and allow smaller or younger fish to reach size thresholds critical to higher early marine survival upon ocean entry. A functioning, productive estuary can help compensate for poor fish production upstream and can also increase overall carrying capacity for a stream system when upstream production is high. Adult salmonids use estuaries as staging areas during upstream migration but the duration of their residence is generally brief compared to juvenile life stages and adults have ceased feeding whereas juveniles are still feeding just prior to ocean entry. A functioning estuary is critical for recovery of federally listed threatened and endangered fish species in Redwood Creek.

Under current conditions, the Redwood Creek estuary is a small fraction of its former area and volume, and has been significantly altered and degraded in numerous ways. This has led to a suite of interacting physical and biological factors that limit the capacity, growth, and survival of juvenile salmonids and other native fishes. Based on available data, general ecological principles, and current understandings of aquatic systems, the likely limiting factors for juvenile salmonids in the Redwood Creek estuary are summarized and described below.

1. <u>Habitat capacity</u>, meaning the maximum or average amount of fish that can successfully reside in a given habitat, is greatly reduced due to the small size of the estuary (area and volume), lack of connectivity to sloughs and off-channel habitats (summer and winter), and reduced food resources associated with habitat degradation. The capacity of the estuary is currently considered deficient compared to upstream production and is likely a limiting habitat factor for salmonid populations in the Redwood Creek watershed (Sparkman, 2008; Anderson, 2010). The habitat capacity of the estuary is significantly reduced compared to historical conditions for all seasons.
2. <u>Growth rates and productivity</u> is reduced because of simplification and loss of habitat, lack of access to productive off-channel habitat, and loss of historical riparian forest and grassy and herbaceous vegetation. Total food resources are reduced due the decreased size of the estuary and associated off-channel habitat, but also due to the reduction in habitat complexity and riparian vegetation. This reduces not only the total food resources, but also the amount of food per unit area, and given that upstream salmonid production generally greatly exceeds the current capacity of the estuary, a greater amount of competition occurs for the remaining food resources. Excessive competition in habitats with reduced capacity

can reduce the size and condition of fish. Growth in the estuary is very important because estuaries typically have rich food resources (i.e., due to complex, low-velocity habitats with tidal or seasonal inundation of riparian vegetation and inputs of marine-derived nutrients and high-quality prey items) that provide a last opportunity for rapid growth just prior to ocean entry (Healey, 1980; Levy and Northcote, 1982; Hayes et al., 2008; Volk et al., 2010; Fuller, 2011). Ocean entry and the first year of marine residence is when the majority of marine-related mortality occurs to immature salmonids and survival during this stage is generally believed to be size-dependent (Ward and Slaney, 1988; Holtby et al., 1990; Bond et al., 2008). A critical size-threshold for improved survival upon ocean entry for juvenile salmonids is approximately 90 to 100 mm (Holtby et al., 1990), and monitoring data for the Redwood Creek estuary suggests that many fish either perish or are forced to enter the ocean before they reach this size (Anderson, 2006).

3. <u>Duration of suitable summer rearing conditions and migratory access to the ocean</u> is reduced. Poor water quality from high water temperatures and low dissolved oxygen resulting from poor water circulation, shallow depth, and other factors limits the quality or over-summer rearing habitat (RSNP, 2005). The main embayment of the estuary gets too hot at times (Figures 5-24 and 5-25), and the sloughs and off-channel features, which have the potential to be colder at depth due to shading and ground-water inputs, have problems with low dissolved oxygen content (Figures 5-22 and 5-23) (RSNP, 2005). These water quality problems typically occur in July to early August, before fish generally reach the critical size threshold of 100 mm, and coincide with dramatic reductions in the number of fish sampled in the estuary (Anderson, 2010). The coincident timing suggests that fish either die in mass at this time or are forced into the ocean prematurely at a less than optimal size assuming they have access to the ocean through the bar (see Figure 5-26 for monitoring data of Chinook salmon). This situation is especially important for juvenile fall Chinook salmon, and to some extent steelhead, as they are the most dependent on summer estuarine rearing (e.g., Hayes et al., 2008; Volk et al., 2010) of salmonids in the Redwood Creek watershed. Notably, a greater portion of Chinook fry appear to be dependent on estuarine rearing during low flow and drought years (Michael Sparkman, CDFW, personal communication), with low flow years becoming more common in recent decades (Jenny Curtis, USGS, personal communication).
4. <u>Suitability of low-velocity winter rearing habitat conditions</u> is reduced due to lack of access to complex, low-velocity habitat in sloughs, off-channel features, small tributaries, and floodplains. During the winter the mainstem channel and main embayment of the estuary is too turbulent with little high-velocity refugia to provide an adequate amount of rearing habitat for juvenile salmonids. However, estuarine sloughs, backwaters, and off-channel features offer optimal winter-rearing conditions at times when potential water quality problems are not an issue (e.g., low dissolved oxygen). These habitat types not only provide refuge from high velocities and high turbidity, with the latter impacting visual foragers such as salmonids, but also contain complex structure, submerged riparian vegetation, and woody debris that can provide cover from predators and improved feeding conditions. Such high-quality winter rearing areas have been shown to allow significant growth even during the winter months (Peterson, 1982; Swales et al., 1986; Brown and Hartman, 1988; Pollock et al., 2004; Lestelle, 2007), and are especially important for coho salmon that must over-winter to complete their life-cycle, and to a lesser extent steelhead (Solazzi et al., 2000; Lestelle, 2007). Under current conditions, however, the vast majority of such areas have been lost due to in-filling with sediment, colonization with reed canary grass, draining, and loss of connectivity with floodplains.

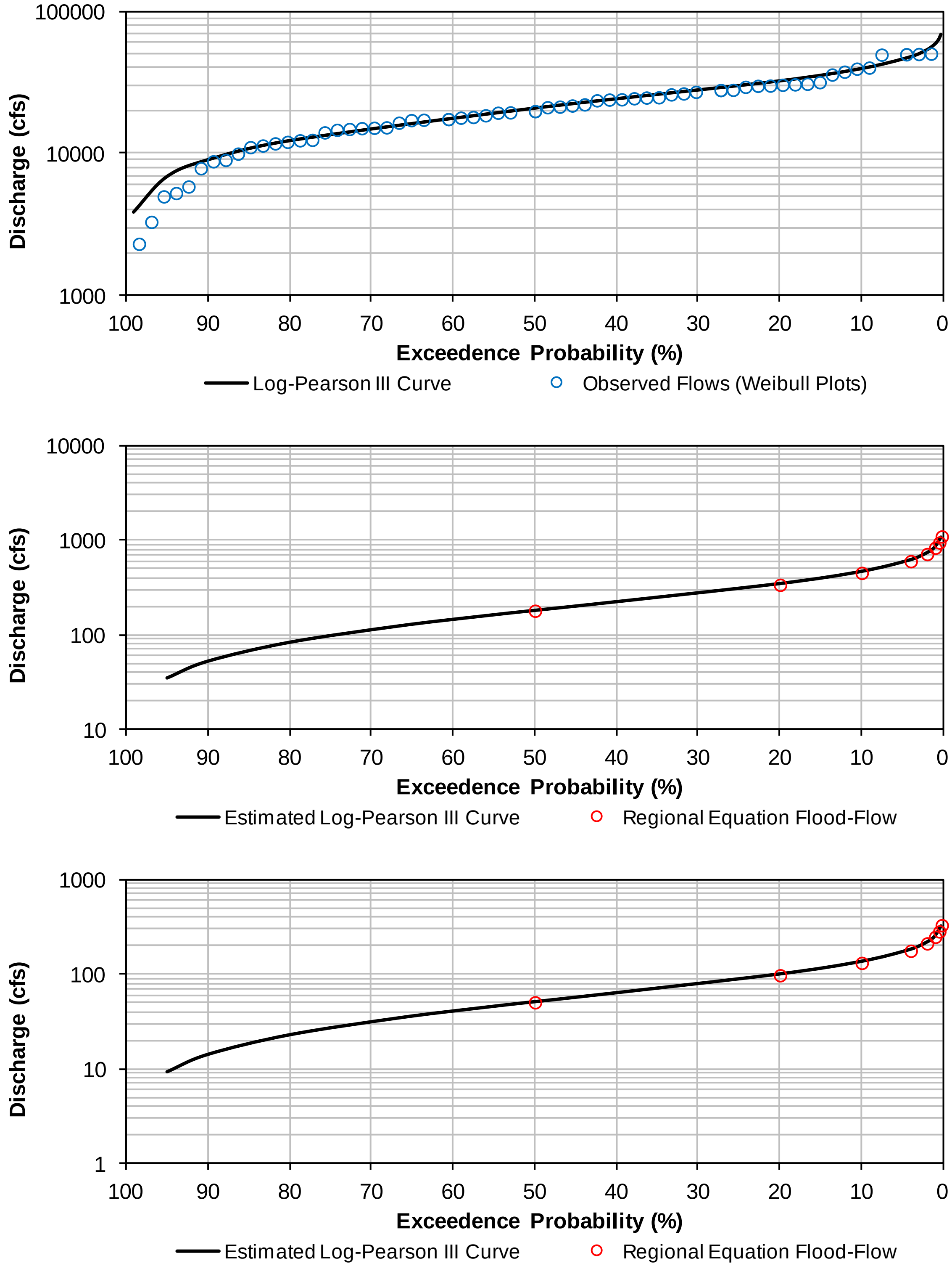


Figure 5-1. Flood-frequency curves for Redwood Creek at Orick (top), Strawberry Creek (middle), and Sand Cache Creek (bottom). Redwood Creek flood-frequency results from NHE and Manhard (2013). Strawberry Creek and Sand Cache Creek flood-frequency results estimated as part of this report.

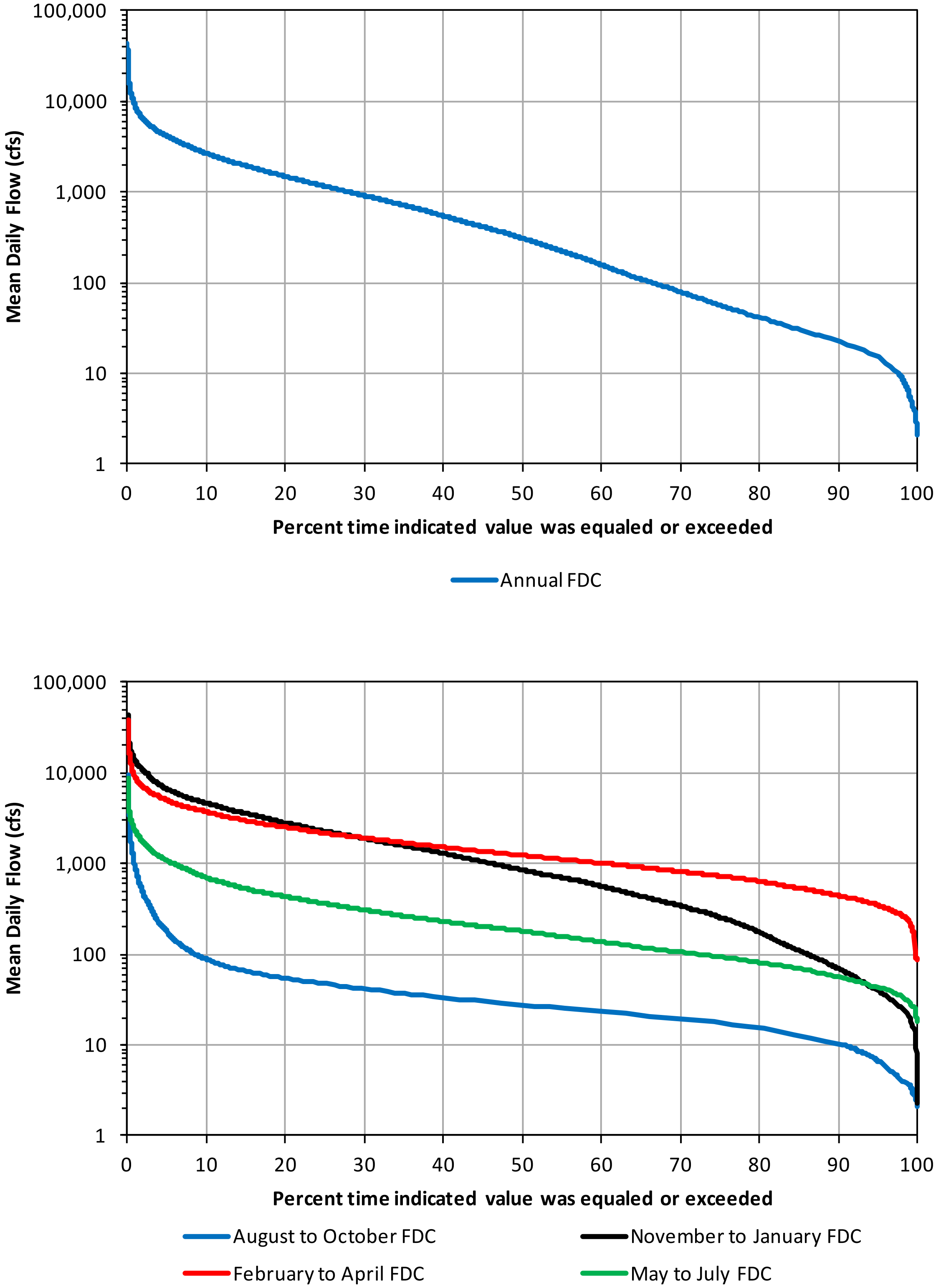


Figure 5-2. Flow duration curves (FDC) for annual (top) and seasonal periods (bottom) for Redwood Creek at Orick, CA mean daily flow for WY 1953 to 2012.

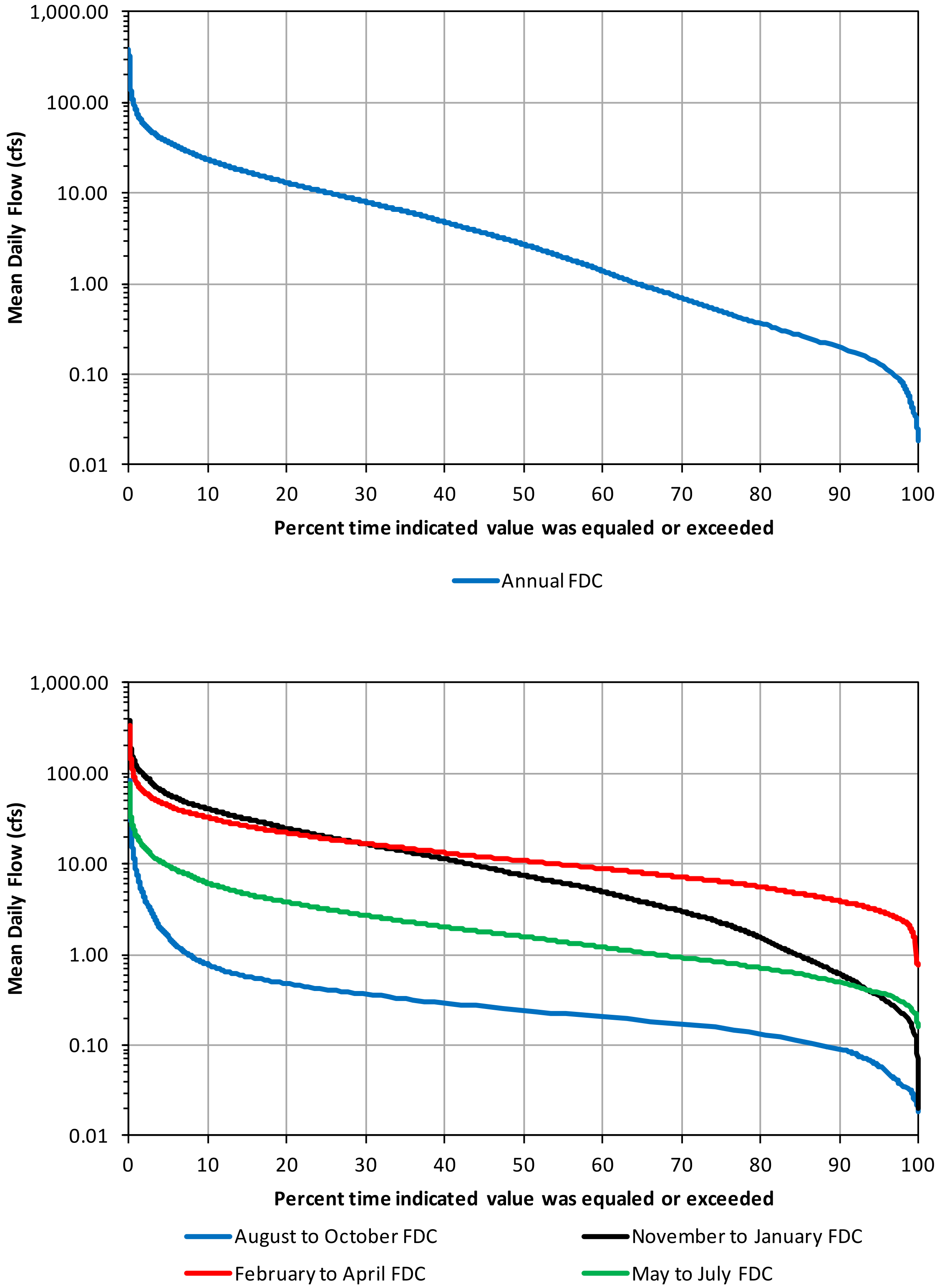
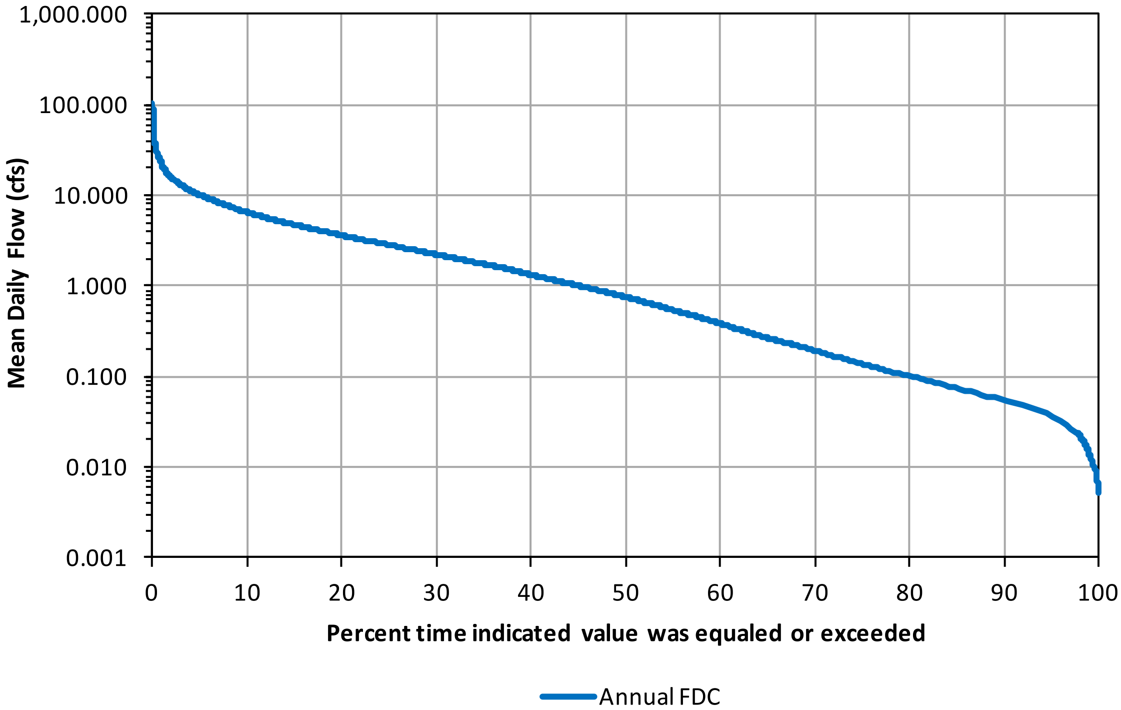


Figure 5-3. Flow duration curves (FDC) for annual (top) and seasonal periods (bottom) for Strawberry Creek estimated using Q_2 ratio method with Redwood Creek at Orick, CA mean daily flow for WY 1953 to 2012.



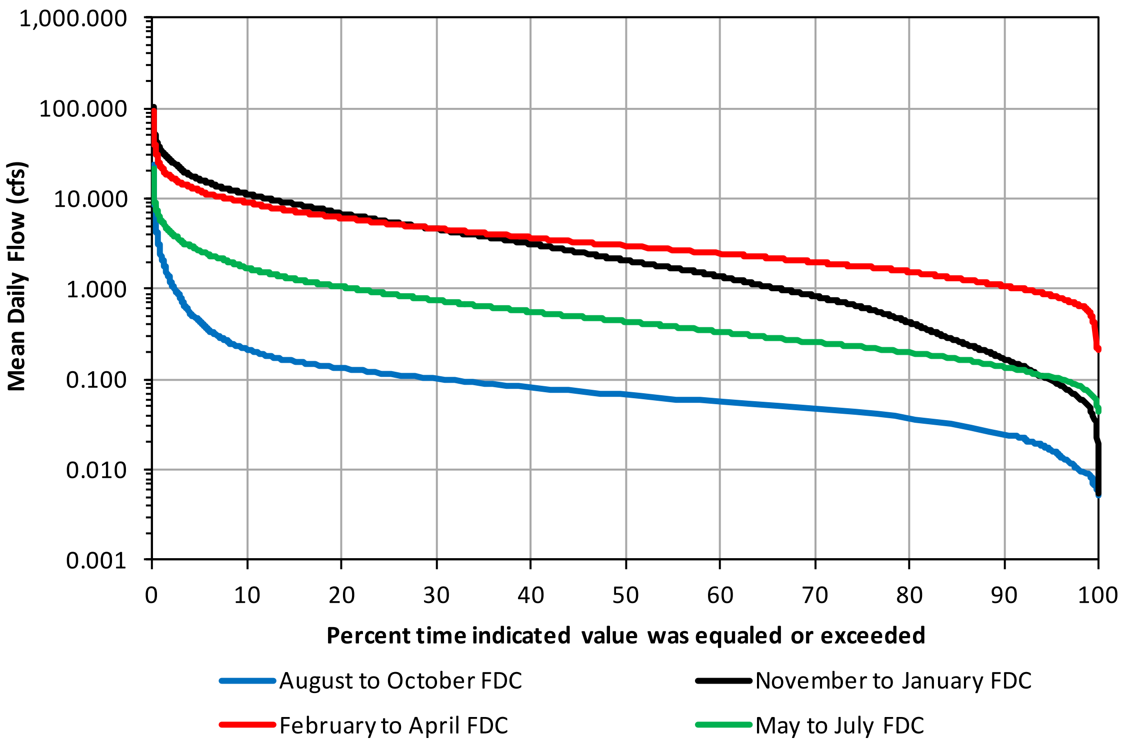


Figure 5-4. Flow duration curves (FDC) for annual (top) and seasonal periods (bottom) for Sand Cache Creek estimated using Q_2 ratio method with Redwood Creek at Orick, CA mean daily flow for WY 1953 to 2012.

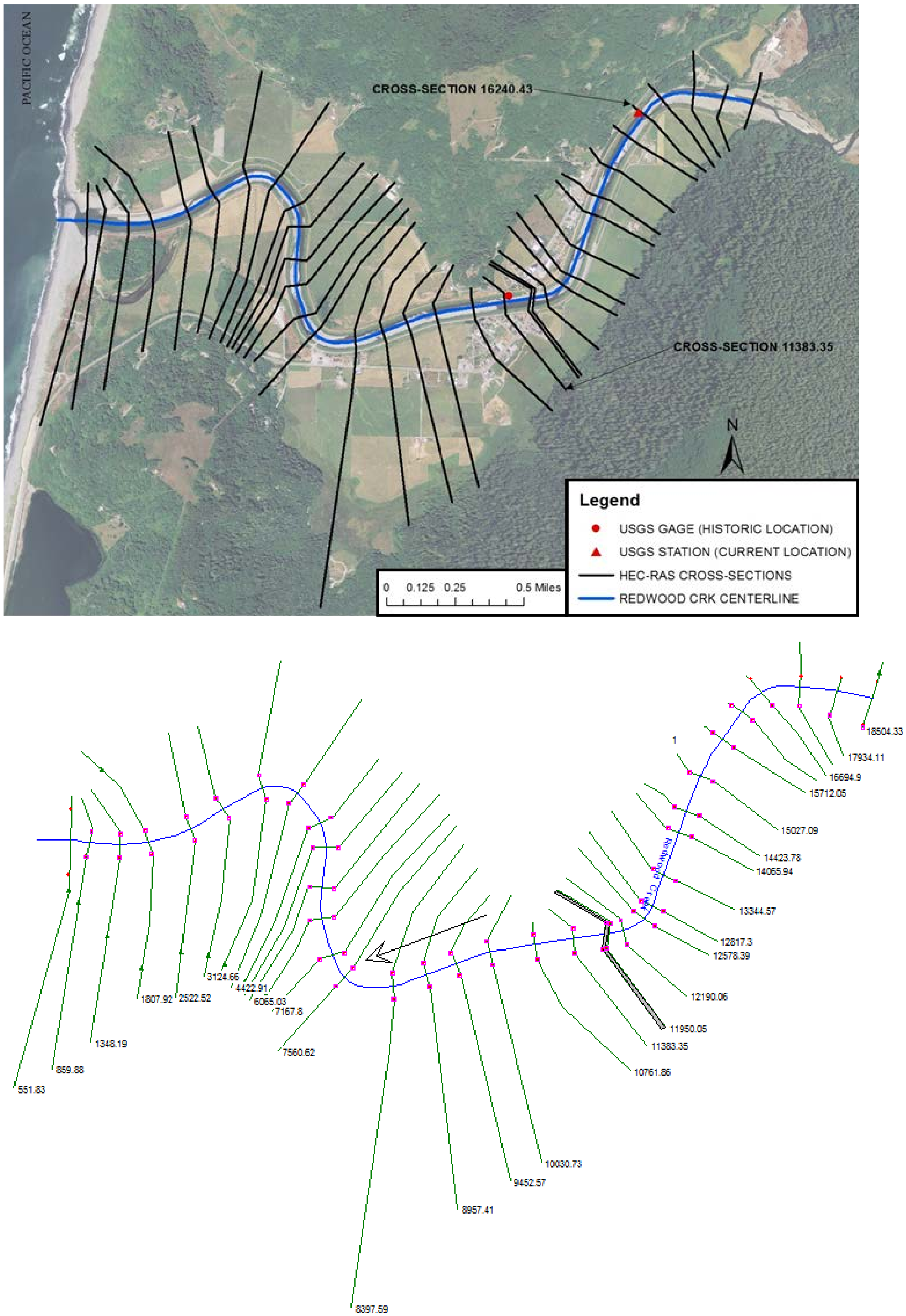


Figure 5-5. Redwood Creek HEC-RAS model configuration (top) and stationing (bottom).

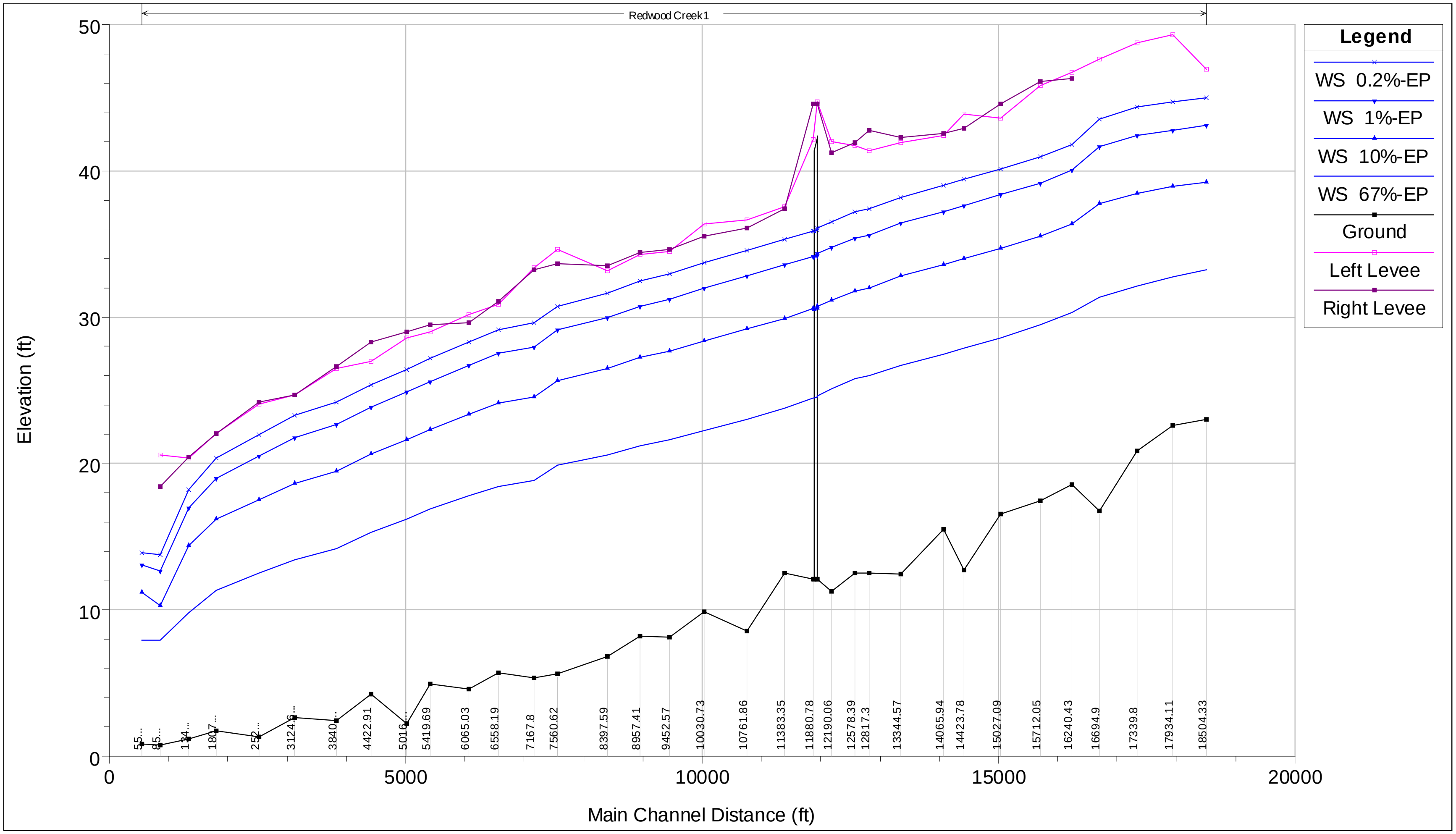


Figure 5-6. Predicted 1.5, 10, 100, and 500-yr peak-flood water surface elevation profiles for lower Redwood Creek with functioning levees (figure generated in HEC-RAS). Predictions made with HEC-RAS developed by NHE and Manhard (2013).

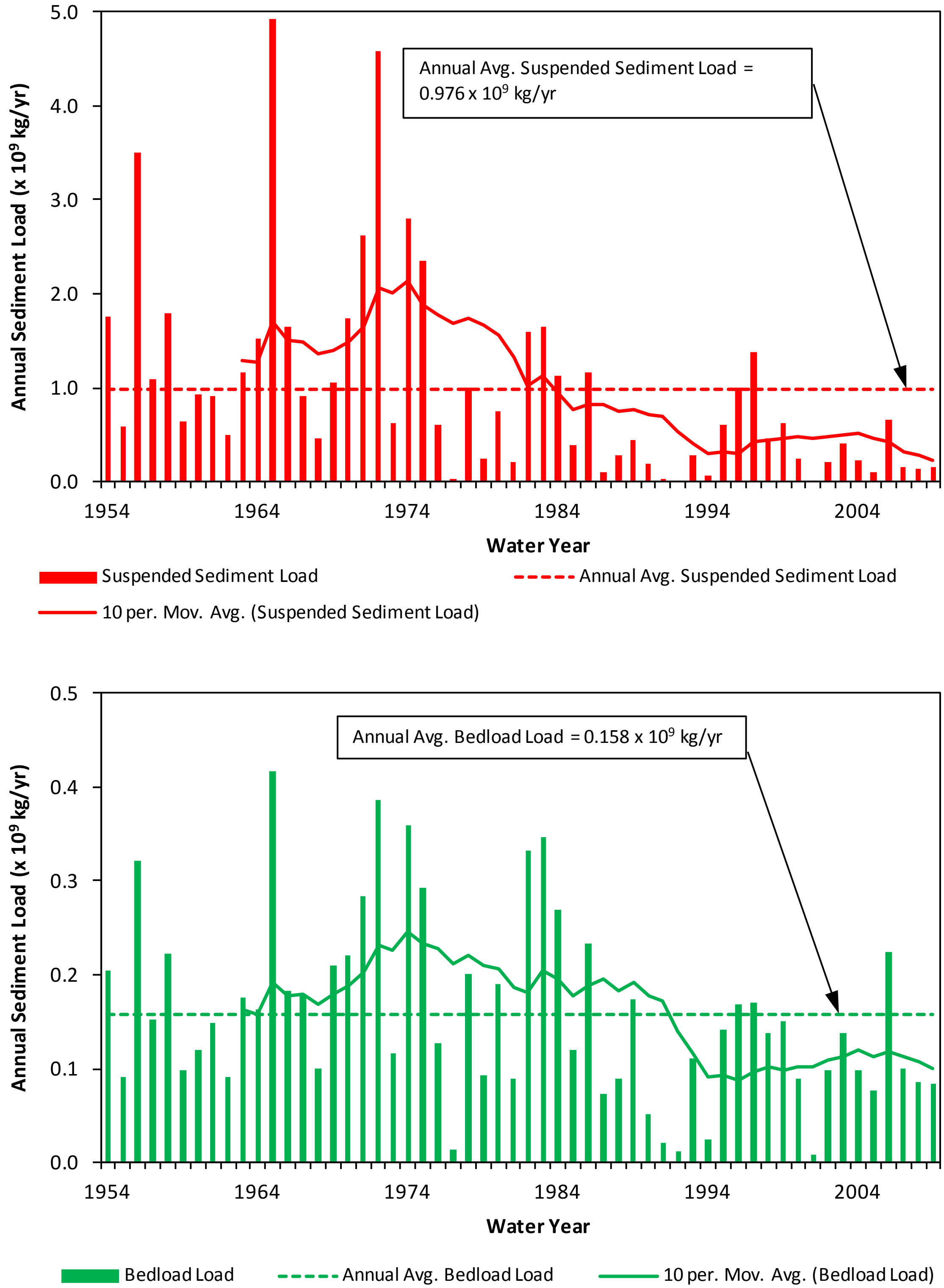


Figure 5-7. Redwood Creek at Orick, CA suspended sediment load (top) and bedload load (bottom) for WY 1953 to 2009, with 10-year moving average and annual average load lines. Note change is Y-axis scale between plots.

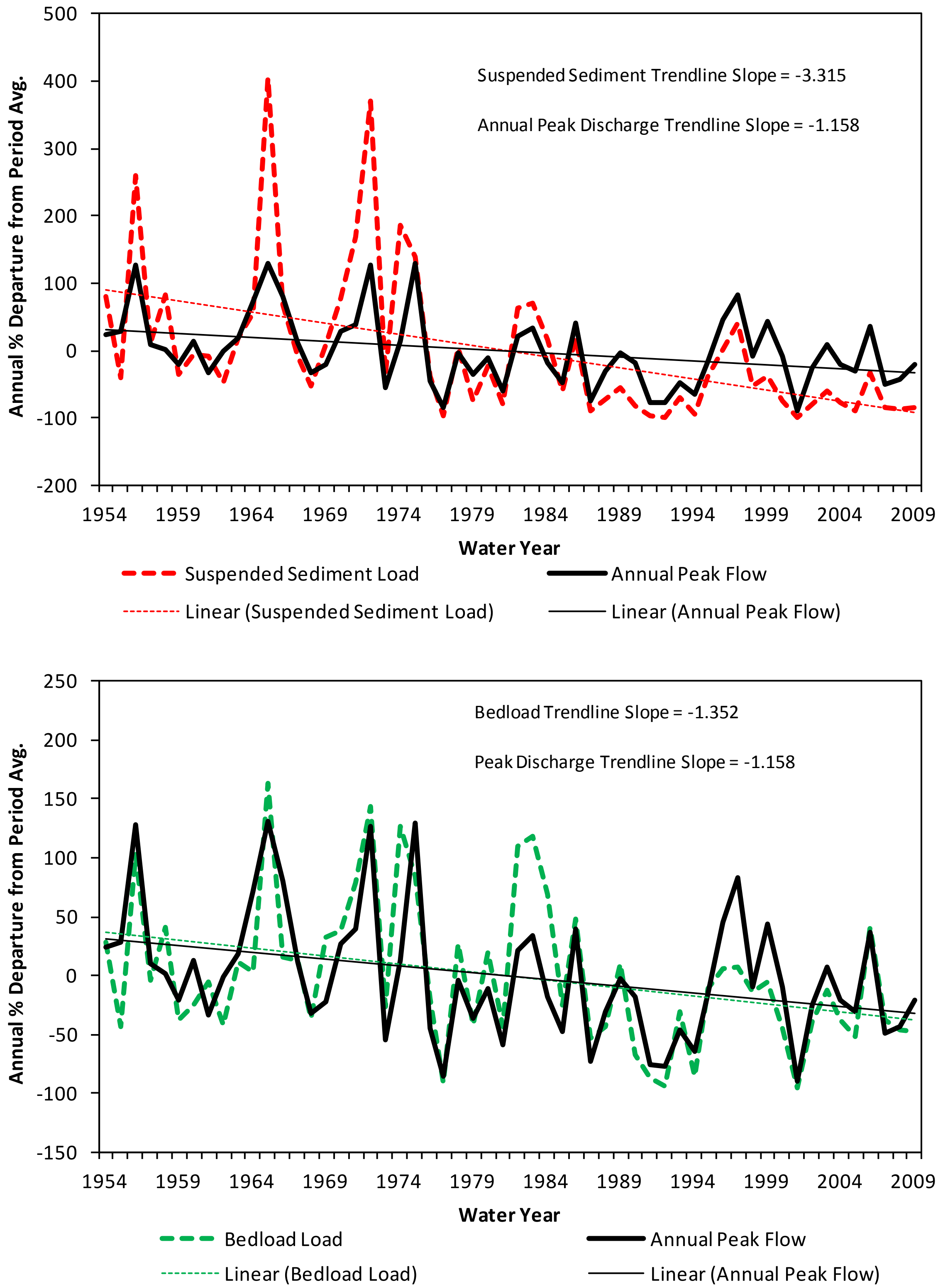


Figure 5-8. Suspended sediment load (top) and bedload load (bottom) and annual peak discharge departures from normal for Redwood Creek at Orick, CA. Trendlines for sediment loads are dashed lines and annual peak discharge is solid line.

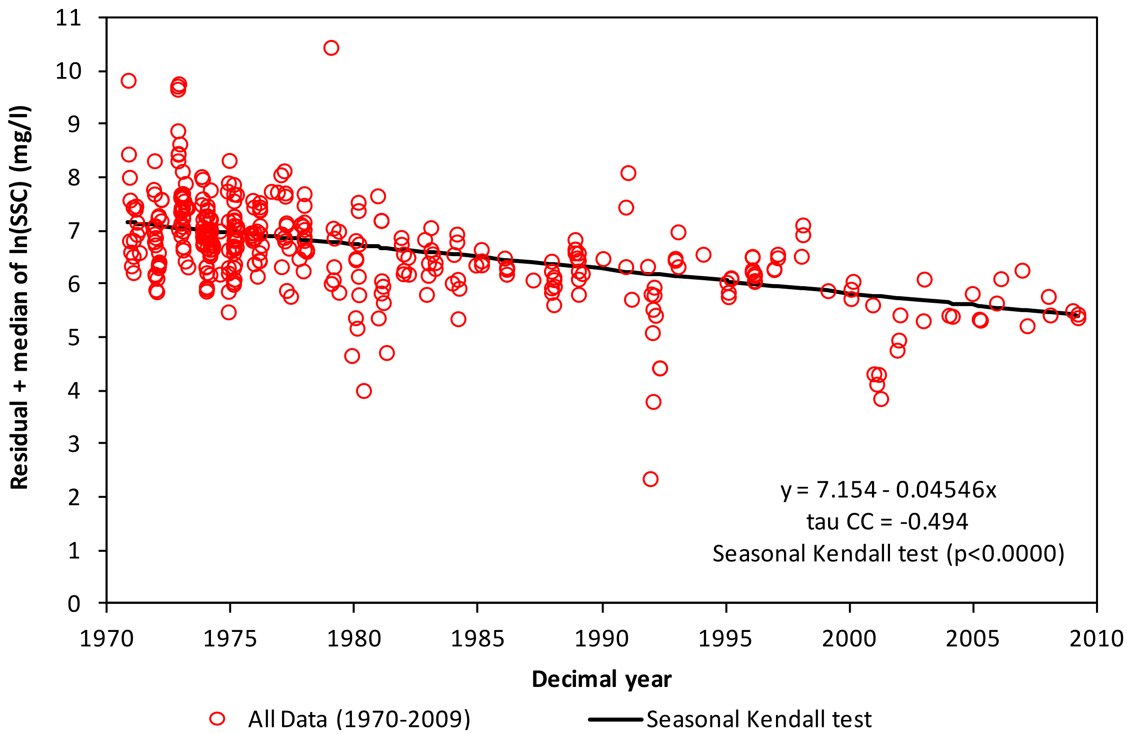


Figure 5-9. Redwood Creek flow-adjusted (flow effects removed) suspended sediment concentration residuals and Seasonal Kendall test results.

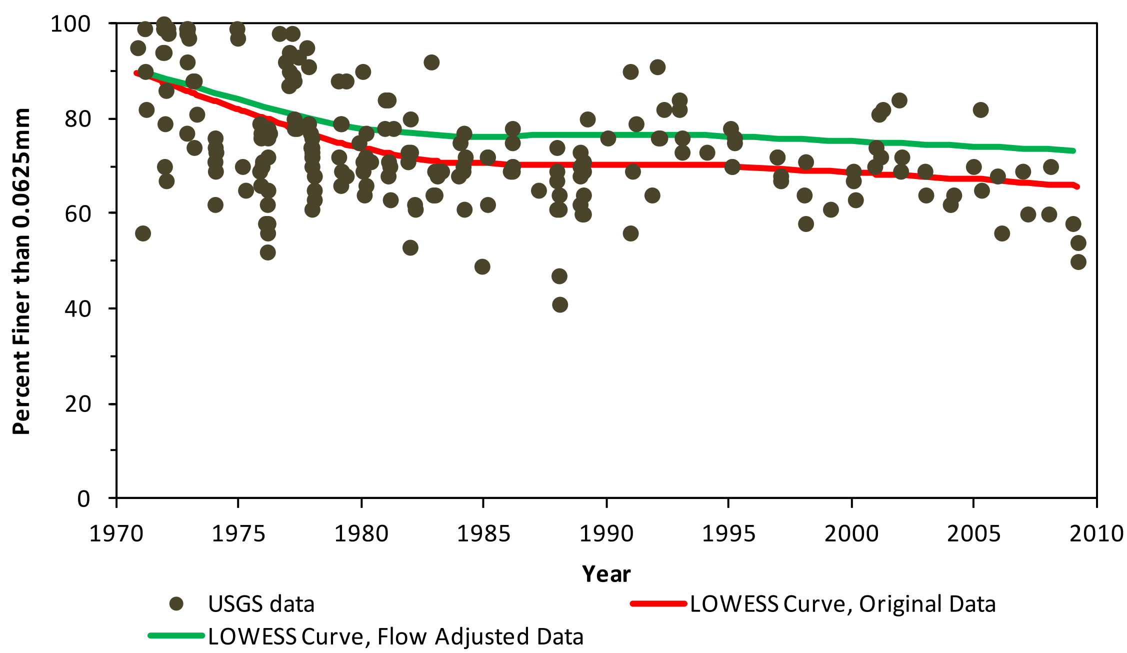


Figure 5-10. Redwood Creek suspended sediment percent finer than 0.0625 mm, with LOWESS curve for original data and flow-adjusted (flow effects removed) data.

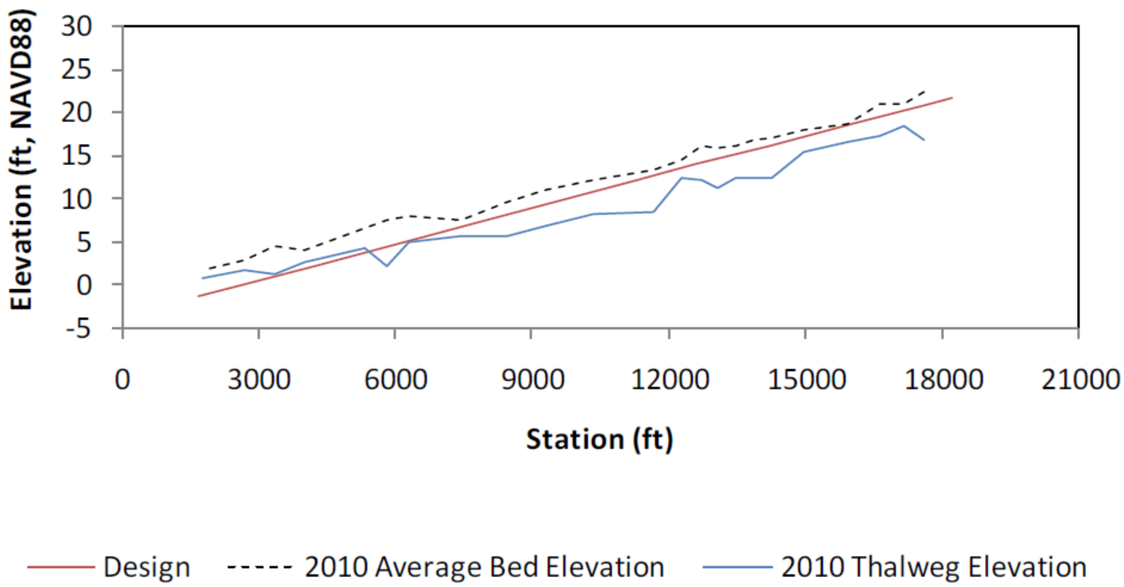


Figure 5-11. Average Redwood Creek bed elevation and thalweg elevation surveyed in 2010 compared to the Corps of Engineers (1966) design grade.

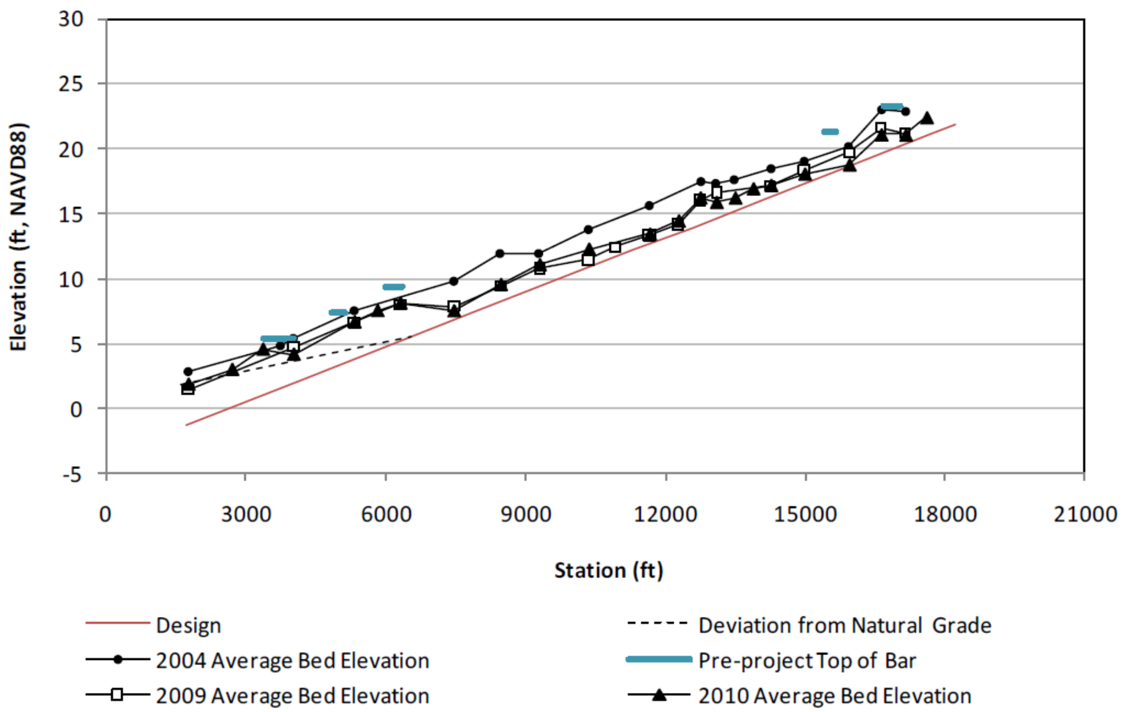


Figure 5-12. Average Redwood Creek bed elevations for 2004, 2009 and 2010 channel surveys, compared to the Corps of Engineers (1966) design grade and pre-project top of bar elevations.

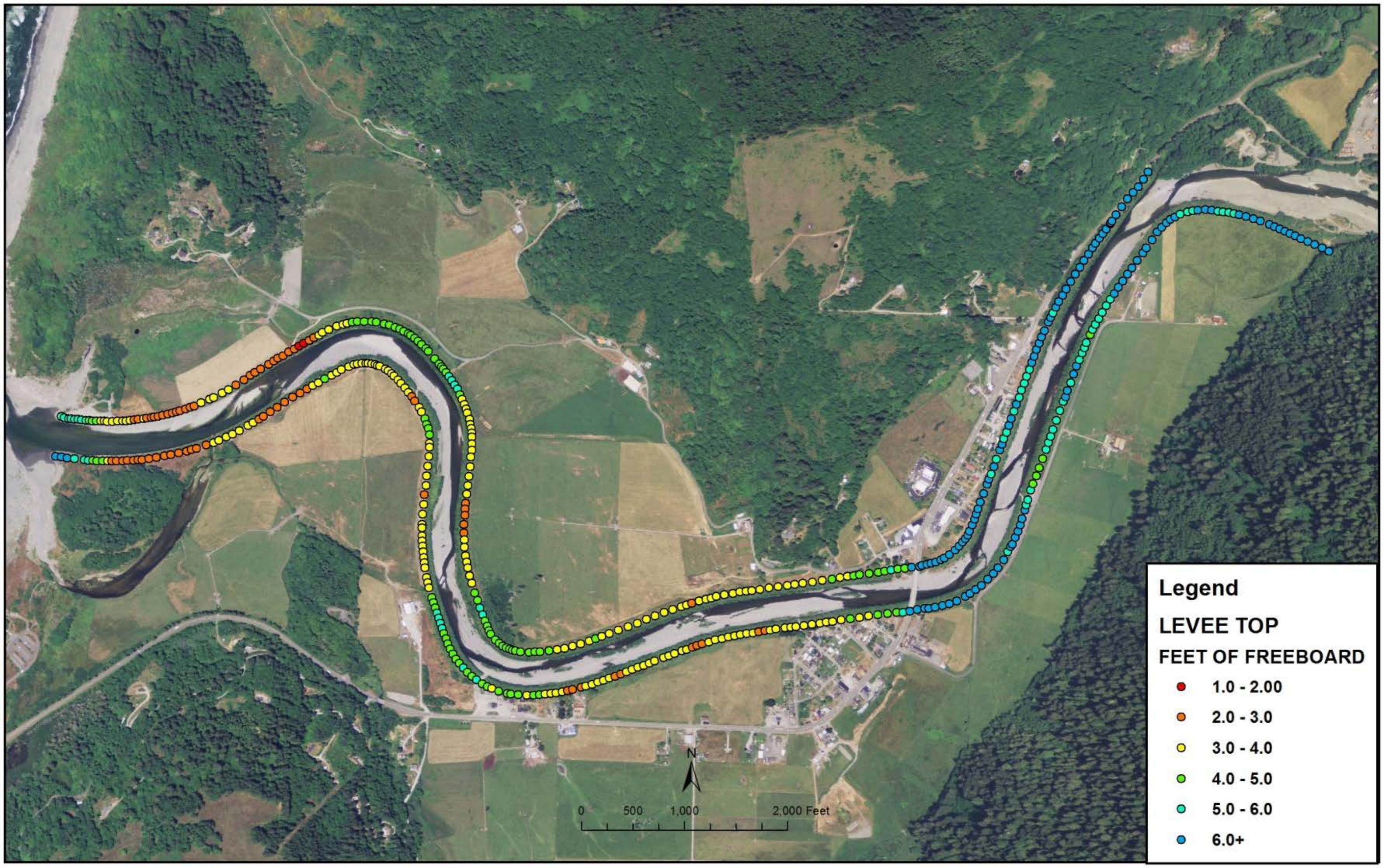


Figure 5-13. Detailed levee freeboard assessment for the Redwood Creek Flood Control at the 100-yr flood event (based on topographic data collected in 2010 and 2011; additional background in Sections 5.3 and 5.5.2).

Figure 5-14. Redwood Creek estuary configuration today (July 6, 2009, USDA-NAIP).

Figure 5-15. Redwood Creek estuary shortly after construction of the Flood Control Project (9 September 1970, Redwood National Park collection) showing the connections and lateral extent of the embayment and North and South Sloughs, and the location of the California-Pacific Mill site south of South Slough.

Figure 5-16. Oblique aerial photograph of Redwood Creek estuary (12 October 1979, California Coastal Records Project) showing the estuary during low creek flow conditions, with North and South Slough areas cut-off from main embayment.

Figure 5-17. Oblique aerial photograph of Redwood Creek estuary (8 March 2002, Don Tuttle photo, Humboldt County Public Works) showing the estuary during moderate creek flow conditions, with North and South Slough areas connected to main embayment.

Figure 5-18. Oblique aerial photograph of Redwood Creek estuary (12 January 2003, Mike Sparkman photo, California Department of Fish and Wildlife) showing the estuary during winter flow conditions, with disconnected North Slough and partially connected South Slough to main embayment.

Figure 5-19. Oblique aerial photograph of Redwood Creek estuary (4 October 2005, California Coastal Records Project) showing the estuary with the barrier beach closed and waves breaking over the barrier and flowing into the embayment. South Slough is connected to the embayment, but North Slough is disconnected. Note the lack of open water in North Slough due to reed canary grass.

Figure 5-20. Oblique aerial photograph of Redwood Creek estuary (7 March 1972, Redwood National Park collection) showing extent of barrier beach scour following the March 1972 flood.

Figure 5-21. Oblique aerial photograph of Redwood Creek estuary (28 November 1994, Redwood National Park collection) showing southerly lateral migration of the Redwood Creek mouth. The National Park Service Thomas H. Kuchel Visitor Center is shown in the foreground.

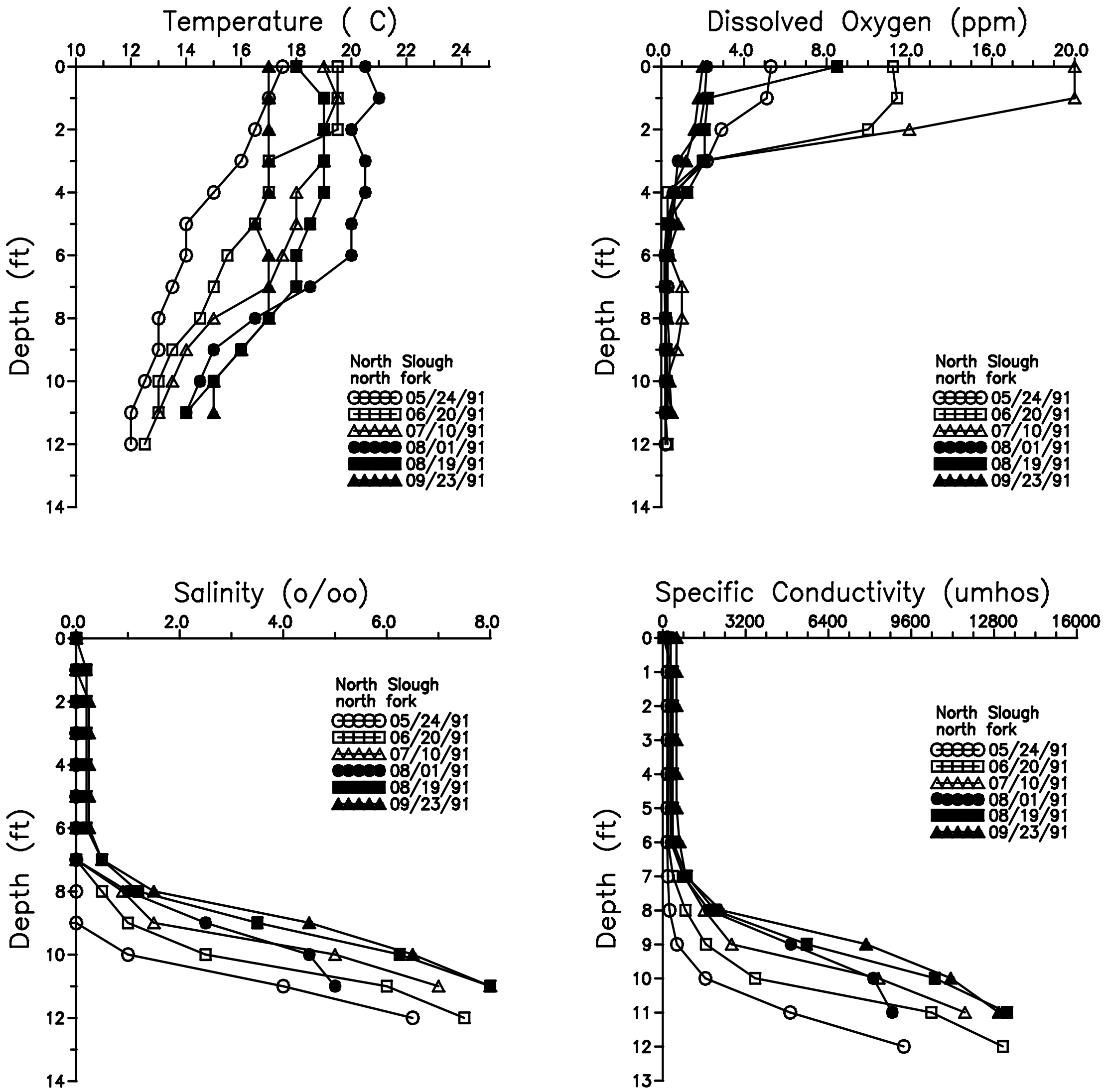


Figure 5-22. Monthly water quality measurements for temperature, dissolved oxygen, salinity, and specific conductivity at one foot intervals in North Slough of the Redwood Creek estuary for summer/fall 1991 (RNSP, 2005).

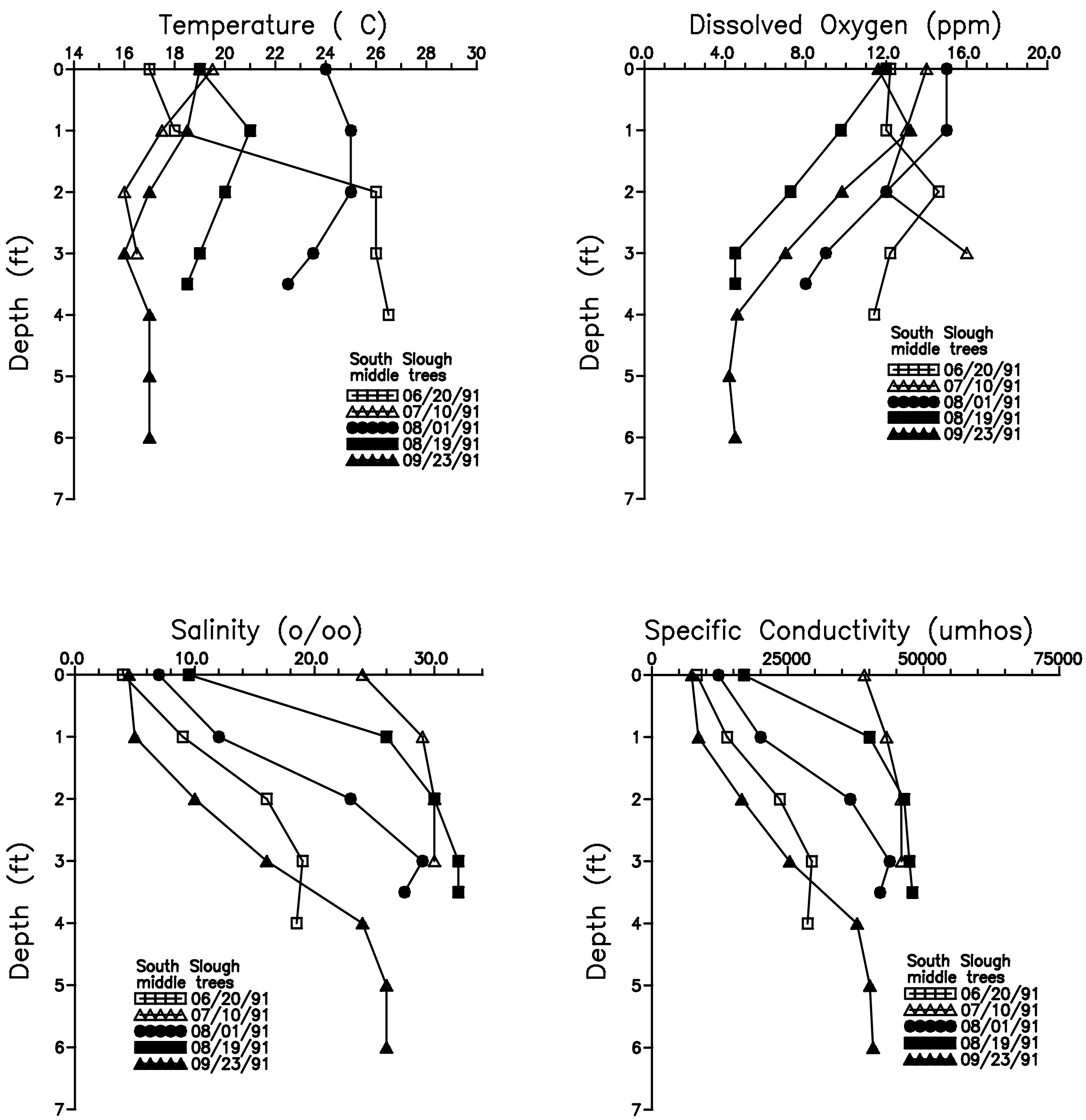


Figure 5-23. Monthly water quality measurements for temperature, dissolved oxygen, salinity, and specific conductivity at one foot intervals in South Slough of the Redwood Creek estuary for summer/fall 1991 (RNSP, 2005).

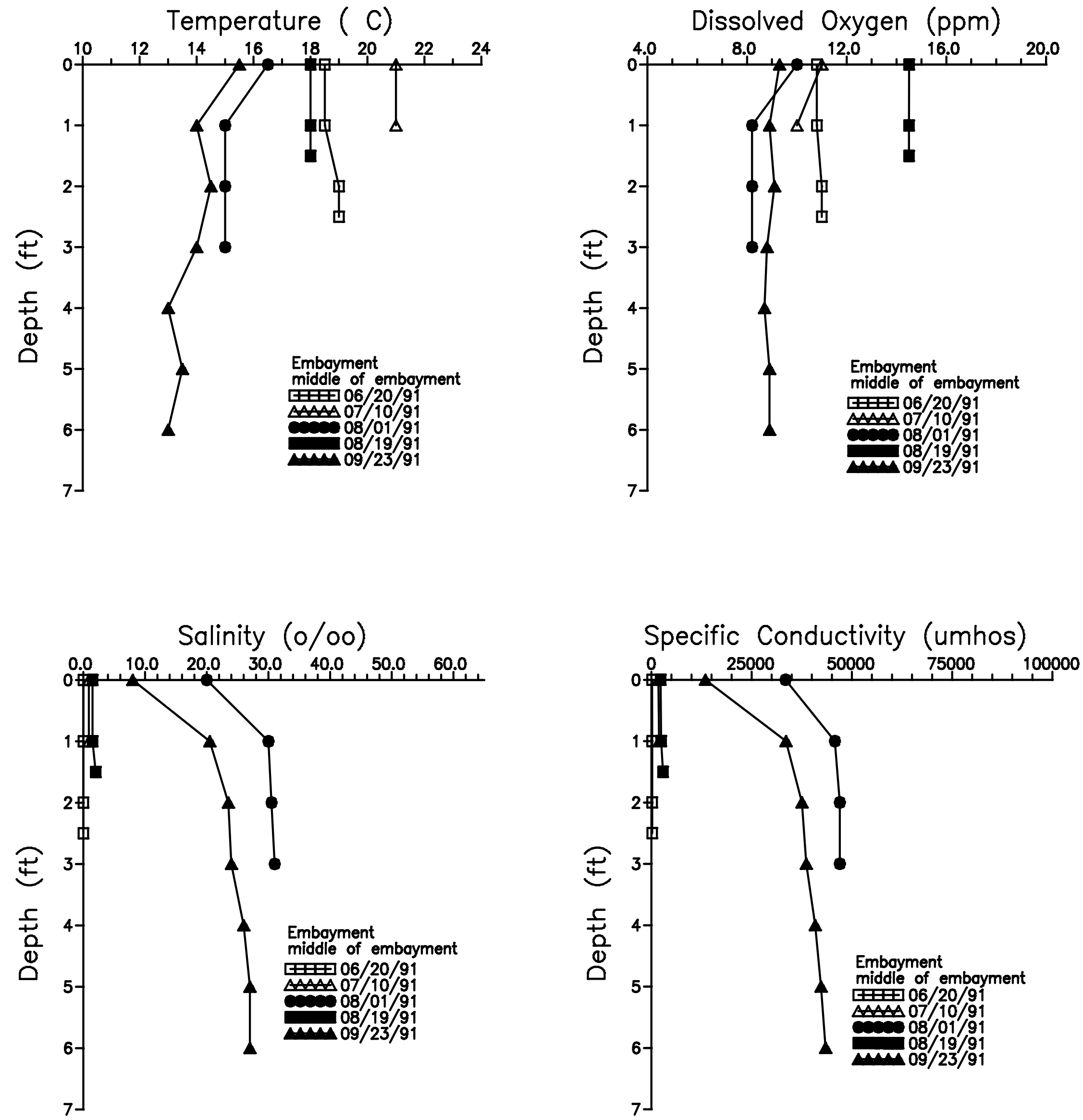
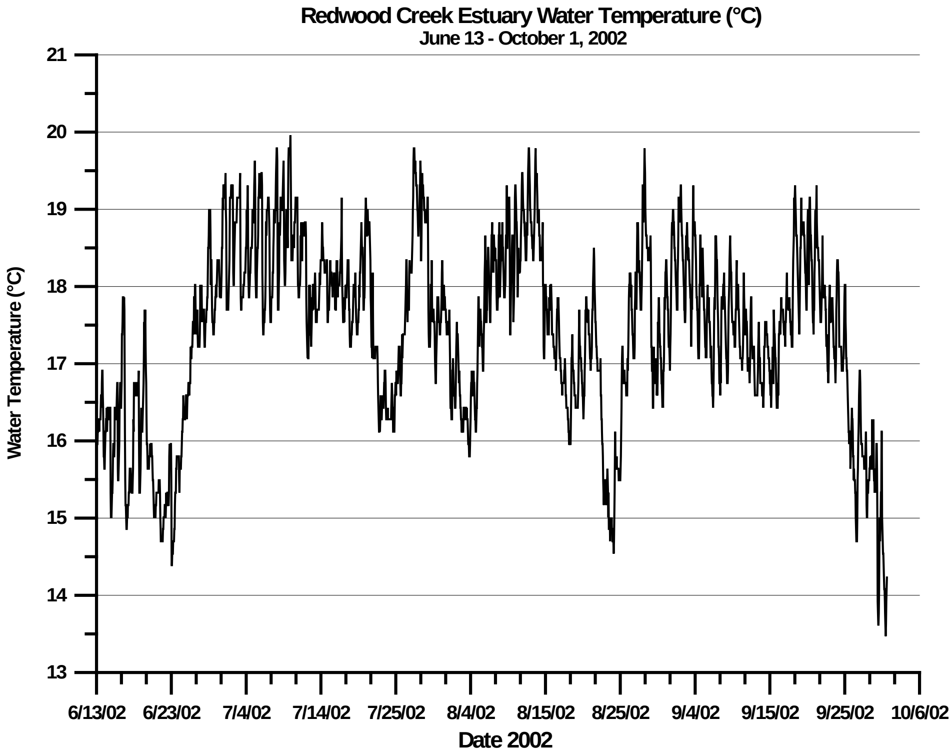


Figure 5-24. Monthly water quality measurements for temperature, dissolved oxygen, salinity, and specific conductivity at one foot intervals in the embayment of the Redwood Creek estuary for summer/fall 1991 (RNSP, 2005).



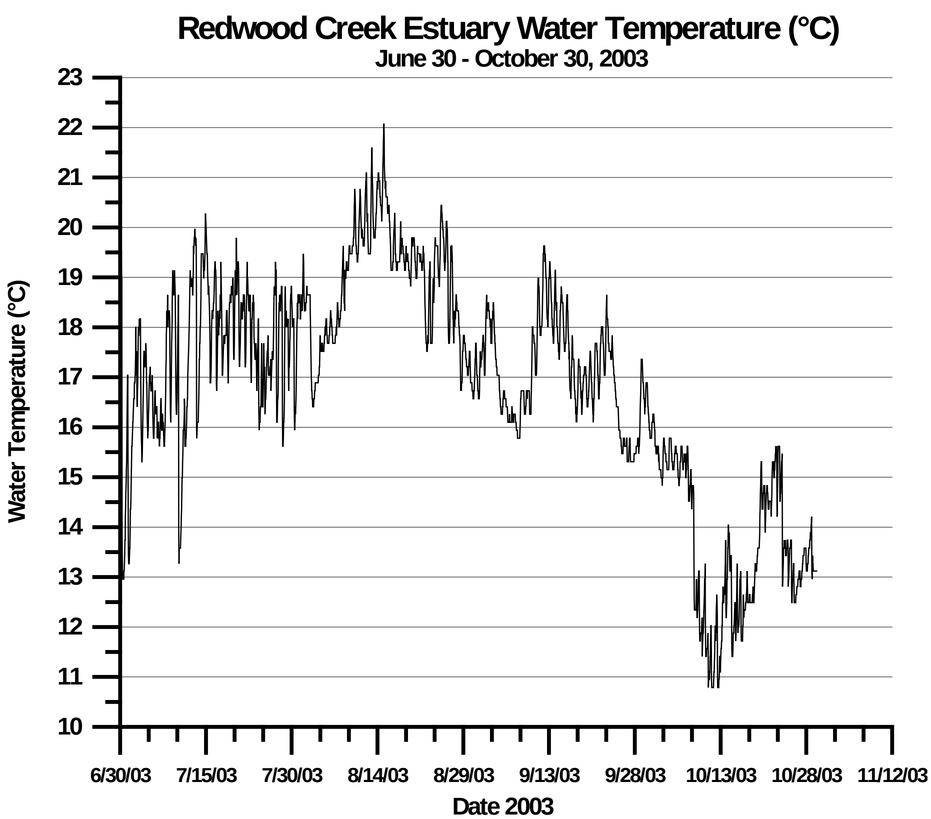


Figure 5-25. Water temperature in the embayment of the Redwood Creek estuary for summer/fall 2002 and 2003 (RNSP, 2005).

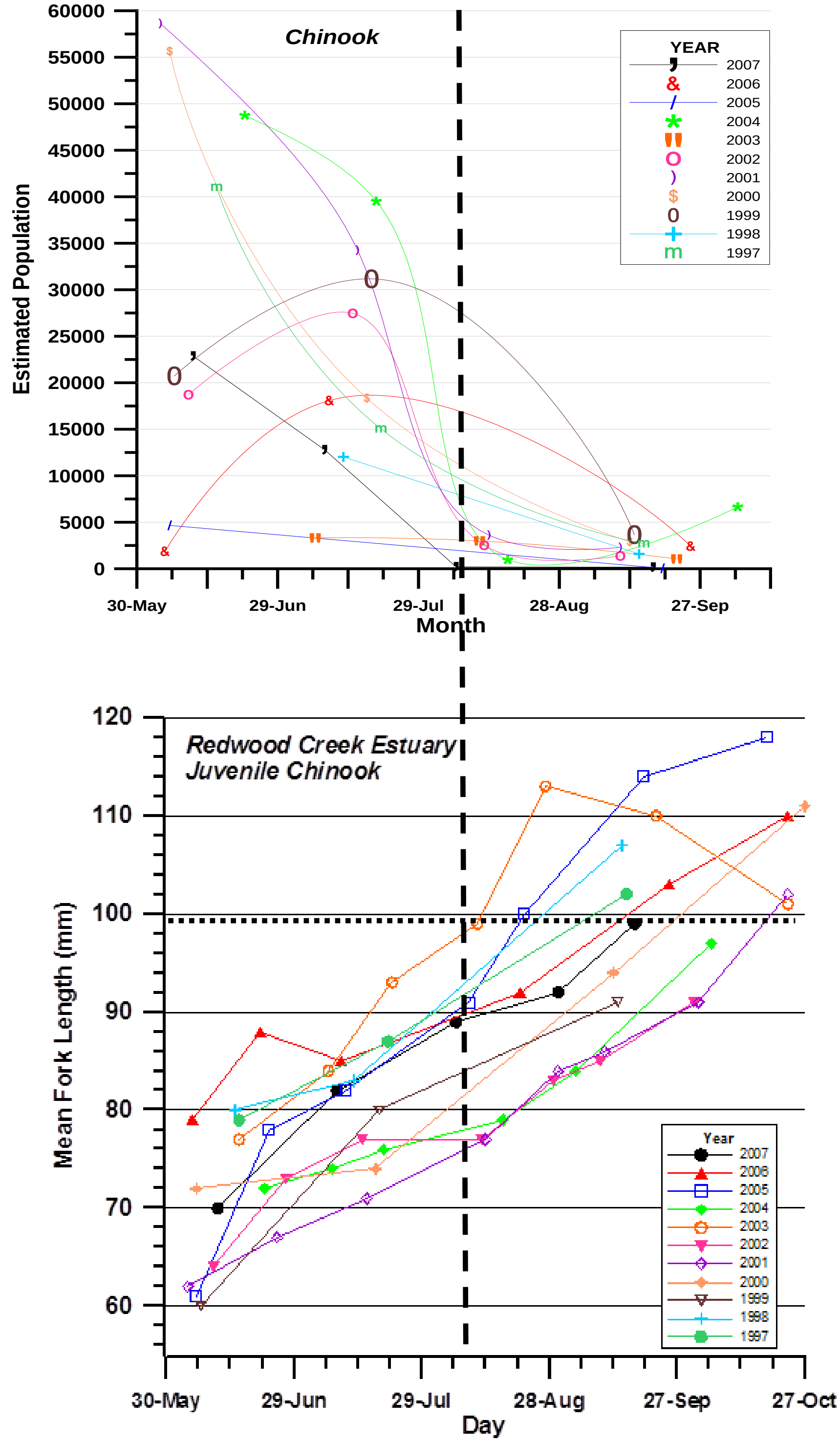


Figure 5-26. Monitoring data of juvenile Chinook in the Redwood Creek estuary from 1997 to 2007 (David Anderson, NPS). The timing of the decrease in the numbers of juveniles in the estuary (dashed vertical line) corresponds with the onset of high water temperatures at which time most fish are below the critical size threshold of 100 mm fork length (dotted horizontal line) for higher early marine survival.

6 DESIRED FUTURE CONDITIONS AND PROCESSES

This section outlines the desired future conditions and processes for restoration of the Redwood Creek estuary and rehabilitation of the Flood Control Project.

6.1 Estuary

The desired future conditions within the Redwood Creek estuary/lagoon revolve around returning the system to a more functioning, self-maintaining and resilient condition by restoring and enhancing dominant physical processes, which in turn would serve to support robust biological processes and ecosystem functions.

6.1.1 Conditions

Desired future conditions include the following:

- Suitable increase in estuary size (i.e., estuary surface area and tidal prism volume, backwater channels, off-channel wetlands/ponds).
- Increased localized scour along the north headland.
- Suitable increase in estuary geomorphic complexity.
- Improved estuary water quality.
- Hydraulic connectivity between the main body of the estuary, slough channels, backwater areas, surrounding freshwater wetlands, and floodplains.
- Recovery of native riparian vegetation along estuarine margin and across floodplain surfaces.

6.1.2 Physical processes

Restoration or enhancement of the following dominant physical processes is necessary to obtain the desired future conditions for a restored Redwood Creek estuary/lagoon system:

- Increase scour and export of marine-derived sediment that deposits in the estuary.
- Increase scour and export of fluvial-derived sediments from the estuary, sloughs, and headland areas.
- Increase high flow flushing of slough channels.
- Increase low flow circulation and mixing patterns within the estuary and sloughs.
- Reduce fluvial sediment delivery to the estuary.

The continuously shifting balance between coastal and fluvial processes and periodic occurrence of disturbance events will create dynamic conditions within the estuary.

6.1.3 Ecological processes and functions

Restoration or enhancement of the following dominant ecological processes and biologic functions is necessary to obtain the desired future conditions for a restored Redwood Creek estuary/lagoon system and improved salmonid fish production:

- Increase low and high flow habitat capacity (includes estuary area and volume, linear shoreline distance, food resources for juvenile salmonids and other fish species, and connectivity to off-channel habitats).
- Increase duration of suitable water quality conditions in the estuary, especially during the spring, summer, and early fall (i.e., increase estuary depth and improve water circulation and mixing patterns within the estuary to help maintain suitable water temperature and dissolved oxygen conditions).
- Increase high-quality, low-velocity winter rearing habitat and access to such habitats (especially off-channel habitats such as backwaters, wetlands, sloughs, floodplains, and ponds).
- Improve growth rates and productivity (increase habitat quality and capacity, re-establish riparian forests and grasslands/wetlands, and facilitate fish access to seasonal wetlands and off-channel habitats).

6.2 Flood Control Project

Desired future conditions for rehabilitation of the Redwood Creek Flood Control Project include:

- Achieve an acceptable and sustainable level of flood protection for the Orick community. The minimum acceptable protection level is the 1% recurrence interval (100-year) flow with three feet of freeboard. The preferred protection level is the 0.5% recurrence interval (200-year) flow with three feet of freeboard. The protection level is sustainable if it accommodates potential future changes in bed elevations and does not depend on gravel extraction and vegetation treatments in the Redwood Creek channel.
- Upgrade the levee embankments to meet applicable Corps of Engineers and FEMA performance criteria.
- Re-gain active status within the Corps of Engineers Rehabilitation and Inspection Program.
- Meet all standards for certification and achieve accreditation on the FEMA flood map.

In addition, the County has identified that long-term cost savings could be achieved through reduced levee maintenance by reducing the overall length of the levees. A long-term goal is to have the Flood Control Project focused on protecting structures and infrastructure.

7 POTENTIAL LIMITING CONDITIONS ON ESTUARY RESTORATION

There are a number of anthropogenic and environmental constraints within the lower Redwood Creek valley (downstream of Orick) that will likely limit the extent and nature of restoration opportunities for the estuary. Potentially limiting conditions include:

- Road infrastructure,
- Private ownership and land use,
- Sediment supply and sedimentation patterns,
- Management of levee spoils and estuary sediment, and
- Sea level rise.

These constraints were carefully considered to develop design alternatives (Section 8) that are most likely to be feasible.

7.1 Road Infrastructure

Effective estuary restoration projects in lower Redwood Creek will need to consider the locations and elevations of the Flood Control Project, Highway 101, and access to residential properties bordering the northern side of the valley.

Highway 101 runs along the base of the hills adjacent to the south side of the valley. The roadbed of the highway is above the 100-year return interval flood elevation along the southwest portion of the valley. The highway surface drops below the 100-year flood elevation in the vicinity of the access road to the County's solid waste container site. A restoration plan that includes realignment of the south levee will need to consider minimizing flood exposure for the highway. Realigning the levee to intersect that portion of the highway that is above the 100-year flood elevation would keep the low elevation portion of the highway protected behind the levee. Alternatively, the roadbed could be elevated so that the entire highway is above the 100-year flood elevation regardless of levee location. In addition, the restoration would need to ensure that Redwood Creek does not threaten the highway through bank erosion.

There are a number of residences currently located along the northern border of the valley. Access to these residences is currently served by Gunst and Hufford roads. Realignment of the north levee would require modifications to Hufford Road and potentially Gunst Road. Depending on the selected levee option, maintaining residential access could range from placing a portion of Hufford Road on top of the realigned levee to construction of a new road.

7.2 Private Ownership and Land Use

The project will need to find an acceptable balance between agricultural productivity, ecological restoration, and flood protection benefits. Agriculture is the primary land use in the lower Redwood Creek valley downstream of Orick. Soils around the Redwood Creek estuary are prime agricultural soils, and the majority of parcels are zoned and planned as agriculture exclusive. Much of the valley bottomland is privately held and has been actively managed for livestock over several generations. Private agricultural operations contribute to the County's economic productivity and are fundamental to the cultural fabric of the Orick community. Through multigeneration ownership, the landowners have a deep connection to the land and a strong sense of land stewardship.

A project that includes levee realignment will need to consider private landowner interests and be acceptable to the landowners. The Flood Control Project has benefited privately owned agricultural land by preventing bank erosion, eliminating inundation from Redwood Creek (except for backwater flooding from North Slough and South Slough), and eliminating deposition of debris and coarse sediment. Conversely, the levees have eliminated the replenishment of fine sediment onto the floodplain pastures and created localized areas with poor drainage. Pasture drainage north of the estuary is currently impaired due to blockage caused by marine-derived sediment and wood in North Slough, while pasture drainage on the south side is currently considered adequate. Drainage will likely become an increasing problem due to land subsidence and sea level rise.

Modification of the levee system would be a significant change from existing conditions, where agricultural operations have benefited from flood protection provided by the levee for over 35 years. The Arcata Bottoms, Eel River Bottoms, and other local areas demonstrate that intermittent flooding can be compatible with agricultural land use; however, potential impacts will need to be carefully evaluated and addressed. Appropriate compensation for any flooding impacts, and for any conversion of private land to non-agricultural use, will be a pre-requisite to moving forward on a project.

7.3 Sediment Supply and Sedimentation Patterns

The combined effects of unstable bedrock, rapid tectonic uplift, steep terrain, intense winter precipitation, and land use (primarily legacy timber harvest practices and associated road construction) in the Redwood Creek basin produces one of the highest annual sediment yields in the conterminous United States for basins of similar sizes. Although the basin's sediment loads have decreased in recent years, they still remain relatively high, are a concern for maintaining flood capacity within the Flood Control Project, and could affect long-term estuary restoration and recovery.

In their current configuration, the levees facilitate the movement of sediment directly into the ocean during high flow periods. Modifying levee alignment (widening or removing) will result in altering the current sediment transport and deposition processes. Sediment deposition within and immediately upstream of the estuary could occur where the levees are removed or pulled back. The upstream-most location where the existing levees are first modified will experience reduced flow velocities shear stresses due to the wider cross-sectional area, which could lead to reduced sediment transport capacity during high flow periods. This could cause increased sedimentation to occur at this location. If the excess stored sediment is not adequately removed during subsequent high river flows, the natural response of the channel would be to migrate laterally or even avulse during another large flood event. The channel would likely avulse to an existing slough channel (e.g., North or Middle slough), or migrate around the sediment deposit through channel widening and bank erosion. To maintain resiliency of the system it is important that the estuary has adequate space for the Redwood Creek channel to migrate and/or avulse as necessary within the restored estuary footprint.

7.4 Management of Levee Spoils and Estuary Sediment

Demolition of levees and excavation of the existing channels and floodplains under any of the potential restoration alternatives will result in the accumulation of many thousands of cubic yards of spoils. Some of these spoils can be reused but a significant amount will remain and need to be managed or disposed of in an environmentally safe manner. A future consideration in project design will be how much sediment should be removed versus leaving sediment in place and allowing the channels and floodplains to adjust through natural transport processes.

Options for reducing costs and maximizing the removal of excess sediment include:

1. Reuse of material for construction of new levee segments.
2. Reuse of material for construction of seepage berms or stability berms to mitigate structural deficiencies.
3. Landspreading of suitable material on agricultural land to improve soil conditions and drainage.
4. Some material may be of marketable quality as aggregate, but the distance to markets and cost of trucking may be a limiting factor.
5. Application of sand for beach nourishment.

7.5 Sea Level Rise

Sea level rise is predicted to occur in conjunction with global climate change and may affect projects, such as the Redwood Creek estuary restoration and levee rehabilitation project that are located on marine shorelines. Sea level rise has the potential to cause harmful economic, ecological, physical and social impacts in coastal areas. Incorporating sea level rise analyses into project designs and agency decisions can help mitigate some of these potential impacts.

The California Coastal Commission has taken steps to incorporate considerations of sea level rise as part of its Coastal Development Permit process and has recently issued guidance on doing so (CCC 2013). North of Cape Mendocino, the rate of sea level rise over the next 100 years is expected to range from 10 to 143 cm (0.3 to 4.69 feet) (CO-CAT 2013) (Table 7-1).

The sections of coastline north and south of Cape Mendocino clearly are parts of different tectonic regimes and tide gages have recorded distinct regional values over their periods of record. The tide gage for the North Spit at Humboldt Bay extends back to 1977 and has recorded an average sea-level rise of +4.73 +/- 1.58 mm/year, equivalent to 1.55 feet over 100 years. This is considerably higher than the global average and indicates significant subsidence in this location. Sixty-five miles north at Crescent City, the tide gage record extends back to 1933 and shows, over the period of record, a local drop in sea level of -0.65 +/-0.36 mm/year, equivalent to -0.21 feet/100 years. The drop in sea level is explained by a rising coastline near Crescent City due to flexure of the North American tectonic plate above the subducting Juan de Fuca plate. Modeling for sea level rise in the lower Redwood Creek area has not been conducted, but CO-CAT (2013) advises using the two different rates (augmented by any future acceleration in rates of sea level rise) for the areas closest to these two gages, with intermediate values for the areas between them.

Table 7-1. Sea-Level Rise Projections using 2000 as the Baseline (CO-CAT 2013).

Time Period	North of Cape Mendocino	South of Cape Mendocino
2000 - 2030	-4 to 23 cm (-0.13 to 0.75 ft)	4 to 30 cm (0.13 to 0.98 ft)
2000 – 2050	-3 to 48 cm (-0.1 to 1.57 ft)	12 to 61 cm (0.39 to 2.0 ft)
2000 – 2100	10 to 143 cm (0.3 to 4.69 ft)	42 to 167 cm (1.38 to 5.48 ft)

Sea level rise will increase the downstream water surface elevation and reduce the gradient of flow through the Flood Control Project. In addition, one of the expected geomorphic consequences of sea level rise is inland migration of the barrier beach, which could reduce the estuary footprint if upstream estuary expansion is constrained. Thus sea level rise will create increasing challenges for both ecological and flood protection needs.

8 GOALS, OBJECTIVES, AND INDICATORS

This section re-states the project goals and identifies specific objectives associated with each goal along with indicators that can be used to evaluate, either quantitatively or qualitatively, the degree to which each project objective is met.

8.1 Goals

Estuary:

1. Restore the hydrologic, morphologic, and ecologic processes necessary to develop and maintain functional, self-sustaining estuarine habitat, especially for the recovery of threatened salmonid species including Southern Oregon/Northern California Coast coho salmon, California Coastal Chinook salmon, and Northern California steelhead.

Levee:

1. Accommodate sediment inflow, remedy structural deficiencies, and achieve an acceptable level of flood protection that can be sustained with normal maintenance.

2. Regain active status in the Corps of Engineers Rehabilitation and Inspection Program and achieve certification and accreditation on the FEMA Flood Insurance Rate Map.

Adjacent Land:

1. Maintain agricultural productivity within the lower Redwood Creek valley and limit the net loss of agricultural land use to the greatest extent possible while meeting other project goals.

2. Fairly compensate affected private landowners for impacts associated with levee modifications.

3. Be consistent with the resource protection and preservation responsibilities of the National Park Service for affected federal land in Redwood National Park.

8.2 Objectives and Indicators

Project objectives represent specific tasks, milestones, or methods for achieving project goals. The three conceptual design alternatives strive to satisfy all project objectives to the extent feasible. However, certain objectives may be in conflict with each other to some extent—for example, ecological and agricultural land use objectives. The designs can be further refined to adjust the balance between the various objectives, for example by adjusting the amount of new riparian vegetation and the amount of seasonal grazing.

Project indicators represent simple metrics that can be used to evaluate, either quantitatively or qualitatively, the degree to which each project objective is met. Table 8-1 shows the project indicators or metrics identified for each project objective. The same set of project indicators will be used for each action alternative. Note that data collection for the metrics identified below would occur during the planning and design period to establish a baseline from which future restoration-affected changes would be assessed. These metrics may be too specific to be evaluated at the current conceptual level of restoration design development; some will also require further development as design proceeds. However, all indicators/metrics identified to date are presented here, because they are expected to provide important guidance during future implementation design phases and long-term monitoring and adaptive management.

Table 8-1. Project objectives, indicators, and monitoring metrics for Redwood Creek estuary/levee project.

Objective	Indicators	Potential Metrics
ESTUARY		
Hydrology/Geomorphology		
1. Increase estuary tidal prism volume	Width and depth of sloughs	Repeat topographic/bathymetric surveys, water level (stage), timing and duration of breaching events, bathymetry, water quality profiles
2. Increase estuary area and volume	Estuary surface area, depth, sediment storage characteristics	Repeat topographic/bathymetric surveys, water level (stage), bathymetry
3. Improve water circulation patterns	Area and volume of estuary, water quality parameters	Portion of time lagoon is open/closed, water quality metrics (dissolved oxygen, salinity, temperature), predictive models
4. Export/flushing of marine- and fluvial-derived sediment from the estuary	Changes in channel and estuary bed elevations, and lateral planform changes	Repeat topographic/bathymetric surveys, direct observations, aerial image comparisons, bank erosion, predictive models, geomorphic assessments
5. Coarse and fine sediment routing through the estuary	Sediment characteristics, channel changes	Repeat topographic/bathymetric surveys, grain size distribution of sediment deposits (bulk sampling, surface grain size distribution mapping), predictive models, geomorphic assessments
6. Slough channel maintenance	Area and volume of sloughs, bed elevation changes, lateral channel migration	Topographic/bathymetric surveys, vegetation monitoring
7. Reestablish distributary channel network	Increased frequency of overbank flows	Repeat topographic/bathymetric surveys, vegetation monitoring, direct observations
8. Direct flood flows toward headlands	High flow water circulation patterns	Topographic/bathymetric surveys, direct observations, predictive models
Ecological		
1. Increase habitat capacity for fisheries	Area and volume of estuary, area and quality of low velocity habitats, instream wood, backwaters, extent of canary reed grass	Surface area and volume, growth rates, abundance patterns (beach seine surveys), linear distance of edgewater habitat, canary reed grass area
2. Increase fish access to floodplains	Increased frequency of overbank flows	Floodplain fish surveys, topographic surveys to demonstrate connectivity Ideal: Winter growth rates, PIT tagging program with tagging at upstream stream trap and detectors at off-channel access points
3. Expand riparian coverage along channel margin and across floodplains	Areal extent of riparian corridor, plant community diversity	Riparian survey (air photo delineation and area calculation), monitoring transects (species, diameter, stem density)
4. Improve water quality in sloughs and embayment	Water circulation patterns	Water quality metrics (dissolved oxygen, salinity, temperature)
5. Increase fish populations (and resiliency)	Increased low and high flow habitat	Fish abundance surveys (beach seining surveys), DIDSON monitoring

Objective	Indicators	Potential Metrics
FLOOD CONTROL PROJECT		
1. Achieve acceptable, sustainable flood protection	Levee capacity (freeboard at specified flow)	Predicted water surface elevations, requires supporting data sets (topography, roughness, etc.)
2. Accommodate episodic high sediment loads	Levee capacity (freeboard at specified flow)	Predictive models, geomorphic assessments
3. Achieve active status in Corps of Engineers Rehabilitation and Inspection Program	Conformance with applicable criteria	Receipt of notice on formal action to restore active status
4. Achieve accreditation on FEMA flood map	Conformance with applicable criteria	Receipt of FEMA flood map with accredited levee
ADJACENT LAND		
1. Maintain agricultural productivity	Continued grazing activity on floodplain, improved pasture drainage	Number of cow/calf units
2. Limit the net loss of agricultural land use	Amount of agricultural land	Acreage
3. Private landowner agreement	Support for project	Formal compensation agreement, completion of easements and/or acquisitions (as applicable)
4. Consistent with National Park Service policies	Compliance with National Environmental Policy Act, other legal requirements	Record of Decision for Environmental Impact Statement

9 CONCEPTUAL DESIGNS

As stated in Section 3, the purpose of the Project is to develop conceptual design alternatives to restore the ecological function of the Redwood Creek estuary and rehabilitate the Redwood Creek Flood Control Project in a manner that achieves desired flood capacity and maintenance goals, and is compatible with adjacent agricultural land use. Feasibility will ultimately be determined by a suite of factors but first and foremost requires private landowner cooperation and agreement. Restoration of hydraulic, sediment transport, and floodplain processes is needed to help the estuary and lower Redwood Creek regain some of its former form, function, resiliency and productivity, and levee rehabilitation is needed to address capacity and structural deficiencies. This section describes actions, elements, and basic conceptual designs for future consideration to implement a multi-objective project for lower Redwood Creek and estuary.

9.1 Estuary Restoration Conceptual Design Actions and Elements

The following specific actions or elements have been identified to help restore or enhance physical processes within the Redwood Creek estuary. Although discussed separately, many of the actions or elements will restore or enhance the same general physical processes in a synergistic manner as they are not mutually exclusive. Rather, they are dynamically coupled by a complex set of interactions and feedback mechanisms, and restoring or enhancing one physical process may improve or enhance another physical process through these interactions and feedbacks.

The individual actions and elements presented below describe how the various project elements restore and/or enhance the identified dominant physical processes and help to meet the desired conditions (Table 9-1). As discussed in Section 9.3, each alternative would provide improved conditions to varying degrees, but it may not be feasible to restore or enhance the physical processes to the full extent based on various constraints.

9.1.1 Reconnect Redwood Creek channel to slough and backwater channels and wetlands

Reconnecting the lower Redwood Creek channel to its historical sloughs (North, Middle, and South) would lengthen the lower channel, expand the estuary footprint, and restore/enhance the complex riverine, estuarine and coastal flow patterns. Returning flow to the sloughs would help to redirect flow towards the north headland, and improve the ability of the system to scour marine and fluvial sediments deposited into the estuary and backwaters. A larger estuary footprint and longer channel will increase the sediment storage capacity of the estuary. Restoring some degree of flow to the sloughs would increase turbulent flows, circulation, and mixing thus improving water quality. A larger estuary surface area and volume also increases wind-driven circulation and other mixing processes, such as density currents.

Establishing reconnections to and restoring wetlands, such as the southern seasonal wetland/lagoon and its channel, will provide high quality off-channel habitat for juvenile salmonids during high flow events. Off-channel habitats such as these have been shown to provide abundant food resources that result in higher growth rates for juvenile fish than main channel areas. Higher growth rates will result in smolts being larger prior to entering the ocean, which will help increase ocean survival and the numbers of returning adults.

9.1.2 Restore ability of lower Redwood Creek to be a dynamic channel

To maintain resiliency of the system, it is critical to allow adequate space for the Redwood Creek channel be dynamic by laterally migrating and/or avulsing as it naturally may do within the restored estuary footprint. Restoring the ability of the lower Redwood Creek channel to migrate or avulse within the estuary footprint allows the channel to dynamically and appropriately respond to depositional patterns from variable sediment loadings, and other disturbances. Channel avulsion and/or migration could potentially create new channel alignments, occupy former channel alignments (e.g., North and Middle sloughs), and create new backwater areas within the former channel alignment. With current sediment loads, excess sedimentation could occur within the main channel of the restored estuary following large flood events if adequate channel and floodplain area is not made available upstream to help sort and store sediment. New levees configurations and strategic bank stabilization could occur to ensure channel migrations or avulsions do not damage areas that are targeted for such protection.

Development of new backwater areas, secondary channels, oxbows, and alcoves from channel realignment and avulsion processes add habitat and topographic variability within the estuary area. This variability enables fish to access a continuum of habitat throughout a wide variety of flows. This enables fish to have continued access to high quality habitat during wet and dry seasons, which improves growth and survival rates.

9.1.3 Expand the extent of active barrier beach for mouth migration

The current levee configuration generally restricts the width of the active barrier beach for channel mouth migration to a small northerly section of the beach immediately adjacent to the levee outlet. Historically the Redwood Creek channel mouth migrated along a much longer active barrier beach, which resulted in a narrower and less stable barrier bar. Restoring flow into south slough, for example, would allow channel flows to actively erode the storm berm and overwash slope that deliver wave- and wind-derived sands into south slough. Higher storm driven river flows would help to remove and/or lower the barrier beach along a much longer length than currently exists. A more actively migrating channel mouth (both north and south) would also promote increased sediment scour within the estuary. A longer, narrower, and lower elevation barrier beach will allow for increased circulation and mixing in the estuary by increased wave overtopping. A longer more active barrier beach would likely restore the breaching and closure processes of the Redwood Creek mouth to more historical patterns. Also, a more historical barrier beach would likely get reworked more frequently, potentially increasing groundwater discharge during closures from the estuary to the ocean and recharge of cold water from the ocean to the estuary.

Biological benefits of a more active barrier beach would likely include improved water quality in the form of lower temperatures, higher dissolved oxygen, and better circulation. Improvements in water quality would increase survivability of juvenile salmonids which are dependent on estuarine rearing for part of their life history (Table 9-2).

9.1.4 Restore floodplain connectivity

The Flood Control Project has disconnected Redwood creek from its floodplains, preventing overbank flows to the floodplains and eliminating the multiple flow paths that maintained the size and complexity of the estuary prior to the levee construction. Increasing floodplain connectivity would facilitate floodwaters entering the heads of the middle and north sloughs, thereby scouring deposited sediment and invasive canary reed grass and increasing slough area and volume. As discussed earlier, overbank flows are critical for helping to export marine-derived sediment from the slough channels. In addition, historical aerial photographs (1936-1968) show a system that was resilient to flood events and associated riverine sediment deposition. Large floods would typically deposit sediment into the estuary, but the estuary would persistently maintain its general planform and the slough channels would remain connected to the embayment. Subsequent moderate to high river flows would help flush fluvial sediment from the estuary and slough channels into the ocean.

Modification of the levee system will change the location of the sediment transition zone, which is the area where creek flows transition from the confined levee reach to an unconfined condition. Where this transition occurs, the spreading of flow will result in reduced water velocity and shear stress and the potential for increased sediment deposition. The existing levee system extends just upstream of the surf zone; bedload sediment is transported during high flows through the leveed channel and deposited in the surf zone. The design alternatives involve different combinations and configurations of removing portions of the existing levee system and constructing new levee segments along an alignment set back from the channel. For each alternative, the sediment transition zone would shift upstream to varying degrees. These shifts are discussed further in Section 9.3.

Increasing floodplain connectivity would help boost winter period fish production by allowing fish to find refuge from very high runoff events in areas that have relatively low water velocity and lower suspended sediment concentrations than currently exists between the existing levees (Table 9-2). In addition, floodplain habitats contain vegetation cover and food resources that would not be available in the mainstem. These floodplain habitat components are critical for the survival of young salmonids for the few days of the year when high flows make mainstem channels inhospitable.

Increasing upstream floodplain connectivity to the active river channel would allow for sediment deposition on the floodplains during flood flows, which would help buffer the effects of sea level rise and reduce the fluvial sediment load entering the estuary. Increased floodplain flows would decrease channel velocities and depth thereby reducing bed shear stresses, which would reduce net fluvial transport of both suspended and bed load sediment to the estuary. Depending on future levee configurations, a varying amount of sediment transported by flood flows would settle onto the floodplains.

9.1.5 Restore native riparian vegetation

Restoring riparian vegetation and mixed Sitka spruce forests along the estuary boundaries and upstream channel margins in the areas with floodplain connectivity would help to reduce and slow bank erosion, channel avulsions, and meander bend migration. Reducing bank erosion would reduce net sediment inputs into the estuary. Restoring native riparian vegetation along and adjacent to the slough and backwater channels would also help to flush sediment by concentrating flow and increasing velocities within the slough and backwater channels. The riparian vegetation would also contribute large-woody-debris (LWD) and increase roughness, which would slow flood flows and allow suspended sediments to deposit on the floodplain, reducing fluvial sediment delivery to the slough channels and main embayment of the estuary.

Restoration of riparian vegetation on the floodplains and channel margins would foster the creation of distributary channels on the floodplain, provide LWD for high flow refugia, increase food resources (with a mix of open and closed canopy areas), and provide shade for summer water temperature moderation. Improvement in these riparian characteristics would result in an increase in winter and summer habitat for juvenile salmonids and their survival rates.

Table 9-1. Summary of conceptual design actions and/or elements and restored/enhanced physical processes for the Redwood Creek estuary.

Project Design Actions or Elements for Redwood Creek estuary	**Restored or enhanced physical processes to the Redwood Creek estuary**			
	Export of marine-derived sediment	**Riverine sediment delivery**	**Export of riverine-derived sediments**	**Circulation and mixing patterns**
Reconnect channel to slough and backwater channels and wetlands	Increased	No change	Increased	Increased
Restore ability of channel to be dynamic	n/a	No change	Increased	Increased
Expand the extent of active barrier beach by mouth migration	Increased	No change	Increased	Increased
Restore floodplain connectivity	Increased	Decreased	Increased	Increased
Restore riparian vegetation and mixed Sitka spruce forest	Mixed	Decreased	Increased	Increased

Table 9-2. Summary of conceptual design actions and/or elements and restored/enhanced biological processes for the Redwood Creek estuary.

Project Design Actions or Elements for Redwood Creek estuary	**Restored or enhanced biological processes to the Redwood Creek estuary**			
	Salmonid high flow habitat	**Salmonid low flow habitat**	**Salmonid size at ocean entry**	**Water quality**
Reconnect channel to slough and backwater channels and wetlands	Increased	Increased	Increased	Increased
Restore ability of channel to be dynamic	Increased	Increased	Increased	Increased
Expand the extent of active barrier beach by mouth migration	No change	Increased	Increased	Increased
Restore floodplain connectivity	Increased	No change	Increased	Increased
Restore riparian vegetation and mixed Sitka spruce forest	Increased	Increased	Increased	Increased

9.2 Levee Rehabilitation Concepts

9.2.1 Capacity

The hydraulic capacity of the Flood Control Project can be increased by one or more of the following measures:

- Raise the height of the levee embankments. Levees are normally raised by widening the embankment fill prism and maintaining a stable side-slope.

- Widen the channel by removing portions of the existing levees and re-constructing new levee segments as appropriate. Based on hydraulic modeling, channel widening can provide a benefit for hydraulic capacity for a distance of 3,000 to 4,000 feet upstream. This concept is consistent with the estuary restoration concept of restoring floodplain connectivity (Section 9.1.4).

Increasing levee height is not incorporated into the conceptual designs presented in Section 9.3, but may need to be incorporated in future design phases. The specific extent of levee area requiring increased height, if any, and the amount of increase will need to be determined based on the selected alignment for re-locating the lower levee segments and further hydraulic and geomorphic analysis. The hydraulic and geomorphic analysis would evaluate the expected future trajectory of bed elevations and support a decision on the appropriate safety factor for levee freeboard to ensure acceptable, sustainable flood protection.

9.2.2 Structural Improvements

<u>Seepage</u>
If adequate space exists, the most economical remedy for areas vulnerable to seepage is likely a landside seepage berm, which consists of applying a layer of fill material to reinforce and increase the thickness of the impermeable blanket layer. The seepage berm would extend from the landside levee toe outward for a distance ranging from approximately 50 feet to over 300 feet, and ranging in thickness from three to five feet, depending on seepage conditions. Further subsurface characterization is needed to delineate the extent of the areas that do not meet the seepage performance criteria. The three locations with the largest deficiencies are located on the right hand (facing downstream) levee at Stations 87, 114, and 132 (CGI, 2011).

<u>Slope Stability</u>
Slope stability can be improved by construction of stability berms or placement of geosynthetic reinforcement. A stability berm would be constructed against the landside levee slope to provide support as a buttress. The height of a stability berm is typically 2/3 of the height of the levee.

Structural improvements are not incorporated into the conceptual designs presented in Section 9.3, but would likely need to be incorporated in future design phases. The specific structural improvements will need to be determined based on additional geotechnical characterization and feasibility evaluation.

9.3 Redwood Creek Estuary Conceptual Designs

As stated above, the construction of the Flood Control Project in the late 1960s caused major physical changes to the lower reach of Redwood Creek and its estuary, including the North and Middle Sloughs. The changes resulted in alteration of water circulation and sediment transport processes, which had the effect of altering sediment-flushing flows, changing sedimentation patterns, reducing the geomorphic complexity of the estuary, stagnating water circulation, and reducing the volume of tidal exchange. The Flood Control Project resulted in the loss of at least half of the estuary volume, significantly reduced fish rearing habitat quantity and quality, creating poor water quality conditions during the summer and fall, and loss of fish production capacity. The purpose of the Project is to restore the ecological function of the Redwood Creek estuary and rehabilitate the Redwood Creek Flood Control Project in a manner that achieves desired flood capacity and is compatible with adjacent agricultural land use.

A broad range of potential design concepts was identified in the initial scoping process in an effort to achieve the desired future conditions, processes, and functions outlined in Section 6. These initial concepts were presented to the affected landowners and the Peer Review Committee for discussion and feedback. Refinements were made in an effort to optimize estuary and levee benefits while achieving alternatives that are most likely to be feasible.

A total of seven alternatives, designated A1 through A7, are presented (Figures 9-1 through 9-14). All alternatives are conceptual in nature and additional modifications and refinements will be needed based on consultations with affected private and public landowners; consultations with funders and regulatory agencies; the results of further technical studies; and further design efforts to optimize the desired conditions and processes. Discussions with the adjacent private landowners were constructive, and the opportunity exists to continue those discussions into the future, and work toward agreement on the footprint for a proposed project with appropriate terms, conditions, and compensation. However, the landowners have not committed to any alternative.

Alternatives A1, and potentially A2 and A4, represent the alternatives most likely to be feasible in terms of landowner acceptance. On the north side, only one conceptual design is considered to be feasible in the short-term, and this design is incorporated into Alternatives A1 through A4. On the south side, three designs are presented for future discussion. Levee modifications will ultimately be needed on both the north and south sides to achieve the overall goals and objectives; however, work could be implemented in phases.

Alternative A4 reflects a slight modification of Alternative A2. Alternative A5 reflects a concept suggested by the adjacent private landowner on the north side of the estuary for a culvert through the levee. This alternative is not evaluated to the same level as the other alternatives due to the concept's limitations for addressing the overall project goals.

Alternatives A6 and A7 are conceptual designs developed with input from the Peer Review Committee. Discussions with the committee generally focused on designs that maximized the desired conditions of the estuary by incrementally increasing the physical and ecological processes and functions across the upstream landscape. These two alternatives extend over large areas on both the north and south sides and would affect multiple ownerships including owners who were not involved in the outreach efforts for the conceptual design project. Alternatives A6 and A7 were developed primarily as reference points for comparison with Alternatives A1 through A3, which affect smaller areas and are more likely to be feasible in the near-term.

An option that could be incorporated into future design work is using excess spoil materials from construction activities for landspreading and grading on adjacent agricultural land to raise the ground elevation, improve soil conditions, and/or improve drainage.

The scoping process identified the concept of converting a portion of the existing riparian area associated with Strawberry Creek on the County-owned solid waste container site to pasture in order to maximize the retention of agricultural acreage for a large-scale project to restore the Redwood Creek estuary. Another potential option includes re-aligning portions of Strawberry Creek to increase the amount of agricultural land protected by an existing (or new) levee and to potentially create opportunities for a more extensive riparian area adjacent to the creek. These options were not incorporated into the alternatives in the final report but could be further evaluated in future phases.

The range of alternatives represents a mix of performance in terms of feasibility for landowner support, optimization of estuary ecological restoration, and levee rehabilitation. A preliminary evaluation of Alternatives A1, A2, A3, A6, and A7 based on the project objectives are presented in Table 9-3. This matrix provides a simplified way of comparing the alternatives with respect to the different objectives. It’s important to note that this conceptual design project was limited to a planning study intended to develop and compile technical information to support future decision-making, and was not intended to select a preferred alternative or provide a formal ranking.

Table 9-3. Evaluation matrix for existing condition and conceptual alternative designs.

Redwood Creek Concept Plan Alternatives Evaluation Matrix						
Objectives	**Alternatives**					
Estuary – Physical Processes	**Existing**	**A1**	**A2**	**A3**	**A6**	**A7**
Increase estuary tidal prism volume	none	med	med	med	high	high
Increase estuary area and volume	none	med	med	med	high	high
Improve water circulation patterns	none	med	med	low	med	high
Export/flushing of marine and fluvial sediment from the estuary	none	low	low/med	med	med/high	high
Sediment routing through the estuary	none	low	low	med	high	high
Slough channel maintenance/scour	none	med	med	med	med/high	high
Reestablish distributary channel network	none	low	low	med	high	high
Direct flood flows toward headlands	none	med	med	med	high	high
Estuary – Ecological Conditions						
Increase habitat capacity for fisheries	none	med	med	med	high	high
Increase fish access to floodplains	none	low	med	med	high	high
Expand riparian coverage along channel margin and across floodplains	none	med	med	high	high	high
Improve water quality in sloughs and embayment	none	med/high	med/high	med	high	high
Increase fish populations (and resiliency)	none	med	med	med	med/high	med
Flood Control Project						
Achieve acceptable, sustainable flood protection	none	low/med	low/med	med	med/high	high
Accommodate high sediment loads	low	low	low	med	med	high
Active status in Corps of Engineers Rehabilitation and Inspection Program	none	med	med	med	med	high
Certification/accreditation on FEMA flood map	none	low	low/med	low/med	high	high
Adjacent Land						
Maintain agricultural productivity	n/a	**	**	**	**	**
Limit net loss of agricultural land use	n/a	**	**	**	**	**
Private landowner agreement	n/a	**	**	**	**	**
Consistent with NPS policies	n/a	**	**	**	**	**

** Note: These objectives will need to be evaluated in more detail in a subsequent phase based on input from the affected landowners.

9.3.1 Alternative A1

The Alternative A1 conceptual design (Figure 9-1) involves relocating the lower portion of the north levee to coincide with the county road and relocating the lower portion of the south levee along a new alignment that ties in to the nearest point along Highway 101. This alternative allows Redwood Creek to re-occupy South Slough and re-establishes the creek-headland interaction on the north side of the estuary. This alternative also restores overbank flooding into North Slough to allow scour of sediment and wood. This alternative allows reconnecting Redwood Creek to the southern wetland near the park visitor center and increases riparian and floodplain areas. Portions of the adjacent agricultural lands are restored as floodplain but retained as pasture for grazing, and portions are converted to floodplain with riparian vegetation. Part of the rationale for this alternative is to maximize the amount of agricultural land protected by a levee on the south side while also allowing re-connection of South Slough to the main Redwood Creek channel.

Alternative A1 consists of the following demolition and removal activities (Figure 9-2):

- Removal of approximately 3,000 feet of the north levee.
- Removal of approximately 2,300 feet of the south levee.
- Removal of a portion of the visitor center parking lot.
- Removal and disposal of old car bodies and other debris lining the south bank of the South Slough.
- Excavation of fill located at the north end of Middle Island, and fill along the northerly edge of the north levee on the North Slough side.
- Demolition of the rock sill at the mouth of the levee system.
- Abandonment and removal of a portion of Hufford Road and the levee road.
- Excavation of accumulated sediment at the mouth of North Slough.

Alternative A1 would require (Figure 9-3):

- Construction of approximately 1,400 feet of new levee on the north side.
- Construction of approximately 2,400 feet of new levee on the south side.
- Bank stabilization (with biotechnical techniques) along portions of the re-connected South Slough.
- Channel, slough, bank, and floodplain excavation.
- Installation of new culverts/tidegates at Sand Cache and Strawberry creeks, north levee drainage ditch, and Highway 101.
- Reconstruction of a section of Hufford Road on top of the new north levee segment.

Figures 9-1 through 9-3 depict one option on the north side for balancing the retained pasture with new riparian vegetation. This balance could be adjusted in a variety of ways, for example as shown in Figure 9-4, based on future landowner discussions. Similarly, the extent of the areas of pasture and riparian vegetation could be adjusted on the south side.

Implementation of Alternative A1 would result in increased water circulation and improved water quality. The realignment of the north levee would allow floodwaters to access a limited amount of floodplain and help flush the North Slough. The southern wetland would also be improved and available for seasonal fish use. This alternative would take the least amount of land out of year-round agricultural production. Some of the land inside the restored area could be available for seasonal grazing.

9.3.2 Alternative A2

Alternative A2 (Figures 9-5 through 9-7) is a refinement of Alternative A1, with the same design on the north side and a different alignment for the setback levee on the south side. The setback levee hinge point is situated further upstream, opposite the hinge point for the setback levee on the north side, to create more floodplain. In common with Alternative A1, Alternative A2 re-occupies South Slough, re-establishes the creek-headland interaction, restores overbank flooding on the north side, re-connects the southern wetland, increases riparian areas, and retains areas for grazing. Alternative A2 is different from Alternative A1 by providing additional floodplain connectivity between South Slough and the new south levee. This additional floodplain provides more high-flow habitat, more floodplain fine sediment deposition, and allows the sediment transition zone to occur further upstream from the estuary than Alternative A1. Alternative A2 would require removal of approximately 3,000 feet of the existing south levee and construction of approximately 2,700 feet of new levee on the south side. This equates to approximately 700 more feet of levee removal and 300 more feet of levee construction than Alternative A1.

9.3.3 Alternative A3

Alternative A3 (Figures 9-8 through 9-10) has the same design on the north side as Alternatives A1 and A2 but takes a different approach on the south side. Alternative A3 was developed to provide an alternative that does not involve constructing a new levee in close proximity to the estuary. This alternative includes removal of the lower portion of the south levee up to the approximate location of the South Slough gated culverts, which would also be removed. The remaining portion of the south levee would remain in place to protect the adjacent agricultural land, and a relatively shorter new setback levee would be constructed to protect structures against flooding. The portion of the existing south levee left in place would continue to be maintained but not to the level of achieving FEMA certification standards. The new setback levee would be maintained to FEMA certification standards. Alternative A3 would require removal of approximately 1,800 feet of the existing south levee and construction of approximately 1,700 feet of new levee.

For Alternative A3, Redwood Creek would not be rerouted into South Slough, but would remain in its current alignment. The lowest end of the channel would be reconfigured slightly to the north to improve scour conditions along the north headlands. The left bank along Middle Island would be lowered so that overbank flows could enter the head of South Slough, similar to overbank flows entering North Slough. The increased overbank flows into South Slough would scour accumulated sediments from the slough, increasing the likelihood that mouth of South Slough would stay connected to the embayment.

The lack of a levee along South Slough would allow backwater flooding to occur onto the adjacent pasture. The extent and frequency of backwater flooding to the adjacent pasture is not currently well defined, and would need to be further evaluated in future analysis. Alternative A3 may require an additional setback berm along South Slough to prevent pasture flooding to an acceptable frequency flood, such as a 10-year event. This additional area of backwater flooding could provide additional floodplain habitat, depending on the frequency of flooding. Since this area would be flooded by backwater conditions, it’s unlikely to contribute significantly to floodplain deposition. However, fine grained sediment deposition would occur in the backwater flooded areas.

More detailed information regarding expected flooding conditions and levee maintenance would be needed to evaluate the feasibility of Alternative A3 from a landowner perspective.

9.3.4 Alternative A4

This alternative (Figure 9-11) reflects a slight modification of Alternative A2, and shows an example of how the south levee could be modified based on future landowner discussions, analysis, and design. This south levee configuration would further increase protection of the northerly end of the adjacent pasture east of Strawberry Creek, but maintains some floodplain connectivity west of Strawberry Creek. Although Alternative A4 has more connected floodplain than Alternative A1, the configuration of the south levee will likely produce sedimentation patterns similar to Alternative A1. However, the increased floodplain west of Strawberry Creek will provide more floodplain habitat than Alternative A1.

9.3.5 Alternative A5

This alternative (Figure 9-12) involves leaving the full levee on the north side in place and installing new culverts through the levee to allow Redwood Creek flow to enter the head of North Slough. Although this alternative would provide flow into the head of North Slough, the quantity of flow would be limited by the culvert size and location in the levee. Furthermore, this alternative would not provide floodplain connectivity along the North Slough side of Redwood Creek, reducing any potential for floodplain habitat or floodplain sedimentation. Although the concept of placing culverts through the levees to provide flow to the heads of the slough channels is logical, the concept is unproven for being effective in scouring sediment. The gated culverts installed through the south side of the levee in 1989 to provide hydraulic connection between the Redwood Creek channel and South Slough have provided seasonal improvements in water quality and circulation but have not provided a benefit for scouring sediment. Additional concerns with the concept of installing culverts though the levee are the long-term functioning of the culverts; the long-term management and maintenance commitment; and scour-related issues to the levee at the culverts.

9.3.6 Alternative A6

This alternative (Figure 9-13) involves setback levees on both the north and south sides with more extensive levee removal. On the north side, approximately 4,000 feet of levee would be removed and approximately 3,800 feet of new levee would be constructed. On the south side, approximately 5,700 feet of levee would be removed and approximately 1,700 of new levee would be constructed. This alternative includes construction of a new access road on top of a new section of levee, leading to the hilltop residences at the end of Hufford Road.

On the north side, this concept would allow floodwaters to access additional floodplain area and help flush sediment from the North Slough and multiple slough channel alignments. On the south side, this concept would allow overbank flows from Redwood Creek to access a large floodplain area and join Strawberry Creek. This alternative allows the sediment transition zone to move further upstream of the estuary. A portion of the fine sediment transported by flood flows would be deposited on the floodplains, reducing the overall sediment load to the estuary. This alternative also allows for North Slough to capture more potential floodplain flows from Redwood Creek. Distributary channels would likely form over time on both the newly restored north and south side floodplains. The increased area of restored floodplains provides greater opportunities for floodplain habitats and high-flow refugia.

The majority of the affected adjacent land could continue to be used for grazing, but this land would no longer be protected by the Flood Control Project. This alternative proposes a new road on the north side of the valley leading up to two residential properties; however, the feasibility of this new road is unknown.

This alternative is not considered feasible at this time due to the extent of the affected areas involving private landowners, lack of private landowner agreement, and the uncertainty in associated risks.

9.3.7 Alternative A7

Alternative A7 (Figure 9-14) is a refinement of Alternative A6 and places a new setback levee on the north side further upstream where a relatively short levee segment could tie into the hillslope on this side of the valley. Approximately 9,400 feet of levee would be removed on the north side and approximately 2,600 of new levee would be constructed. This alternative has the same levee concept and floodplain restoration for the south side as Alternative A6. This alternative would have the highest cost of all the alternatives considered (approximately 25% more expensive than Alternative A1).

This alternative represents the maximum amount of potential restored floodplain connectivity available with adjacent agricultural land along lower Redwood Creek. This alternative would maximize floodplain flow in the lower valley and have the greatest potential for sediment reduction from floodplain deposition and North Slough scouring. This alternative further allows the sediment transition zone to begin a short distance downstream of Orick, well above the estuary. A significant portion of the fine sediment transported by flood flows would be deposited on the northern and southern floodplains. This alternative provides the greatest ecological benefit to the estuary.

This alternative is not considered feasible at this time due to the extent of the affected areas involving private landowners, lack of private landowner agreement, and the uncertainty in associated risks.

9.4 Preliminary Hydraulic Analysis

Preliminary hydraulic analysis was performed to understand the effects of the conceptual design alternatives on water surface elevations for the 100-year flood (1%-annual-chance-flow). The 1D HEC-RAS model prepared for the update of the FEMA flood map (Section 5.3) was modified to determine longitudinal profiles for Alternatives A1, A2, A3, A6, and A7. The model geometry for the conceptual designs was based on a developed historical Redwood Creek estuary topography and bathymetry surface, and assumptions regarding levee removal and floodplain grading. The model geometry for each simulated alternative relied on the existing condition geometry upstream of the conceptual design footprint. Manning's roughness values were consistent with the values used in the FEMA floodplain mapping study (NHE and Manhard, 2013b). The downstream boundary condition was assumed to be normal depth calculated using Manning's Equation and average bed slope.

The developed HEC-RAS models are fixed-bed models that do not account for bed changes or sediment transport. Furthermore, each conceptual design consists of multi-dimensional flow and circulation patterns that cannot be predicted by the 1D HEC-RAS models. A more detailed quantification of expected flow patterns for the conceptual designs will require two or three-dimensional hydrodynamic modeling. However, the developed HEC-RAS models do provide reasonable planning level flood profiles for comparing flood improvements of each conceptual design to existing conditions.

9.4.1 Alternative A1

The existing HEC-RAS model described in Section 5.3.1 was modified to account for the conceptual design elements described for Alternative A1, which consist of the levee setbacks, channel realignment into South Slough, and accommodating the historical estuary configuration. Modeling results for Alternative A1 indicate that the 100-year flood profile is lower than existing conditions (Figure 9-15) downstream of the levee setbacks, and gradually transitions to existing flood levels upstream. The extent of flood reduction greater than 0.25 feet extends approximately 3,500 feet upstream of the upper most levee setback. Alternative A1 effectively removes the lower portion of the Flood Control Project that does not provide three feet of freeboard at the 100-year event (Reach 1 in Table 5-6). Based on modeling results, Alternative A1 would provide three feet of freeboard at the 100-year event for the entire Flood Control Project for existing bed elevations and channel conditions.

9.4.2 Alternative A2

Modeling results for Alternative A2 are similar to A1, with a 100-year flood profile that is lower than existing conditions (Figure 9-16) downstream of the levee setbacks. The extent of flood reduction greater than 0.25 feet is approximately 3,700 feet upstream of the levee setbacks. Similar to Alternative A1, Alternative A2 removes the Reach 1 portion of the Flood Control Project levees (Table 5-6), and provides three feet of freeboard at the 100-year event for the remaining Flood Control Project for existing bed elevations and channel conditions.

9.4.3 Alternative A3

Modeling results for Alternative A3 are similar to Alternatives A1 and A2, with a 100-year flood profile that is lower than existing conditions (Figure 9-17) downstream of the levee setbacks. The extent of flood reduction greater than 0.25 feet is approximately 3,700 feet upstream of the upper levee setback. Similar to Alternatives A1 and A2, Alternative A3 removes the Reach 1 portion of the Flood Control Project levees (Table 5-6), and provides three feet of freeboard at the 100-year event for the remaining Flood Control Project for existing bed elevations and channel conditions.

9.4.4 Alternative A6

Modeling results for Alternative A6 demonstrate that the 100-year flood profile is significantly lower than existing conditions well upstream of the levee setbacks (Figure 9-18). The extent of flood reduction greater than 0.25 feet extends approximately 900 feet upstream of the Highway 101 bridge, well above the upper most levee setback. Similar to the other alternatives, Alternative A6 removes the Reach 1 portion of the Flood Control Project levees (Table 5-6), and provides three feet of freeboard at the 100-year event for the remaining Flood Control Project.

This alternative would provide improved flood conditions for the remaining lower end of the Flood Control Project and for the lowest lying residential areas. Reduced flood levels could extend as far upstream as the Highway 101 bridge. The remaining upstream levee sections would likely achieve three feet of freeboard capacity at the 100-year flood event without raising levee height. The additional freeboard capacity could help to offset in-channel sedimentation and vegetation effects downstream of Highway 101.

9.4.5 Alternative A7

Modeling results indicate that Alternative A7 provides the greatest flood reduction, significantly lowering the existing condition 100-year flood profile over most of the Flood Control Project (Figure 9-19). The extent of flood reduction greater than 0.25 feet extends approximately 4,500 feet upstream of the Highway 101 bridge, near the end of the Flood Control Project's right-bank levee. Similar to the other alternatives, Alternative A7 removes the Reach 1 portion of the Flood Control Project levees (Table 5-6), and provides three feet of freeboard at the 100-year event for the remaining Flood Control Project.

Alternative A7 would have significant benefits to flood protection for the central residential and commercial area of Orick by increasing the overall capacity of the Flood Control Project. Reduced flood levels would extend most of the way through the remaining portion of the Flood Control Project. The additional freeboard capacity could help offset in-channel sedimentation and vegetation affects within the entire Flood Control Project. As with Alternative A6, the majority of the affected adjacent land could continue to be used for grazing, but this land would no longer be protected by the Flood Control Project.

9.5 Sediment Mobility Analysis

Sediment mobility analysis was conducted for conceptual design Alternatives A1, A2, A3, A6, and A7 to highlight areas that will be particularly prone to large shifts in sediment transport rates and to identify the direction those shifts may occur. The analysis is based on the cross-sectionally averaged Shields Parameter, a non-dimensionalization of shear stress. Full sediment mobility (all particles of a given size will move at least one time) is assumed for a Shields Parameter greater than 0.06, and partial mobility (some particles of a given size will move at least once) for values between 0.03 and 0.06. The bed material is considered immobile if the Shields Parameter is less than 0.03. Higher shear stress (and Shields Parameter values) indicates a higher capacity to transport sediment. A Shields Parameter less than 0.03 would indicate zones where flows cannot mobilize the median particle size. Identification of areas with a Shields Parameter less than 0.03 is of highest concern in this assessment because the river would not be able to re-distribute this material downstream under any sediment supply condition.

The analysis also highlights a sediment transition zone where the shear stress (Shields Parameter) follows a regular pattern of increasing as flow exits the Flood Control Project, and decreases as flow spreads across the floodplain and estuary. The position, length, and magnitude of shear stress variations in the transition zones changes depending on the levee configuration, floodplain width, and distance from the ocean. Within the sediment transition zone, the channel is expected to be more dynamic and more prone to bed fluctuations (e.g., deeper incision and aggradation) and channel planform adjustments (e.g., channel widening, bar formation and shifting) compared to other areas within the reach. Sediment sorting is also expected to be more pronounced as shear stress declines.

The Shields Parameter alone cannot provide predictions of bed aggradation or incision over time. These sedimentation patterns depend on the transport rate and sediment supplied from both fluvial and coastal sources. If the sediment supply rate is higher than the sediment transport rate at a given location, aggradation will occur. If the sediment supply rate is lower than the transport rate at a given location, incision will occur. The transport capacity of the channel at a given flow is not a fixed value and is dependent on the channel morphology (planform, bed forms, grain size, channel slope, vegetation, etc.). Quantitative predictions of expected sedimentation patterns within this complex zone will require an analysis that includes variable sediment supplies, varying spatial and temporal flow conditions, and bed morphology responses.

The sediment mobility analysis was based on the 1-D HEC-RAS model developed for each conceptual design alternative, and initiation of motion using Shields Parameter to determine the mobility of the median diameter sediment (d_{50}). A sediment d_{50} of 8.4 mm (Klein and Anderson, 2012) was assumed for the surface layer within the Flood Control Project. Sediment mobility for the 1.5- and 100-year flood events was assessed for existing conditions and each alternative.

9.5.1 Existing Conditions

Results of the sediment mobility analysis for existing conditions at the 1.5- and 100-year flood events are shown for comparison with each analyzed alternative (Figures 9-20 through 9-24). Results indicate that for both the 1.5- and 100-year flood events, the Shields Parameter for existing condition is well above the full mobility threshold of 0.06, indicating that coarse grained sediments remain mobile. The results show relatively constant sediment mobility through the Flood Control Project at both flows for existing conditions, except at the upstream and downstream ends of levees. The change in Shields Parameter at the downstream end of the levees indicates a sediment transition zone from increased sediment mobility to lower mobility as flood flows exit the levees. Under existing conditions, this transition zone occurs at the existing small estuary embayment, and all sediment is delivered directly to the embayment. Since the sediment transition zone for existing conditions occurs directly at the end of the levees, there is limited or no opportunity for sediment sorting to occur prior to entering the small embayment. Similarly, there is no space for lateral channel adjustments to re-distribute deposited sediments.

9.5.2 Alternative A1

Results of the sediment mobility analysis for Alternative A1 at the 1.5- and 100-year flood events are shown in Figure 9-20. Results indicate that for both the 1.5- and 100-year flood events the Shields Parameter is well above the full mobility threshold of 0.06, indicating that coarse grained sediments should remain mobile. Based on the sediment mobility assessment, the river under Alternative A1 should be able to redistribute or remove sediment delivered to the estuary.

Figure 9-20 shows relatively constant sediment mobility through the Flood Control Project at both flows for Alternative A1, except at the upstream and downstream ends of levees. The change in Shields Parameter at the downstream end indicates a sediment transition zone from increased sediment mobility to lower mobility as flood flows exit the setback levees. For Alternative A1, the sediment transition zone begins above of the estuary upstream of the north levee setback, and provides a longer zone (compared to existing conditions) for sediment sorting and fining to occur within the restored South Slough reach prior to flows entering the estuary embayment. During larger floods, an increase in fine sediment deposition may occur across the newly connected floodplains. Within the transition zone, the channel is expected to be more dynamic and more prone to bed fluctuations (e.g. deeper incision and aggradation) and channel planform adjustments (e.g. channel widening, bar formation and shifting) than other areas within the reach. These bed and planform adjustments may also result in the channel migrating or avulsing into Middle or North Slough alignments over the long-term.

9.5.3 Alternative A2

Results of the sediment mobility analysis for Alternative A2 at the 1.5- and 100-year flood events are shown in Figure 9-21. Results indicate that for both the 1.5- and 100-year flood events the Shields Parameter is well above the full mobility threshold of 0.06, indicating that coarse grained sediments should remain mobile. Based on the sediment mobility assessment, the river under Alternative A2 should be able to redistribute or remove sediment delivered to the estuary.

Overall, the sediment mobility assessment for Alternative A2 is very similar to A1 (Figure 9-20), with relatively constant sediment mobility through the Flood Control Project for both flows, and a change in Shields Parameter at the downstream end indicating a sediment transition zone at the levee setbacks. For Alternative A2, the sediment transition zone begins above of the estuary upstream of the levee setbacks, and provides a longer zone for sediment sorting and fining to occur within the restored South Slough reach prior to flows entering the estuary embayment. The response of the sediment transition zone for Alternative A2 will be similar to what was described for Alternative A1. During larger floods, an increase in fine sediment deposition may occur across the newly connected floodplains.

9.5.4 Alternative A3

Results of the sediment mobility analysis for Alternative A3 at the 1.5- and 100-year flood events are shown in Figure 9-22. Results indicate that for both the 1.5- and 100-year flood events the Shields Parameter is well above the full mobility threshold of 0.06, except for the small dip for the 1.5-year event which is still above the partial mobility threshold of 0.03, indicating that coarse grained sediments should remain mobile. Based on the sediment mobility assessment, the river under Alternative A3 should be able to redistribute or remove sediment delivered to the estuary.

Figure 9-22 shows relatively constant sediment mobility through the Flood Control Project at both flows for Alternative A3, and a sediment transition zone that begins upstream of the north levee setback. By not redirecting the channel flow into South Slough, Alternative A3 has a smaller sediment transition zone than Alternatives A1 and A2. The sediment transition zone is also closer to the estuary for Alternative A3 compared to A2 and A1. The Shields Parameter values are higher in Alternative A3 within the transition zone compared to A1 or A2. The shorter sediment transition zone and proximity to the estuary indicates that Alterative A3 would have less channel length to sort and store sediments, and would likely deliver more sediment directly to the estuary compared to A2 and A1. During larger floods, an increase in fine sediment deposition may occur across the newly connected floodplains.

9.5.5 Alternative A6

Results of the sediment mobility analysis for Alternative A6 at the 1.5- and 100-year flood events are shown in Figure 9-23. Results indicate that for both the 1.5- and 100-year flood events the Shields Parameter is well above the full mobility threshold of 0.06, indicating that coarse grained sediments should remain mobile. Based on the sediment mobility assessment, the river under Alternative A6 should be able to redistribute or remove sediment delivered to the estuary.

Figure 9-23 shows relatively constant sediment mobility through the Flood Control Project at both flows for Alternative A6, and a sediment transition zone that begins upstream of the north levee setback. The sediment transition zone for Alternative A6 is much further upstream of the estuary than for Alternatives A1, A2, and A3, and would provide a longer zone for sediment sorting and fining to occur within the existing and restored South Slough channel. Within the transition zone, the channel is expected to be more dynamic and more prone to bed fluctuations (e.g. deeper incision and aggradation) and channel planform adjustments (e.g. channel widening, bar formation and shifting) than other areas within the reach. These bed and planform adjustments may also result in the channel migrating or avulsing into Middle or North Slough alignments over the long-term. Due to the longer transition zone and location above the estuary, Alternative A6 would likely deliver less sediment directly to the estuary than Alternatives A1, A2 and A3. Alternative A6 also has more floodplain area for fine sediment deposition than Alternatives A1, A2, and A3.

9.5.6 Alternative A7

Results for Alternative A7 (Figure 9-24) indicate that for both the 1.5- and 100-year flood events the Shields Parameter is well above the full mobility threshold of 0.06, indicating that coarse grained sediments should remain mobile. Based on the sediment mobility assessment, the river under Alternative A7 should be able to redistribute or remove sediment delivered to the estuary.

Figure 9-24 shows relatively constant sediment mobility through the Flood Control Project at both flows for Alternative A7, and a sediment transition zone that begins upstream of the north levee setback. The sediment transition zone for Alternative A7 is much further upstream of the estuary than for any of the other Alternatives, and would provide the longest zone for sediment sorting and fining to occur within the existing and restored South Slough channel. Within the transition zone, the channel is expected to be more dynamic and more prone to bed fluctuations (e.g. deeper incision and aggradation) and channel planform adjustments (e.g. channel widening, bar formation and shifting) than other areas within the reach. These bed and planform adjustments may also result in the channel migrating or avulsing into Middle or North Slough alignments over the long-term. Due to the longer transition zone and location above the estuary, Alternative A7 would likely deliver less sediment directly to the estuary than the other alternatives. Alternative A7 has the most floodplain area for fine sediment deposition than any of the other alternatives.

9.6 Productivity and Capacity

One of the goals of the estuary restoration and levee rehabilitation project is to restore hydrologic, morphologic, and ecologic processes sufficient to develop and maintain functional, self-sustaining estuarine habitat, especially to help recover Endangered Species Act-listed salmonids. As stated above, this includes reestablishing floodplain and slough connectivity with Redwood Creek during low and high flow periods. Restoring floodplain and slough connectivity would allow fish, especially juvenile coho, to find refuge from very high runoff events, provide juvenile fish access to off-channel food resources, boost winter survival of young salmonids, and increase smolt size prior to ocean entry. Another major aspect is to increase capacity, growth, and survival of juvenile Chinook salmon (ocean type/fall run) during the summer (as well as spring and autumn), which are the most dependent on estuarine rearing of all salmonids in Redwood Creek (Volk et al., 2010) along with cutthroat trout. In addition, steelhead have the potential to use the estuary during all seasons and likely have the highest potential to provide a robust recreational fishery in the near-term, and are thus an important species in terms of estuary restoration benefits.

Appendix B contains maps depicting the extent of inundation associated with existing conditions and Alternatives A1, A2, A3, A6, and A7 for three flow scenarios. This information was developed by overlaying modeled water surface elevations for the summer low flow (under barrier beach backwatered conditions), 1.5-year recurrence interval flood, and 5-year recurrence interval flood on top of floodplain topography with similar elevations.

The alternatives described in Section 9.3 would result in variable but significant increases in low flow and high flow habitat (Table 9-4). The sections below describe the amount of habitat area that would be provided for each of the proposed alternatives compared to the existing condition.

To allow better comparisons, the inundation areas in Table 9-4 were converted to percent increase relative to existing conditions in Table 9-5. The percentage increase for the alternatives, however, are almost entirely comprised of off-channel areas that would contain high value winter refuge habitat with complexity and areas of no or low water velocity, which are especially critical to juvenile coho salmon. The increased floodplain area available for juvenile salmonids under the project alternatives would provide the critical off-channel high flow refuge and feeding areas that these fish need during the winter. It is likely that implementation of any of the alternatives will result in improved juvenile coho winter growth and survival rates and larger size at ocean entry. The larger smolts are at ocean entry, the greater their chances of survival and returning as adults. Simply put, under existing conditions the amount of winter habitat for coho salmon and the associated fish capacity could be considered negligible relative to the size of the Redwood Creek watershed, whereas the various alternatives provide significant increases in such habitat with Alternative A7 providing the maximum area.

Table 9-4. Inundation areas for alternative levee locations.

Alternatives' Inundation Area (ft²)						
Flow Condition	Existing condition	Alternative A1	Alternative A2	Alternative A3	Alternative A6	Alternative A7
Low flow backwatered	1,269,337	2,797,958	2,797,958	2,412,958	2,714,225	2,714,225
Q1.5 (16,000 cfs)	3,629,353	9,224,250	9,607,925	4,990,675	13,010,600	15,220,650
Q 5 (31,900 cfs)	4,598,124	10,447,825	11,219,425	9,438,025	16,580,475	23,905,550

*North and south slough areas were estimated from aerial photographs. Does not include seasonal wetland to the south of the south slough.

Table 9-5. Percent increase in inundation areas for alternative levee locations relative to existing conditions.

Alternatives' Percent Increase					
Flow Condition	Alternative A1	Alternative A2	Alternative A3	Alternative A6	Alternative A7
Low flow backwatered	120%	120%	90%	114%	114%
Q1.5 (16,000 cfs)	154%	165%	38%	258%	319%
Q 5 (31,900 cfs)	127%	144%	105%	261%	420%

9.6.1 High flow periods

The 5-year flood would carry a substantial amount of sediment in the form of suspended and bedload sediment. Under the existing condition, much of this material is transported through the levee system and is deposited in the wave action zone and recruited into the longshore transport. The alternatives would result in the bulk of the bedload being deposited in upstream locations where the levee alignment is modified, the confined channel widens, and overbank flows have access to the floodplain. The farther upstream this sediment transition zone is located, the greater the benefit to the estuary due to less risk of such sediment depositing in the estuary (i.e., the sediment transition zone would be upstream of the estuary). The potential for 5-year flood events to scour sediment and vegetation from the North Slough and its fingers increases in proportion to the amount of floodplain available to accept flood flows on the northern floodplain thus increasing flow volumes and velocities in the North Slough system for scouring.

9.6.2 Low flow periods

The Redwood Creek estuary forms a larger lagoon when the mouth of the creek becomes blocked by wave-driven sand and creek flows and tidal action are insufficient to keep the mouth open (Section 4.2). The development of this blockage causes the creek to backwater until the time when there is sufficient flow or lagoon water elevation to breach the barrier and reconnect the creek to the ocean. Ocean-type Chinook salmon (fall run) in particular are reliant upon the estuary and associated lagoon for rearing during the summer in order to (hopefully) reach size thresholds for greater marine survival (Holtby et al., 1990).

The low flow period inundation condition comparison between alternatives was based on the late-summer/early fall backwater period when the mouth of the creek is closed off by the barrier beach. Under the existing conditions, water primarily backs up in the channel between the levees (Figure 9-12). A sediment accumulation located at the mouth of the south slough currently restricts backwatering in the slough and contributes to excessively shallow conditions in the main embayment, which restricts fish capacity (i.e., Figure 5-26) and contributes to water quality issues (i.e., Figures 5-22 and 5-23) for over-summering Chinook salmon juveniles. Groundwater elevations likely allow filling the south slough upstream of the blockage with water but fish access is uncertain and capacity in the sloughs is severely reduced and water quality is degraded. Under the existing condition, approximately 1,269,337 ft² of water surface area is created during the backwater period (Table 9-4).

Given the availability of long-term juvenile Chinook salmon abundance data for the estuary, a simple model was developed to estimate Chinook salmon production estimates for the estuary rearing fish under estimating conditions compared to the restoration Alternatives. While it would be possible to develop full-scale life-cycle population dynamics models for salmonids species in Redwood Creek as part of a cost-benefit analysis, such an effort would require extensive funding, data collection, and major assumptions. As part of this project, a simpler and quicker hybrid approach was used to develop some reasonable fish production estimates using existing data and regional ocean survival estimates that allowed for plausible estimates of increased adult returns under a restored estuary summer conditions. Notably, these estimates only apply for smolts reared in the estuary and not for smolts produced from upstream reaches.

The backwatered summer low flow inundation conditions under Alternatives A1, A2, A4, A6, and A7 are approximately equivalent and result in over twice the area as compared to existing conditions during periods (Table 9-4 and 9-5; Figures 9-1, 9-5, 9-11, 9-13, 9-14). Alternative 3 (Figure 9-8) results in slightly less than twice the area under existing conditions (Alternative 5 was not analyzed). Given the lack of substantial differences in backwatered inundation areas for most of the alternatives, the same area value was used for calculating summer habitat capacity estimates. Known estimates of summer capacity for Chinook salmon juveniles under existing conditions were used as the basis to estimate the increase in juvenile Chinook salmon capacity associated with the increases in low flow inundation area during the summer for the various alternatives (Table 9-6) (i.e., Figure 5-26; 2,260 fish, which is considered to be deficient for Chinook salmon in Redwood Creek relative to upstream production, Sparkman, 2008; Anderson, 2010).

Inherent in this approach was the assumption that habitat area was directly related to the habitat capacity. This assumption is common for modeling fish habitat capacity, however food resources and volume can also be important. In this case, as opposed to doing a bioenergetics foraging sub-model to assess increased food resources, we assumed that increased growth would lead to increased smolt size and marine survival, which is well supported in the scientific literature (e.g., Holtby et al., 1990). Other factors that impact population dynamics, such as predation or disease, are typically independent of fish density and as such are not factors that influence habitat carrying capacity and can be safely ignored in estimating habitat capacity. For volume, capacity was calculated assuming a direct proportional relationship of capacity with volume, and then applied to a scenario of doubling and tripling of average estuary depth and therefore volume.

Finally, a range of typical marine survival values for Chinook salmon for the California/Oregon coast was used to produce estimates of the number of adults returning from estuarine rearing juveniles (Table 9-6). The resulting adult numbers are provided as a matrix so the reader can see the range of potential estimates, but most likely outcomes would be towards the smaller ranges under existing conditions and towards the larger ranges under the restoration Alternatives.

Table 9-6. Increases in capacity and adult returns for estuarine rearing Chinook salmon under existing conditions and for the design alternatives under low flow backwatered inundation.

	Existing Conditions at Summer Low Flow	Alternatives at Summer Low Flow Backwatered*		
	Surface Area & Volume	Surface Area	Volume at 2x Depth	Volume at 3x Depth
Factor of Increase	1	2.20	4.41	9.00
Juvenile Capacity (# of Chinook)	2,260	4,982	9,963	20,340
Adults at 1% marine survival	23	50	100	203
Adults at 3% marine survival	68	149	299	610
Adults at 5% marine survival	113	249	498	1,017
Adults at 10% marine survival	226	498	996	2,034

*Note: Alternative 3 has 33% less area than the other alternatives. Alternative 5 has substantially less area than the other alternatives and is not included in this analysis.

9.7 Summary of Key Project Elements

Table 9-7 provides a summary of approximate lengths of levee removal and construction and approximate areas of agricultural land affected by Alternatives A1, A2, A3, A6, and A7. Tables 9-8 through 9-12 provide summaries of key project elements.

Table 9-7. Overview of affected levee and agricultural land. (Note 1)

Alternative	Existing Levee Removed		New Levee Constructed		Agricultural Land Converted to Levee, Open Water, or Riparian		Agricultural Land Potentially Affected by Flooding (Note 2)	
	North Side	**South Side**	**North Side**	**South Side**	**North Side**	**South Side**	**North Side**	**South Side**
A1	3,000 ft	2,300 ft	1,400 ft	2,400 ft	10.7 ac	16.8 ac	27.7 ac	21.3 ac
A2	3,000 ft	3,000 ft	1,400 ft	2,700 ft	10.7 ac	20.5 ac	27.7 ac	39.9 ac
A3	3,000 ft	1,800 ft	1,400 ft	1,700 ft	10.7 ac	5.5 ac	27.7 ac	96.4 ac
A6	4,000 ft	5,700 ft	3,800 ft	1,700 ft	43.8 ac	30.9 ac	72.1 ac	96.4 ac
A7	9,400 ft	5,700 ft	2,600 ft	1,700 ft	51.4 ac	30.9 ac	228.6 ac	96.4 ac

Notes:

(1) These estimates of effects on agricultural lands provide a general picture of the respective alternatives based on various assumptions including width of riparian areas. The estimates are subject to change based on further consultation with the landowners and refinement of the project design components.

(2) Further technical study is needed to assess the specific flooding impacts and the level of significance (i.e., recurrence interval, depth of water, inundation duration, erosion potential, potential for deposition of coarse sediment and debris).

(3) ft = feet
ac = acres

Table 9-8. Key planning level demolition and construction elements for Alternative A1.

Element/Component	Demolition	Construction
Estuary (includes North and South Slough, Middle Slough, and floodplain excavation quantities)	Removal of the grade control structure at the end of the Flood Control Project Levees	Excavation of approximately 555,000 cubic yards, and the placement of 117,000 cubic yards of material to restore the estuary to near historical configuration
Barrier Beach and Storm Berm	Remove a portion of the visitor center parking lot, and the potential relocation of the visitor center	Excavate and lower a portion of the barrier beach and storm berm to appropriate elevations
North Slough	Remove reed canary grass and other debris from North Slough, removal of fill along the existing north levee	Excavate and lower a portion of the pasture to floodplain elevations, replant riparian and wetland vegetation
South Slough	Removal and disposal of old car bodies and other debris lining the south bank of the South Slough channel	Bank stabilization (biotechnical and/or riprap) along portions of re-connected South Slough channel, replant riparian and wetland vegetation
Middle Island and Middle Slough	Removal of fill along the north side of Middle Island	Reconstruct Middle Island and Middle Slough, construct banks for restored Redwood Creek alignment, replant riparian and wetland vegetation
South Wetlands	Remove fill and other debris from south wetlands	Excavate a portion of the south wetland, expand wetland channel network, replant wetland and riparian vegetation
Strawberry Creek	Remove fill and other debris from Strawberry Creek west of the new south setback levee	Excavate and enhance Strawberry Creek and connection with South Slough west of the new setback levee, replant wetland and riparian vegetation
Levees	Remove approximately 3,000 feet of north levee, and 2,300 feet of south levee	Construction of approximately 1,400 feet of north setback levee, and 2,400 feet of south setback levee
Roads	Remove of approximately 4,200 feet of road	Construction of approximately 1,400 feet of new road
Infrastructure	Remove existing south levee tide gate structure, and other structures such as culverts	Install culvert under Highway 101 to expand South Wetlands, install tide gate structures in setback levees for Strawberry Creek, North Slough, and north side levee ditch
Agricultural Land	No demolition actions to agricultural lands	Approximately 8.1 acres of agricultural land will be lost to new setback levee construction, approximately 49.0 acres of agricultural land will potentially be affected by the restoration

Table 9-9. Key planning level demolition and construction elements for Alternative A2.

Element/Component	Demolition	Construction
Estuary (includes North and South Slough, Middle Slough, and floodplain excavation quantities)	Removal of the grade control structure at the end of the Flood Control Project Levees	Excavation of approximately 555,000 cubic yards, and the placement of 117,000 cubic yards of material to restore the estuary to near historical configuration
Barrier Beach and Storm Berm	Remove a portion of the visitor center parking lot, and the potential relocation of the visitor center	Excavate and lower a portion of the barrier beach and storm berm to appropriate elevations
North Slough	Remove reed canary grass and other debris from North Slough, removal of fill along the existing north levee	Excavate and lower a portion of the pasture to floodplain elevations, replant riparian and wetland vegetation
South Slough	Removal and disposal of old car bodies and other debris lining the south bank of the South Slough channel	Bank stabilization (biotechnical and/or riprap) along portions of re-connected South Slough channel, replant riparian and wetland vegetation
Middle Island and Middle Slough	Removal of fill along the north side of Middle Island	Reconstruct Middle Island and Middle Slough, construct banks for restored Redwood Creek alignment, replant riparian and wetland vegetation
South Wetlands	Remove fill and other debris from south wetlands	Excavate a portion of the south wetland, expand wetland channel network, replant wetland and riparian vegetation
Strawberry Creek	Remove fill and other debris from Strawberry Creek west of the new south setback levee	Excavate and enhance Strawberry Creek and connection with South Slough west of the new setback levee, replant wetland and riparian vegetation
Levees	Remove approximately 3,000 feet of north levee, and 3,000 feet of south levee	Construction of approximately 1,400 feet of north setback levee, and 2,700 feet of south setback levee
Roads	Remove approximately 4,200 feet of road	Construction of approximately 1,400 feet of new road
Infrastructure	Remove existing south levee tide gate structure, and other structures such as culverts	Install culvert under Highway 101 to expand South Wetlands, install tide gate structures in setback levees for Strawberry Creek, North Slough, and north side levee ditch
Agricultural Land	No demolition actions to agricultural lands	Approximately 8.9 acres of agricultural land will be lost to new setback levee construction, approximately 67.6 acres of agricultural land will potentially be affected by the restoration

Table 9-10. Key planning level demolition and construction elements for Alternative A3.

Element/Component	Demolition	Construction
Estuary (includes North and South Slough, Middle Slough, and floodplain excavation quantities)	Removal of the grade control structure at the end of the Flood Control Project Levees	Excavation of approximately 318,000 cubic yards, and the placement of 26,000 cubic yards of material to restore the estuary to near historical configuration with modification
Barrier Beach and Storm Berm	Remove a portion of the visitor center parking lot, and the potential relocation of the visitor center	Excavate and lower a portion of the barrier beach to appropriate elevations, keep storm berm to protect new South Slough connection to embayment
North Slough	Remove reed canary grass and other debris from North Slough, removal of fill along the existing north levee	Excavate and lower a portion of the pasture to floodplain elevations, replant riparian and wetland vegetation
South Slough	Removal and disposal of old car bodies and other debris lining the south bank of the South Slough channel	Restore/enhance South Slough channel, construct connection at head of slough channel to allow overbank flows from Redwood Creek, replant riparian and wetland vegetation
Middle Island and Middle Slough	Removal of fill along the north side of Middle Island	Construct portion of Middle Island, lower left bank of Redwood Creek to allow overbank flows into South Slough, provide bank stabilization along South Slough reach to prevent channel capture, replant riparian and wetland vegetation
South Wetlands	Remove fill and other debris from south wetlands	Excavate a portion of the south wetland, expand wetland channel network, replant wetland and riparian vegetation
Strawberry Creek	Remove fill and other debris from Strawberry Creek west of the new south setback levee	Excavate and enhance downstream end of Strawberry Creek, replant wetland and riparian vegetation
Levees	Remove approximately 3,000 feet of north levee, and 1,800 feet of south levee	Construction of approximately 1,400 feet of north setback levee, and 1,700 feet of south setback levee
Roads	Remove approximately 3,800 feet of road	Construction of approximately 1,400 feet of new road
Infrastructure	Remove existing south levee tide gate structure, and other structures such as culverts	Install culvert under Highway 101 to expand South Wetlands, install tide gate structures in setback levees for Strawberry Creek, North Slough, and north side levee ditch
Agricultural Land	No demolition actions to agricultural lands	Approximately 4.7 acres of agricultural land will be lost to new setback levee construction, approximately 124.0 acres of agricultural land will potentially be affected by the restoration

Table 9-11. Key planning level demolition and construction elements for Alternative A6.

Element/Component	Demolition	Construction
Estuary (includes North and South Slough, Middle Slough, and floodplain excavation quantities)	Removal of the grade control structure at the end of the Flood Control Project Levees	Excavation of approximately 585,000 cubic yards, and the placement of 117,000 cubic yards of material to restore the estuary to near historical configuration with modification
Barrier Beach and Storm Berm	Remove a portion of the visitor center parking lot, and the potential relocation of the visitor center	Excavate and lower a portion of the barrier beach and storm berm to appropriate elevations
North Slough	Remove reed canary grass and other debris from North Slough, removal of fill along the existing north levee	Excavate and lower a portion of the pasture to floodplain elevations, expand north slough channels, replant riparian and wetland vegetation
South Slough	Removal and disposal of old car bodies and other debris lining the south bank of the South Slough channel	Bank stabilization (biotechnical and/or riprap) along portions of re-connected South Slough channel, replant riparian and wetland vegetation
Middle Island and Middle Slough	Removal of fill along the north side of Middle Island	Reconstruct Middle Island and Middle Slough, construct banks for restored Redwood Creek alignment, replant riparian and wetland vegetation
South Wetlands	Remove fill and other debris from south wetlands	Excavate a portion of the south wetland, expand wetland channel network, replant wetland and riparian vegetation
Strawberry Creek	Remove fill and other debris from Strawberry Creek west of the new south setback levee	Excavate and enhance Strawberry Creek and connection with South Slough west of the new setback levee, replant wetland and riparian vegetation
Levees	Remove approximately 4,000 feet of north levee, and 5,700 feet of south levee	Construction of approximately 3,800 feet of north setback levee, and 1,700 feet of south setback levee
Roads	Remove approximately 4,900 feet of road	Construction of approximately 1,600 feet of new road
Infrastructure	Remove existing south levee tide gate structure, and other structures such as culverts	Install culvert under Highway 101 to expand South Wetlands, install tide gate structures in setback levees for Strawberry Creek, North Slough, and north side levee ditch
Agricultural Land	No demolition actions to agricultural lands	Approximately 8.5 acres of agricultural land will be lost to new setback levee construction, approximately 168.5 acres of agricultural land will potentially be affected by the restoration

Table 9-12. Key planning level demolition and construction elements for Alternative A7.

Element/Component	Demolition	Construction
Estuary (includes North and South Slough, Middle Slough, and floodplain excavation quantities)	Removal of the grade control structure at the end of the Flood Control Project Levees	Excavation of approximately 605,000 cubic yards, and the placement of 117,000 cubic yards of material to restore the estuary to near historical configuration with modification
Barrier Beach and Storm Berm	Remove a portion of the visitor center parking lot, and the potential relocation of the visitor center	Excavate and lower a portion of the barrier beach and storm berm to appropriate elevations
North Slough	Remove reed canary grass and other debris from North Slough, removal of fill along the existing north levee	Excavate and lower a portion of the pasture to floodplain elevations, expand north slough channels, replant riparian and wetland vegetation
South Slough	Removal and disposal of old car bodies and other debris lining the south bank of the South Slough channel	Bank stabilization (biotechnical and/or riprap) along portions of re-connected South Slough channel, replant riparian and wetland vegetation
Middle Island and Middle Slough	Removal of fill along the north side of Middle Island	Reconstruct Middle Island and Middle Slough, construct banks for restored Redwood Creek alignment, replant riparian and wetland vegetation
South Wetlands	Remove fill and other debris from south wetlands	Excavate a portion of the south wetland, expand wetland channel network, replant wetland and riparian vegetation
Strawberry Creek	Remove fill and other debris from Strawberry Creek west of the new south setback levee	Excavate and enhance Strawberry Creek and connection with South Slough west of the new setback levee, replant wetland and riparian vegetation
Levees	Remove approximately 9,400 feet of north levee, and 5,700 feet of south levee	Construction of approximately 2,600 feet of north setback levee, and 1,700 feet of south setback levee
Roads	Remove approximately 10,200 feet of road	Construction of approximately 1,600 feet of new road
Infrastructure	Remove existing south levee tide gate structure, and other structures such as culverts	Install culvert under Highway 101 to expand South Wetlands, install tide gate structures in setback levees for Strawberry Creek, North Slough, and north side levee ditch
Agricultural Land	No demolition actions to agricultural lands	Approximately 6.5 acres of agricultural land will be lost to new setback levee construction, approximately 325.0 acres of agricultural land will potentially be affected by the restoration

9.8 Planning-level Cost Estimates

Tables 9-13 through 9-18 summarize the planning-level cost estimates for Alternatives A1, A2, A3, A4, A6, and A7. Costs are based on the major demolition and construction elements identified for each conceptual design alternative, including levee removal and construction, lowering of the barrier beach and storm berm, grade control removal, road removal and construction, and new culverts and tide gates. Cut and fill quantities for the estuary are based on assuming the estuary will be restored to near its historical configuration. The total cost assumes unit construction costs with a 30 percent contingency, and includes a 40 percent design, engineering and permit cost. Total costs do not include land acquisition or conservation easement costs.

Table 9-13. Planning level cost estimate for Alternative A1.

Component	Element	Unit	Quantity	Unit Cost	Sub Total
Estuary	Cut	cy	554,677	$10	$5,547,000
	Fill	cy	116,537	$10	$1,165,000
	Net Offhaul	cy	438,140	$10	$4,381,000
Demolition	Levee	cy	158,479	$10	$1,585,000
	Grade Control	cy	25,138	$30	$754,000
	Road	ft	4,223	$30	$127,000
Construction	Levee	cy	111,913	$20	$2,238,000
	Road	ft	1,416	$50	$71,000
	Culvert/Tide Gate	no.	4	$100,000	$400,000
				Construction Costs =	$16,268,000
				Contingency (30%) =	$4,880,000
				Design/Engineering/Permitting (40%) =	$6,507,000
				Total Cost =	**$27,655,000**

Table 9-14. Planning level cost estimate for Alternative A2.

Component	Element	Unit	Quantity	Unit Cost	Sub Total
Estuary	Cut	cy	554,677	$10	$5,547,000
	Fill	cy	116,537	$10	$1,165,000
	Net Offhaul	cy	438,140	$10	$4,381,000
Demolition	Levee	cy	177,733	$10	$1,777,000
	Grade Control	cy	25,138	$30	$754,000
	Road	ft	4,223	$30	$127,000
Construction	Levee	cy	121,895	$20	$2,438,000
	Road	ft	1,416	$50	$71,000
	Culvert/Tide Gate	no.	5	$100,000	$500,000
				Construction Costs =	$16,760,000
				Contingency (30%) =	$5,028,000
				Design/Engineering/Permitting (40%) =	$6,704,000
				Total Cost =	**$28,492,000**

Table 9-15. Planning level cost estimate for Alternative A3.

Component	Element	Unit	Quantity	Unit Cost	Sub Total
Estuary	Cut	cy	317,747	$10	$3,177,000
	Fill	cy	25,753	$10	$258,000
	Net Offhaul	cy	291,995	$10	$2,920,000
Demolition	Levee	cy	140,469	$10	$1,405,000
	Grade Control	cy	25,138	$30	$754,000
	Road	ft	3,749	$30	$112,000
Construction	Levee	cy	94,658	$20	$1,893,000
	Road	ft	1,416	$50	$71,000
	Culvert/Tide Gate	no.	4	$100,000	$400,000
				Construction Costs =	$10,990,000
				Contingency (30%) =	$3,297,000
				Design/Engineering/Permitting (40%) =	$4,396,000
				Total Cost =	**$18,683,000**

Table 9-16. Planning level cost estimate for Alternative A4.

Component	Element	Unit	Quantity	Unit Cost	Sub Total
Estuary	Cut	cy	554,677	$10	$5,547,000
	Fill	cy	116,537	$10	$1,165,000
	Net Offhaul	cy	438,140	$10	$4,381,000
Demolition	Levee	cy	152,406	$10	$1,524,000
	Grade Control	cy	25,138	$30	$754,000
	Road	ft	4,223	$30	$127,000
Construction	Levee	cy	105,189	$20	$2,104,000
	Road	ft	1,416	$50	$71,000
	Culvert/Tide Gate	no.	5	$100,000	$500,000
				Construction Costs =	$16,173,000
				Contingency (30%) =	$4,852,000
				Design/Engineering/Permitting (40%) =	$6,469,000
				Total Cost =	**$27,494,000**

Table 9-17. Planning level cost estimate for Alternative A6.

Component	Element	Unit	Quantity	Unit Cost	Sub Total
Estuary	Cut	cy	584,677	$10	$5,847,000
	Fill	cy	116,537	$10	$1,165,000
	Net Offhaul	cy	468,140	$10	$4,681,000
Demolition	Levee	cy	286,299	$10	$2,863,000
	Grade Control	cy	25,138	$30	$754,000
	Road	ft	4,930	$30	$148,000
Construction	Levee	cy	163,544	$20	$3,271,000
	Road	ft	1,550	$50	$78,000
	Culvert/Tide Gate	no.	6	$100,000	$600,000
				Construction Costs =	$19,407,000
				Contingency (30%) =	$5,822,000
				Design/Engineering/Permitting (40%) =	$7,763,000
				Total Cost =	**$32,992,000**

Table 9-18. Planning level cost estimate for Alternative A7.

Component	Element	Unit	Quantity	Unit Cost	Sub Total
Estuary	Cut	cy	604,677	$10	$6,047,000
	Fill	cy	116,537	$10	$1,165,000
	Net Offhaul	cy	488,140	$10	$4,881,000
Demolition	Levee	cy	446,377	$10	$4,464,000
	Grade Control	cy	25,138	$30	$754,000
	Road	ft	10,198	$30	$306,000
Construction	Levee	cy	128,605	$20	$2,572,000
	Road	ft	1,642	$50	$82,000
	Culvert/Tide Gate	no.	4	$100,000	$400,000
				Construction Costs =	$20,671,000
				Contingency (30%) =	$6,201,000
				Design/Engineering/Permitting (40%) =	$8,268,000
				Total Cost =	**$35,140,000**

9.9 Persistence and Resilience

One question to answer during the future comprehensive design process is, "What evidence is there that a particular restoration design is persistent and resilient?" In this context, "resilient" is defined as being able to maintain its function and integrity when exposed to a stressor, and "persistent" is defined as maintaining resilience over a long period of time. Intrinsically related to resilience is the concept of vulnerability. Restoration design can aim to enhance the physical or biological attributes or processes that reduce an ecosystem's vulnerability to stressors.

To address this key question, it will be necessary to design a project that draws upon the historical estuary and channel characteristics observed in historical pre-levee photographs and other physical data (e.g., longitudinal profiles, cross-sections, sediment deposition patterns), which proved to be persistent and resilient prior to construction of the Flood Control Project. Evidence that the historical estuary configuration was persistent and resilient can be seen in the historical photographs that show an estuary and slough network that was in roughly the same configuration year after year starting with the earliest known photos from the early 1900s, and consistent with older Tribal histories. In addition, hydraulic, hydrodynamic, and sediment transport models should be utilized to predict channel and estuarine response and conditions to different designs over a range of flow, sediment, and coastal input scenarios.

9.10 Approaches for Modifying a Federal Flood Control Project

The federal programs and processes for modifying a federal flood control project are complex and challenging, with limited success stories. Corps of Engineers (1982) contains the general policy on federal project modifications. One pathway is for the Army Corps of Engineers to perform a study to determine if a project is feasible and justified, and if the results are positive then the Corps of Engineers can administer a federal funding share and provide oversight for project implementation. This pathway depends on receiving Congressional authorization and appropriation, first for the study phase and then for the construction phase. An alternative pathway (Section 408 modification, described below) is for a non-federal entity to lead the project with the Corps of Engineers serving in a review and approval role.

Staff from the Army Corps of Engineers, San Francisco District identified the following potential approaches for modifying the Redwood Creek Flood Control Project:

<u>General Investigation Study</u>
This approach has the most flexibility, covers all possible objectives and solutions, and has no mandatory funding limits. This approach would enable the option of revising the intended performance level (standard project flood) and area protected by the Flood Control Project. However this approach requires the longest lead time and the highest level of approval (by Congress) and is very difficult to initiate. The Corps of Engineers is currently authorized to conduct a study for Redwood Creek to determine the feasibility of carrying out a project for flood damage reduction and ecosystem restoration and restoring or rehabilitating the levee system (Public Law 110-114, Section 4021, Water Resources Development Act of 2007). Funding for a new authorized study by the Corps of Engineers has been in the County's federal platform for the last several years, but an appropriation for the study has not been forthcoming.

For this approach it would be very important to include both flood risk reduction benefits and ecological benefits to ensure that the overall Benefit/Cost ratio exceeds the minimum threshold.

The typical study process includes a reconnaissance study, feasibility study, Chief's report, and record of decision. The reconnaissance study determines if there is federal interest in proceeding with subsequent phases. Each phase has different cost-share requirements. The timeframe for a reconnaissance study and feasibility study could be at least five years, and the timeframe for completion of a project could be at least 10 to 20 years. Two examples for this approach include a large-scale project along the west bank of the Sacramento River at Hamilton City, and levee improvements and restoration activities along the San Lorenzo River near Santa Cruz.

A General Reevaluation Report (GRR) may be required due to the identified deficiencies for the Redwood Creek Flood Control Project. The Pajaro River Project near Watsonville had a GRR completed in 2012.

<u>Study under Section 1135 of the Continuing Authorities Program (CAP)</u>
This program is limited to projects for the sole purpose of ecosystem restoration, and assumes no reduction in the intended protection level of the flood control project (Corps of Engineers, 2007). This program does not appear to be a viable option for Redwood Creek.

<u>Section 408 Modification</u>
Local sponsors of federal flood control projects can pursue modifications under United States Code Title 33, Section 408, as amended, which allows the Corps of Engineers to grant permission for the alteration of a federal project if the modification "will not be injurious to the public interest and will not impair the usefulness of such work." Local entities are 100% responsible for funding and performing all engineering studies, design, permitting, and construction. This approach is attractive if project funding is available from sources other than federal funding routed through the Corps of Engineers for water resource projects.

Corps of Engineers staff were not able to conclude whether or not this approach was possible for the Redwood Creek Flood Control Project due to the Project's performance deficiencies. Further consultation with the Corps of Engineers is needed to determine the viability of this approach.

<u>Design Deficiency Study</u>
Federal policies (Corps of Engineers, 1982 and 2007) create criteria for establishing the existence of a design deficiency. A design deficiency report for the Santa Maria Levee Project near Santa Barbara was completed in 2008. According to Corps of Engineers (2007), the costs for corrections would need to be cost-shared with the local sponsor. In addition, any corrective action work is likely limited to addressing the deficiencies and re-establishing the design performance level. Pursuing a design deficiency study for Redwood Creek would not necessarily address the estuary restoration needs.

<u>Update the Operations and Maintenance Manual</u>
This action is not relevant as it would address neither the levee performance deficiencies nor the estuary restoration needs.

<u>Special Legislation</u>
Congress could pass special legislation addressing the performance level and allowing modification. Corps of Engineers staff indicated that this route is untested, but could be attractive to Congress because it does not commit the federal government to spend additional funds and could be considered a reduction in the portfolio of federal projects. Congressman Huffman, who represents the California Second District, and his predecessor (Mike Thompson) are very supportive of finding a solution for the Redwood Creek Flood Control Project.

Three hypothetical options for special legislation were identified:

- Option 1 – Change the protection level and area of protection for the Flood Control Project and authorize modifications to achieve ecological benefits, with the entire levee system remaining a federal flood control project.
- Option 2 – Allow the changes and modifications in Option 1, but specified downstream portions of the levee system would be de-authorized and no longer considered part of the federal flood control project.
- Option 3 – De-authorize the entire levee system so it would no longer be a federal flood control project; the federal government would extinguish its involvement and the levee system would solely be a County responsibility.

9.11 Environmental Permitting and Compliance

Permitting and compliance will require an extensive process due to the scale and complexity of the project. Anticipated permitting and compliance requirements are listed on Table 9-19. An Environmental Impact Report (EIR) and Environmental Impact Statement (EIS) will be required for compliance with the California Environmental Quality Act (CEQA) and National Environmental Policy Act (NEPA), respectively. The EIR and EIS will need to consider formal alternatives to a proposed project, and feasible opportunities to avoid or reduce impacts will need to be implemented as appropriate. For coastal development permitting, the project area will likely include both state and local jurisdiction. This multi-jurisdiction situation is typically addressed by obtaining a consolidated coastal development permit through the California Coastal Commission. The project will need to be consistent with the California Coastal Act and the North Coast Area Plan of the Humboldt County Local Coastal Program (Humboldt County, 1981), which includes policies for hazards, agriculture, resource protection, environmentally sensitive habitat areas, and other issues. The permitting and compliance process will likely require four to six years.

Table 9-19. Anticipated environmental permitting and compliance requirements.

Law/Regulation	Permit/Approval	Authority
CEQA	Environmental Impact Report (completed with Notice of Determination)	Humboldt County
NEPA	Environmental Impact Statement (completed with Record of Decision)	National Park Service and/or U.S. Army Corps of Engineers
California Coastal Act	Coastal Development Permit (consolidated for state and local jurisdiction)	California Coastal Commission
Clean Water Act Section 404	Individual Permit	U.S. Army Corps of Engineers
Endangered Species Act	Biological Opinions	• National Marine Fisheries Service • U.S. Fish & Wildlife Service
Porter-Cologne / Clean Water Act Section 401	401 Certification and/or Waste Discharge Requirements (WDR)	North Coast Regional Water Quality Control Board
Fish and Game Code	Streambed Alteration Agreement	California Department of Fish and Wildlife
National Historic Preservation Act	Letter of concurrence	• State Historic Preservation Office • Tribal Historic Preservation Offices

9.12 Phased Implementation

Ultimately, work will be required on both the north and south sides of the Redwood creek estuary and Flood Control Project in order to achieve the overall project goals. In terms of implementation, work could be performed in phases, for example an initial project on either the north side or south side, and then a subsequent project on the opposite side. A phased approach to implementation could also be developed to prioritize work on the downstream end and then identify future phases further upstream.

Advantages of phased implementation include:

- Landowner agreement may occur at different times rather than concurrently. In addition, the amount of funding available may only be sufficient to perform work in phases. Phased implementation may be required as a practical matter, and would allow at least some improvements to occur as soon as possible.
- Phased implementation would provide an opportunity to observe and monitor how the system responds to changes in physical conditions, and then to adapt the design for subsequent phases based on this information.

Challenges for phased implementation include:

- The initial project phases will need to accommodate sediment transport and have longevity until the subsequent phases are implemented.
- Uncertainty regarding the footprint and scope of subsequent phases could create challenges for securing funding and completing the environmental review and permitting process.
- The pathway to modifying a federal flood control project is complex (Section 9.11) and will require Congressional action. For Redwood Creek, this action will likely need to address the Flood Control Project as a whole and will require a clearly defined and feasible phasing plan to accomplish the overall project goals.

9.13 Recommended Next Steps

This planning study identified that Alternative A1, and potentially Alternatives A2 or A4, are more likely to be feasible in terms of acceptability from the affected private landowners. The fundamental question that must be addressed is whether one of these alternatives would provide sufficient benefits to the estuary and Flood Control Project to justify the substantial investment. The following next steps are recommended to address this question:

1. Continue the dialogue with affected private landowners and the National Park Service.

2. Perform additional detailed technical studies to evaluate the effectiveness of the alternatives identified in this report. These additional studies should include:

   - Hydrodynamic modeling with spatial and temporal flow conditions that can predict circulation, salinity, and temperature patterns and mixing processes,
   - Sediment transport modeling that includes variable sediment supplies, varying spatial and temporal flow conditions, and bed morphology responses,
   - Coastal and barrier beach analysis and modeling, and
   - Fish and other species habitat evaluations.

These additional technical studies would be continually updated throughout development of the restoration alternatives to provide supporting information, address landowner needs and interests, refine agency needs and expectations, evaluate alternative goals and objectives, and evaluate design criteria.

Additional data will need to be collected to support the detailed technical studies and provide the base level conditions against which the restoration alternatives can be evaluated. These data include:

- Water surface elevation observations
- Additional topographic and bathymetric surveys
- Particle size distributions of surface and subsurface bed sediments
- Suspended sediment and bedload observations
- Water quality observations
- Site specific meteorological data
- Vegetation assessments
- Various habitat evaluations.

3. Perform additional site characterization to delineate the extent of the areas along the levee vulnerable to seepage and slope instabilities. Develop engineering plans for appropriate mitigation measures.

4. Perform more extensive consultation with the permitting agencies (Coastal Commission, NOAA-National Marine Fisheries Service, California Department of Fish and Wildlife, U.S. Army Corps of Engineers, North Coast Regional Water Quality Control Board, Humboldt County Building and Planning Department) to identify the studies and information that will be required and what requirements and conditions will apply for acquiring all the necessary permits and approvals for a proposed project.

5. Use the results of the additional technical studies and design efforts to identify a project design that is acceptable to the adjacent private landowners and National Park Service and can maximize achievement of the overall goals and objectives. <u>If agreement can be reached</u>, secure compensation and develop the appropriate legal documents for easements and/or land acquisition. Consider taking a phased approach if agreement with the adjacent landowners can be reached on one side of the creek before the other side. <u>If agreement can be reached</u>, work with Congressional and Corps of Engineers staff to develop the necessary re-authorization provisions into the appropriate federal legislation.

6. Based on the selected alternative for estuary restoration, perform additional technical studies (hydrodynamic and sediment transport modeling) and engineering design to evaluate the residual need for improvement in hydraulic capacity for the Flood Control Project. Determine the vertical and longitudinal extent of levee raising needed, if any, and incorporate this component into the overall project plans and specifications.

7. Refine the conceptual designs and advance at least one design to a 30% to 65% completion stage, to allow completion of the environmental review (NEPA and CEQA) and permitting process.

In addition, concurrent with these steps, efforts should continue to obtain a Congressional appropriation for the Corps of Engineers to initiate a General Investigation Study.

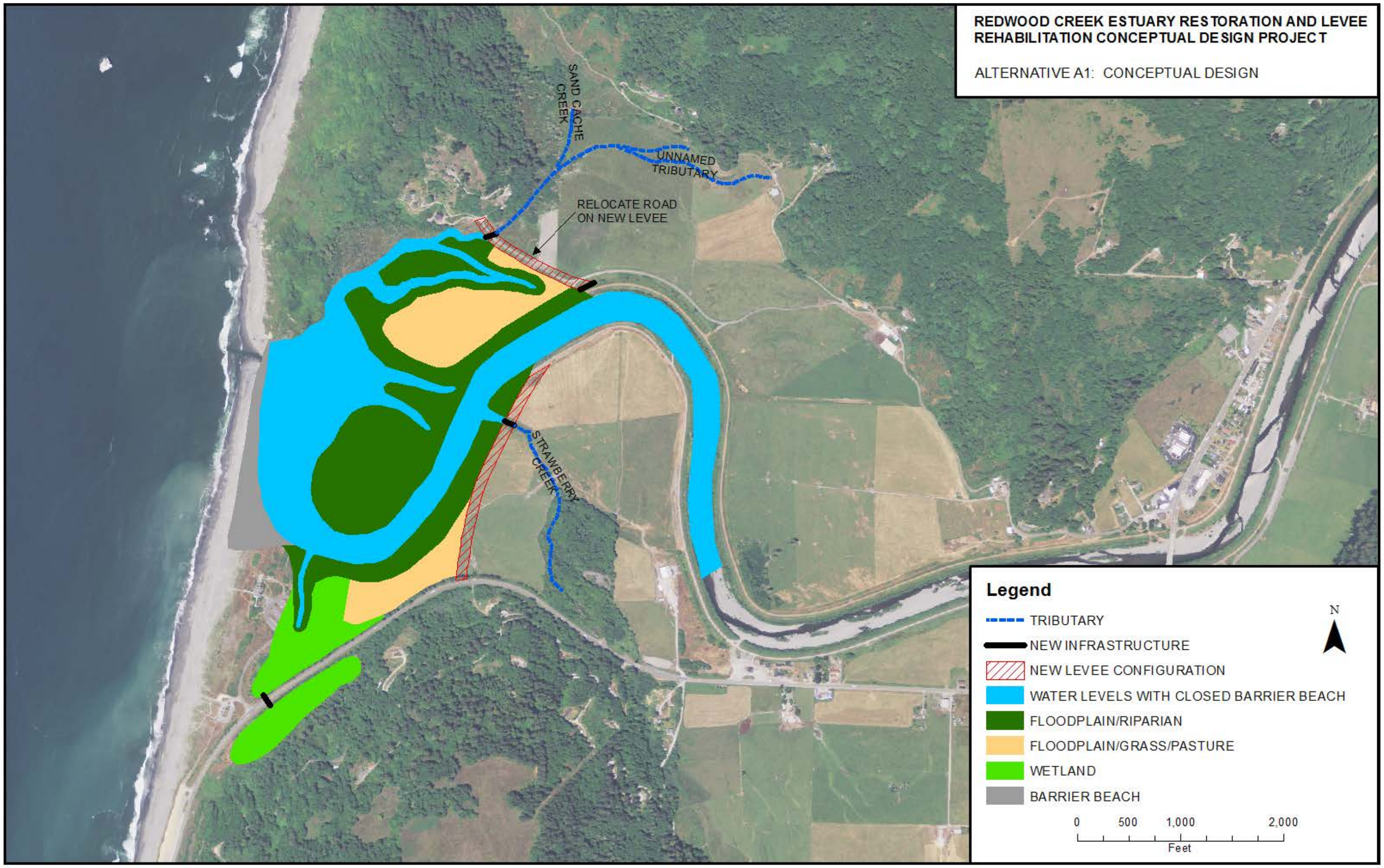


Figure 9-1. Alternative A1 conceptual design.

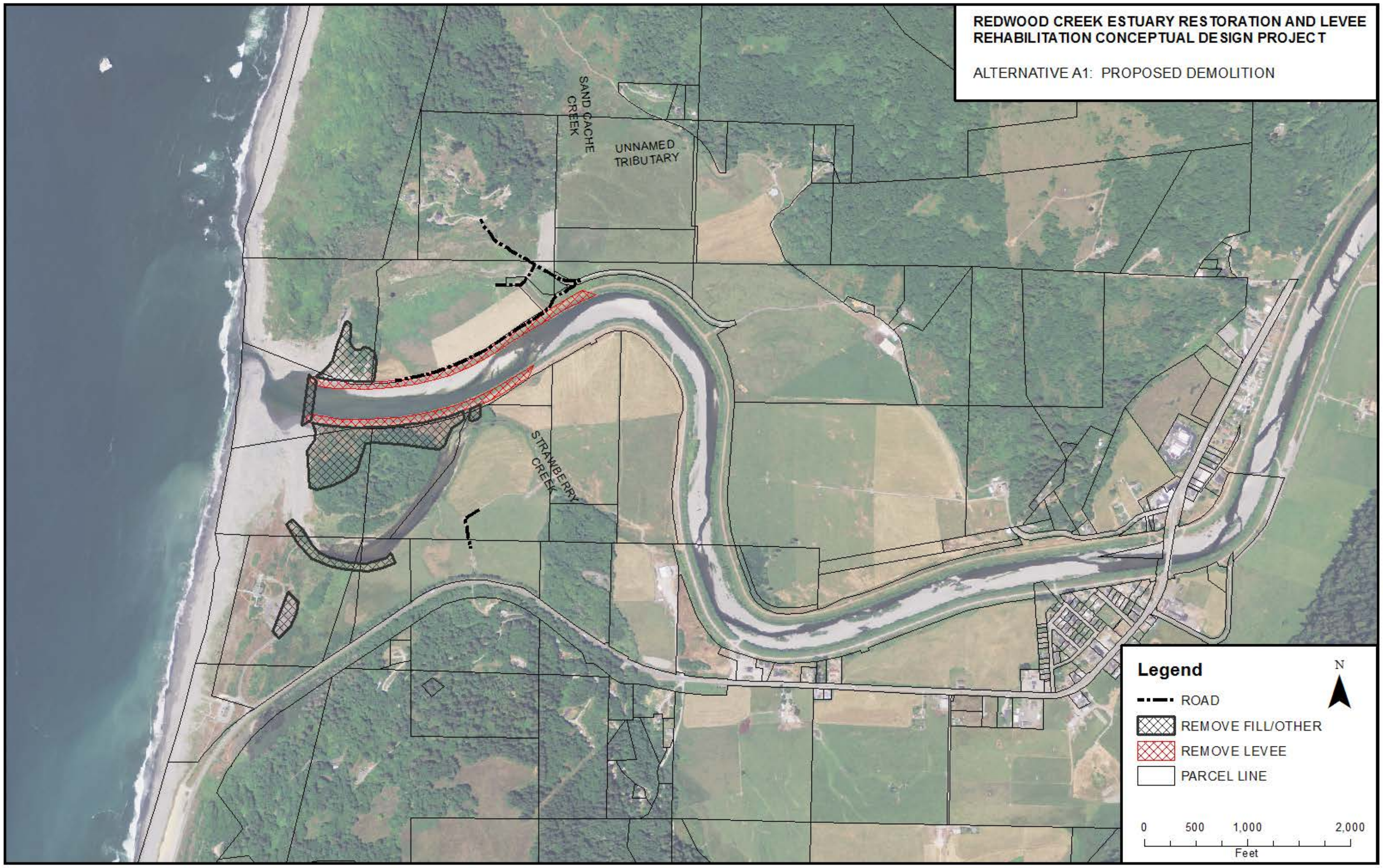


Figure 9-2. Alternative A1 proposed demolition design.

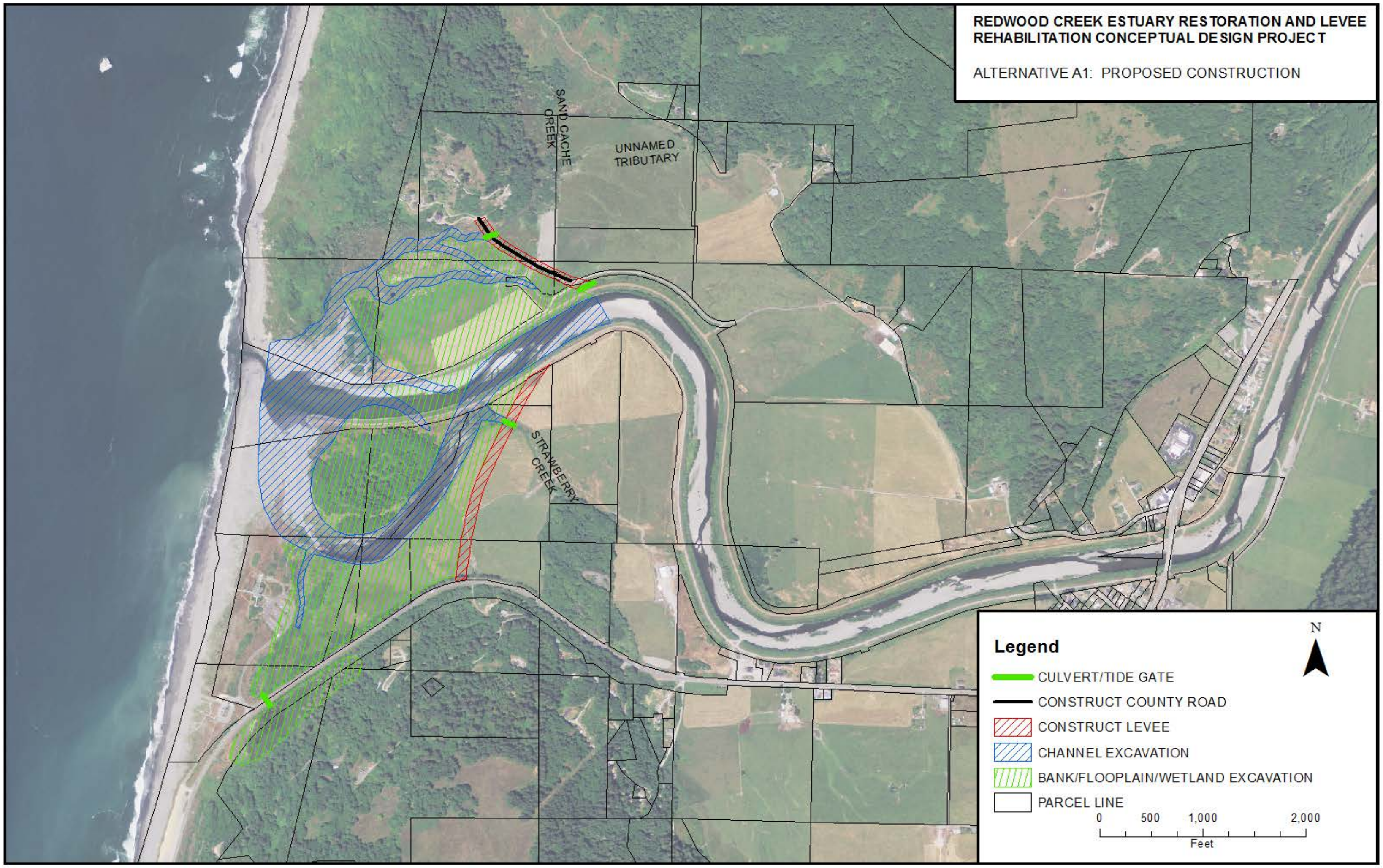


Figure 9-3. Alternative A1 proposed construction design.

Figure 9-4. Riparian and pasture restoration option on North Slough side.

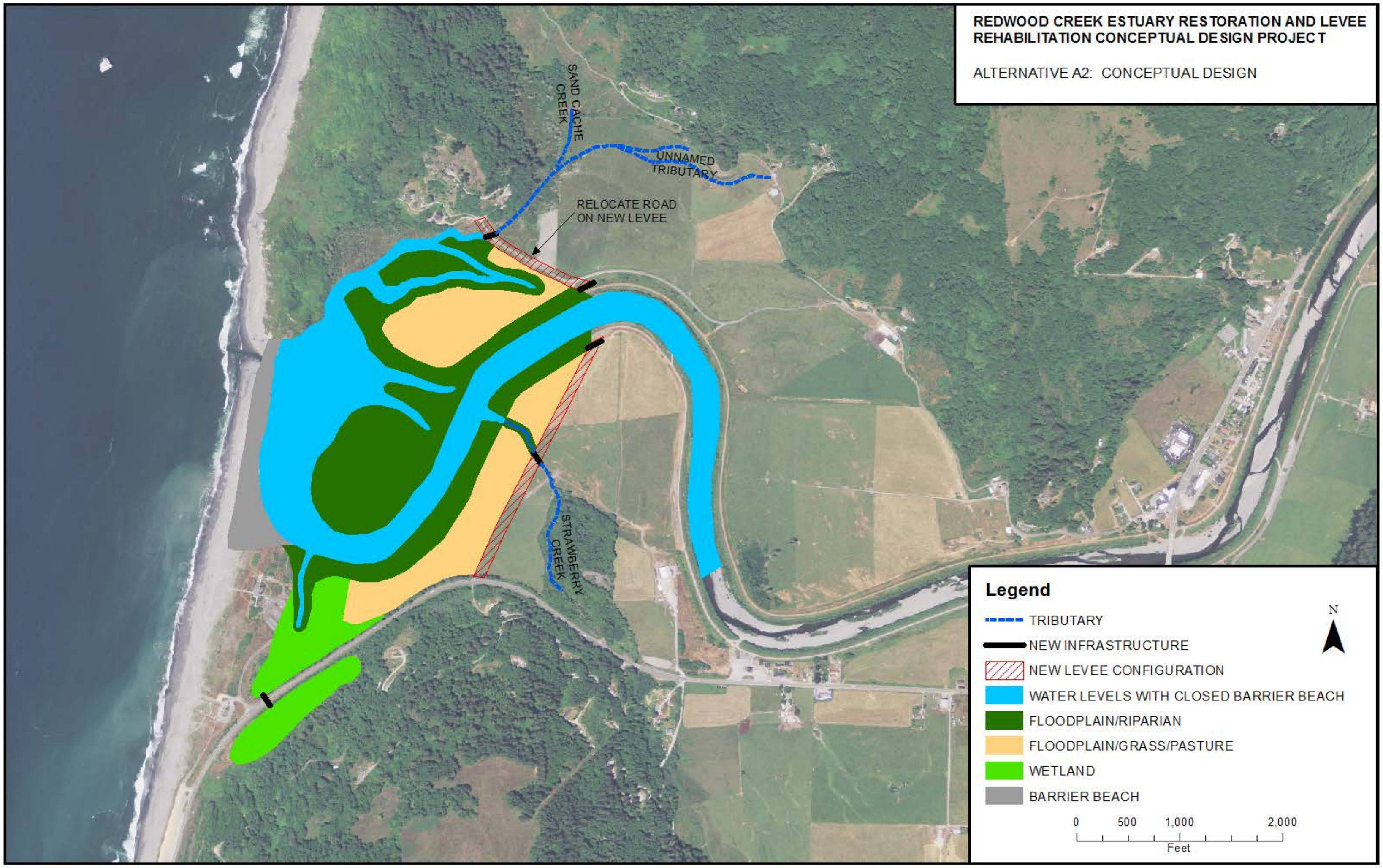


Figure 9-5. Alternative A2 conceptual design.

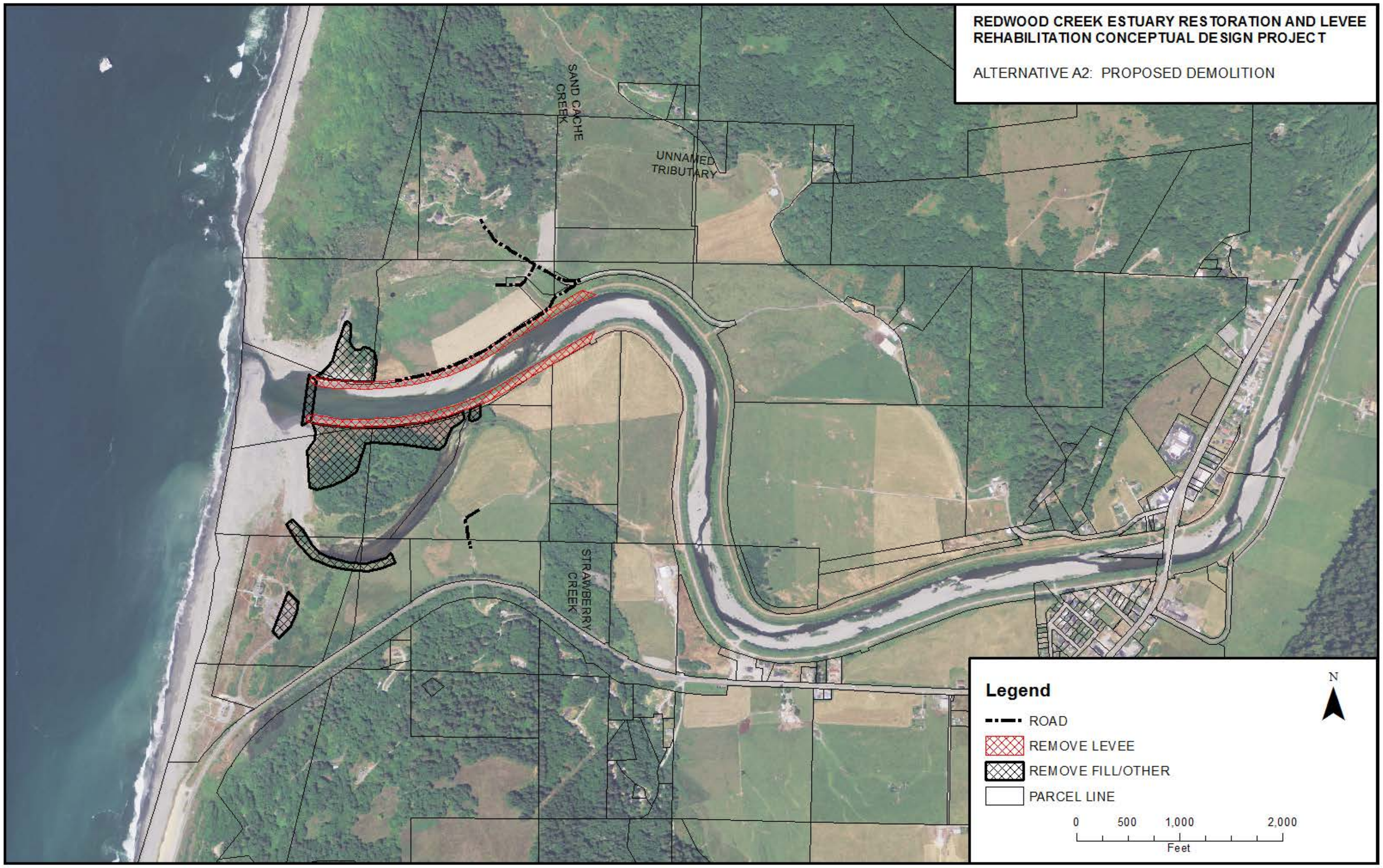


Figure 9-6. Alternative A2 proposed demolition design.

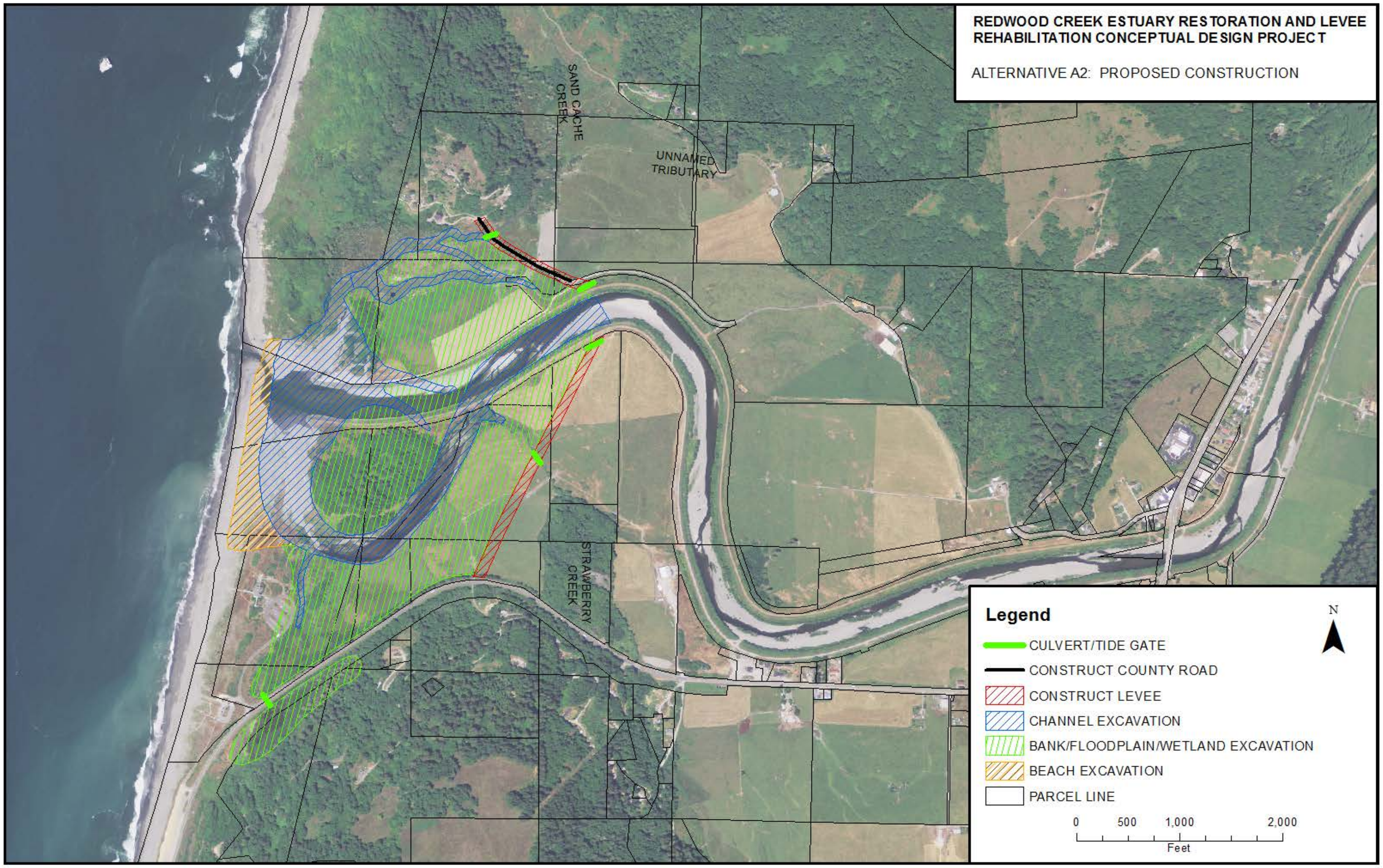


Figure 9-7. Alternative A2 proposed construction design.

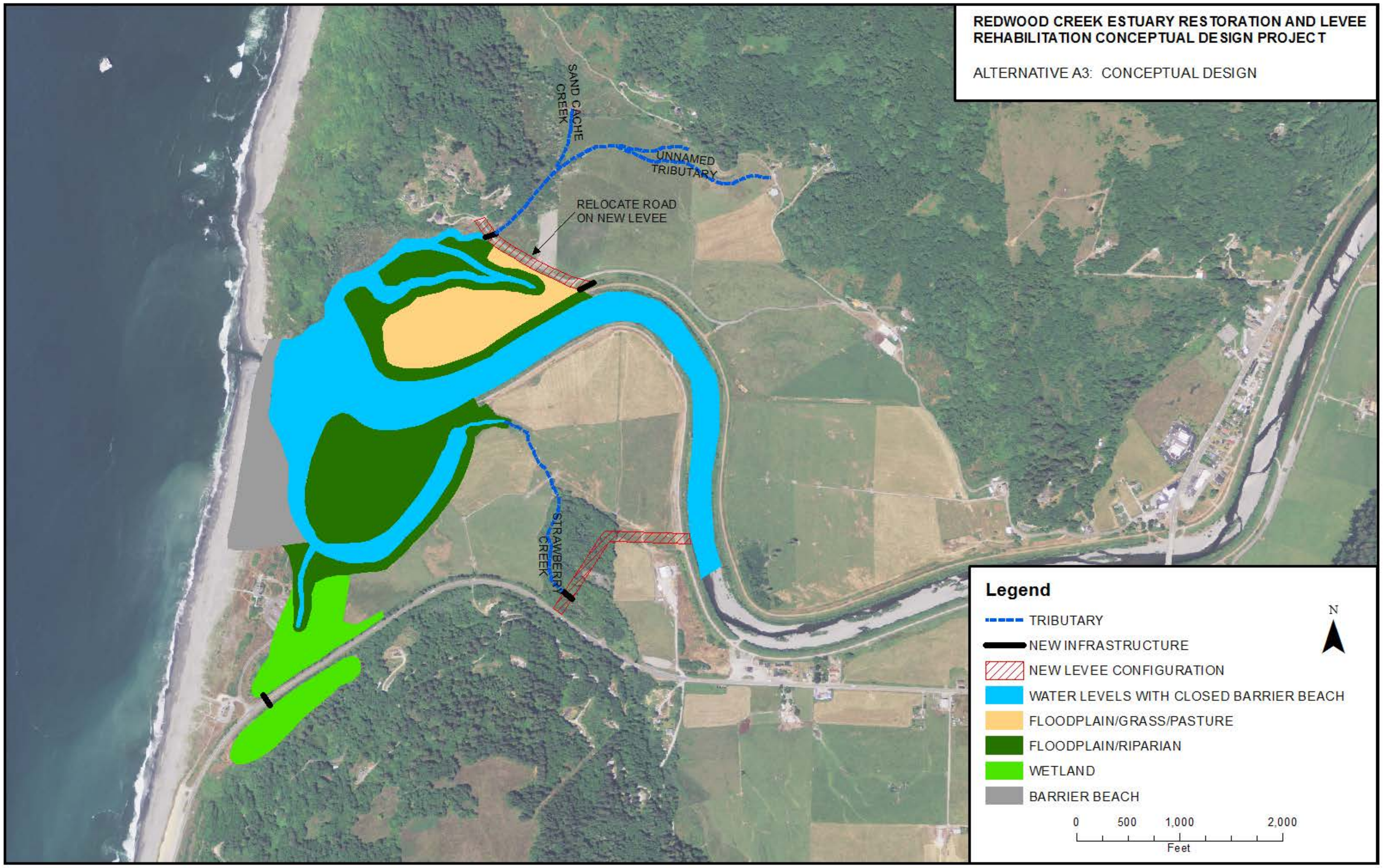


Figure 9-8. Alternative A3 conceptual design.

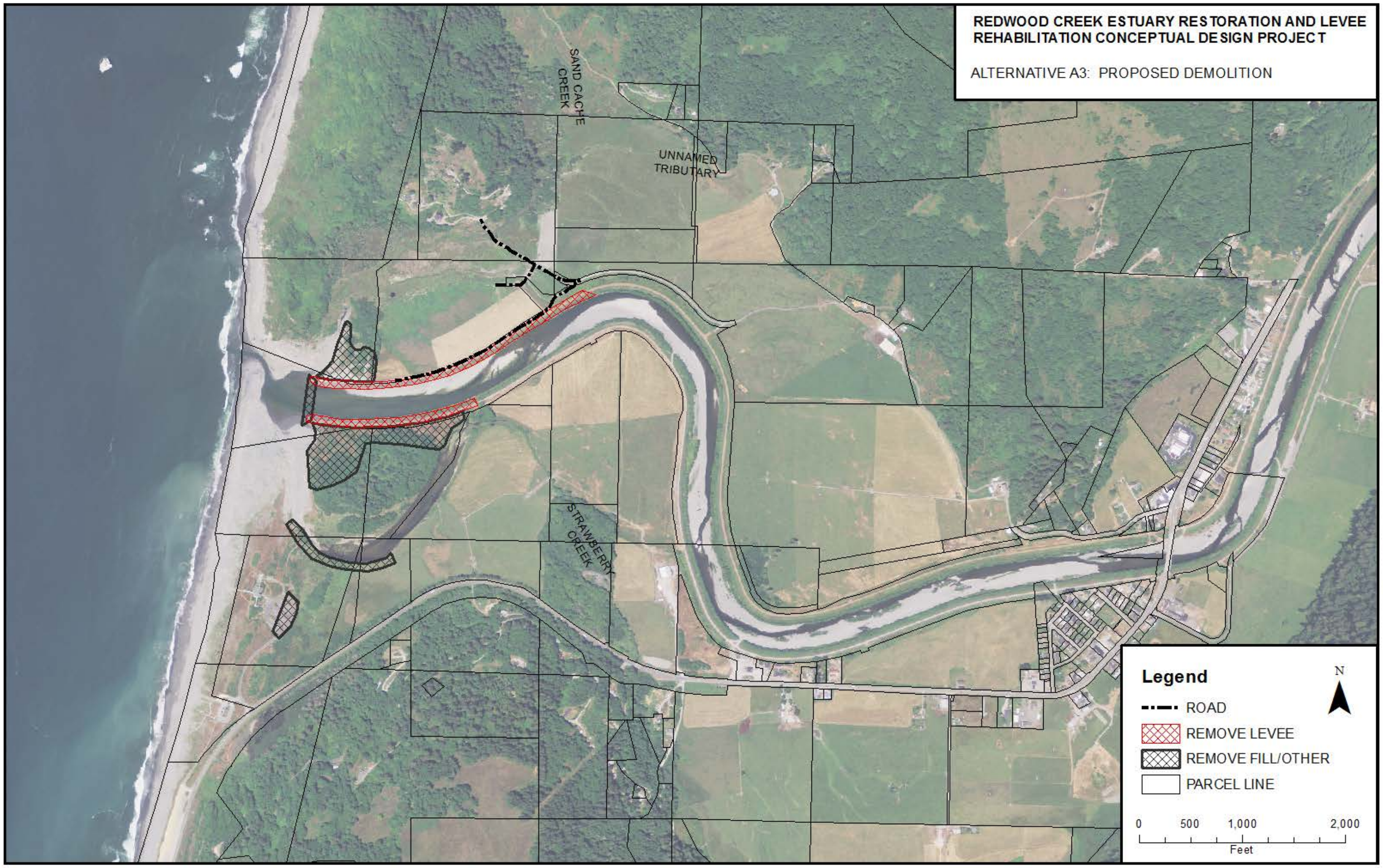


Figure 9-9. Alternative A3 proposed demolition design.

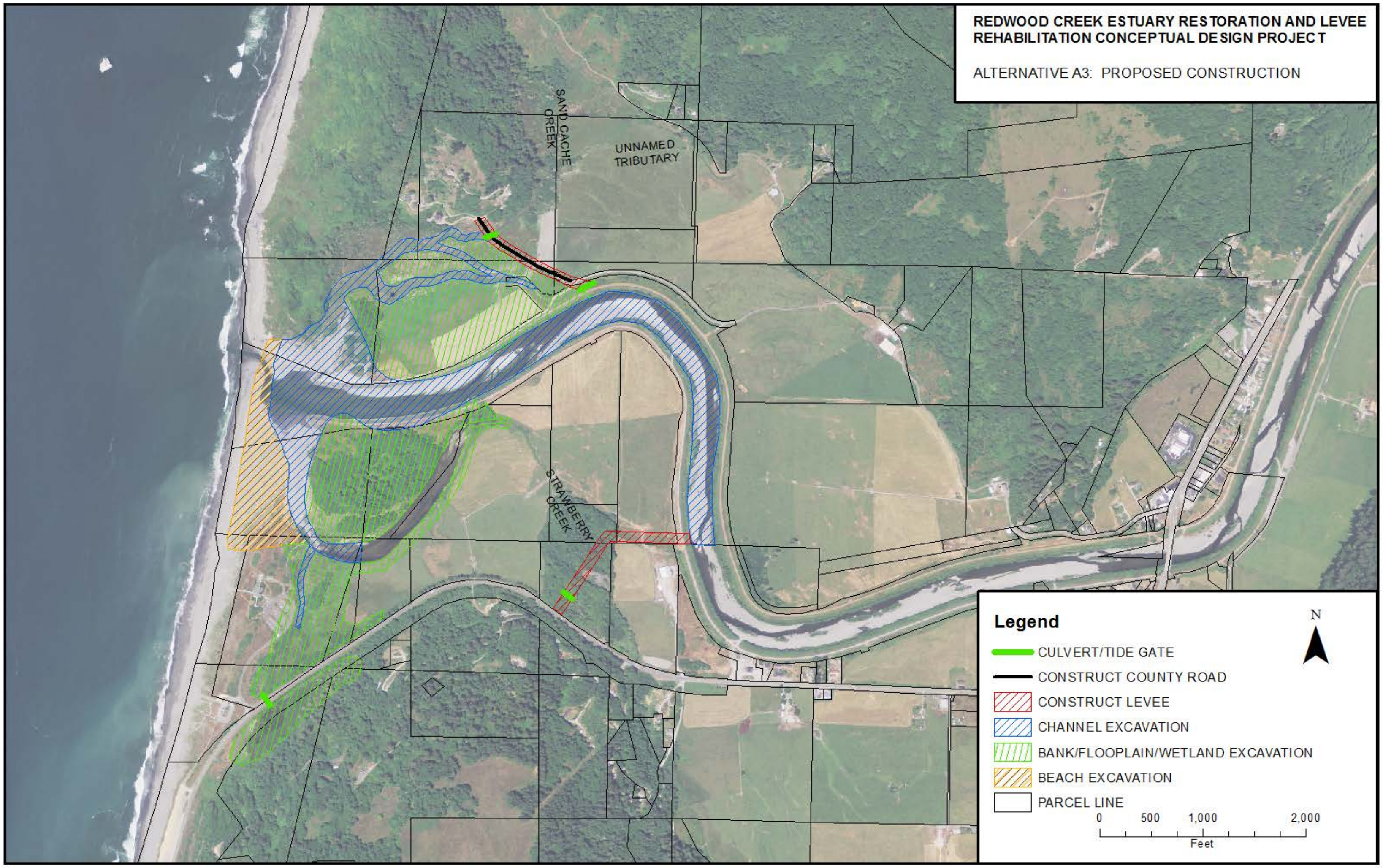


Figure 9-10. Alternative A3 proposed construction design.

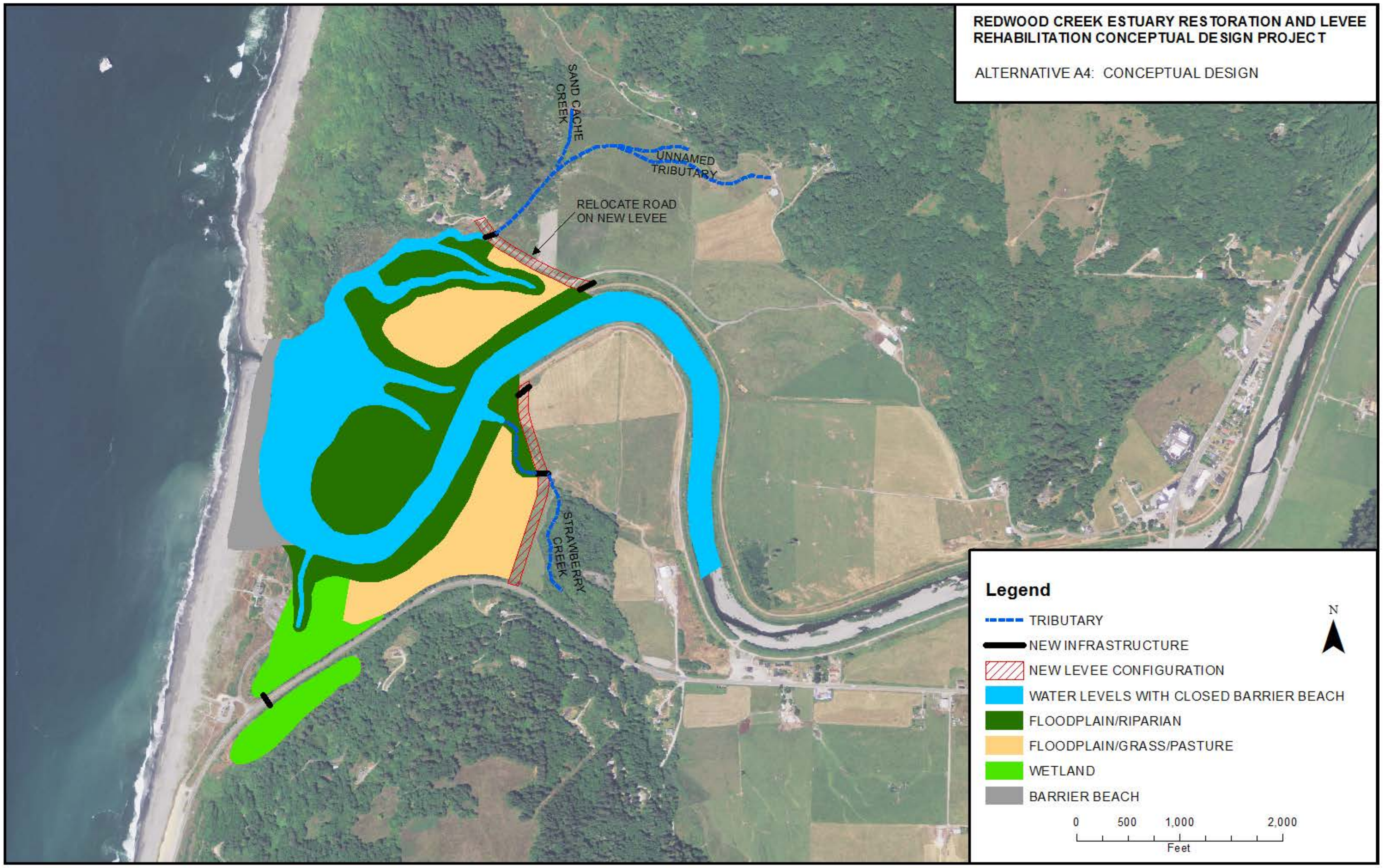


Figure 9-11. Alternative A4 conceptual design.

Figure 9-12. Alternative A5 conceptual design.

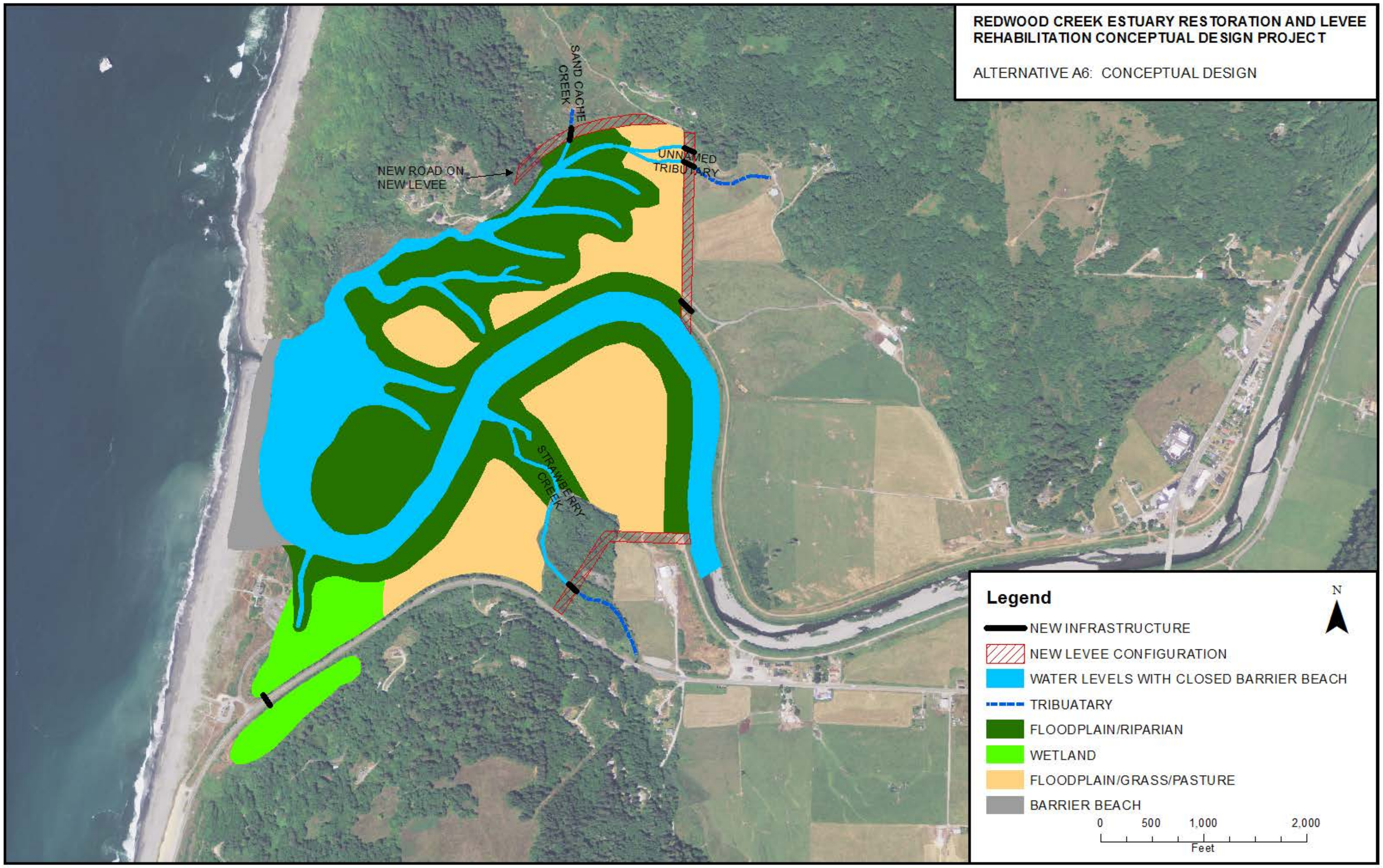


Figure 9-13. Alternative A6 conceptual design.

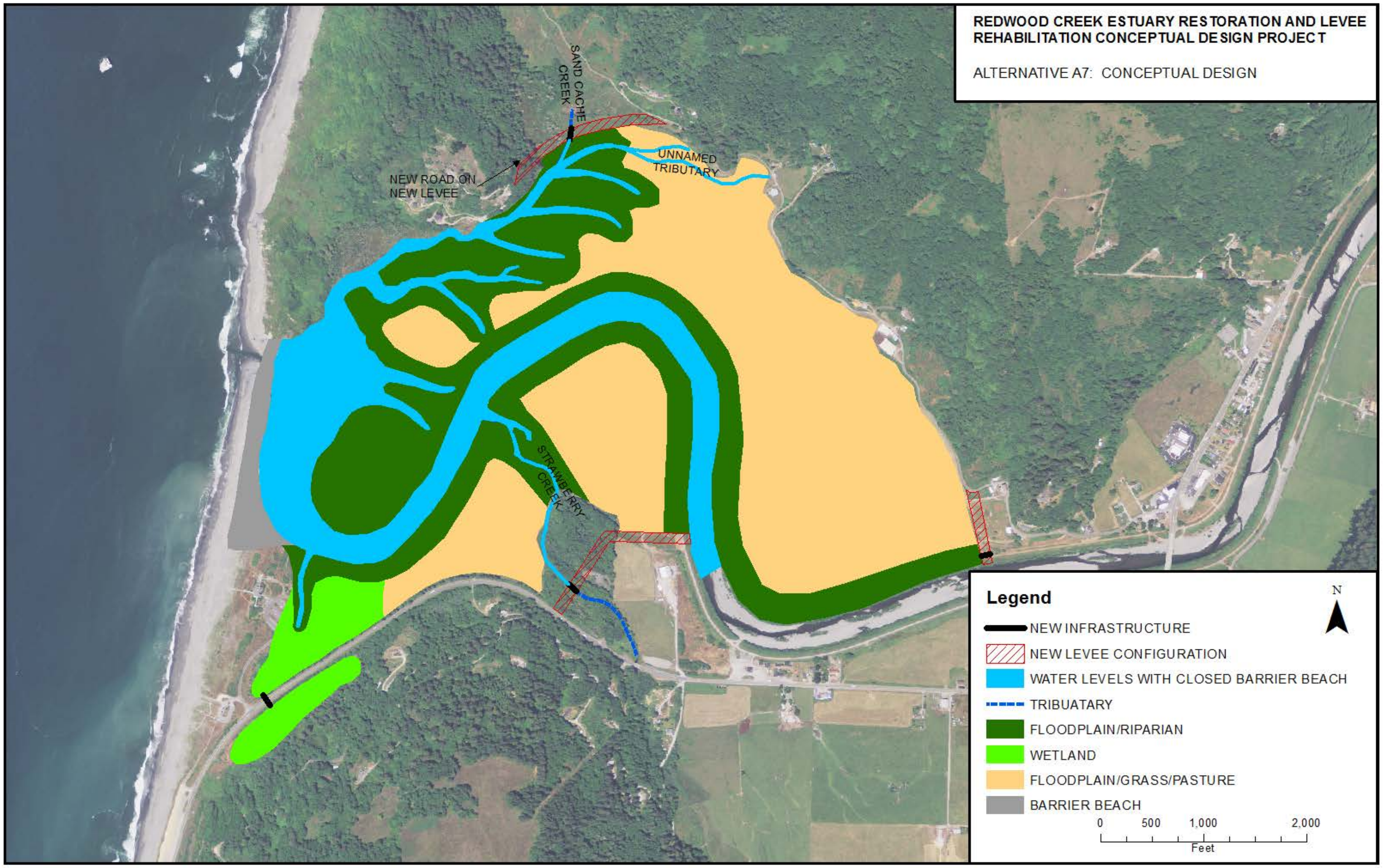


Figure 9-14. Alternative A7 conceptual design.

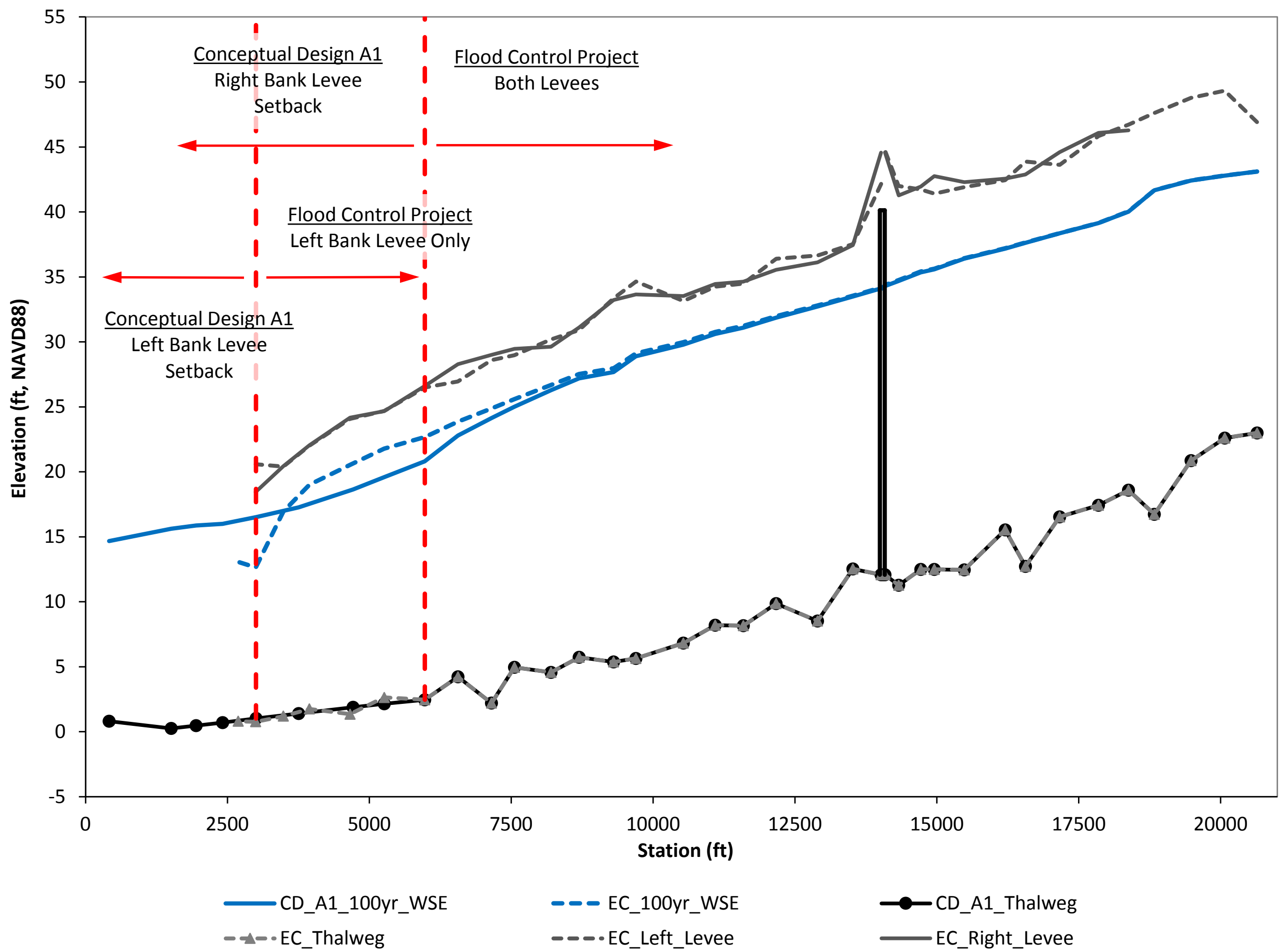


Figure 9-15. Predicted 100-yr flood profiles for existing conditions and Alternative A1. For comparison, the stationing for the existing condition was adjusted so that cross-section 3840.01 is consistent with the stationing for the Alternative A1 model at cross-section 5976.96.

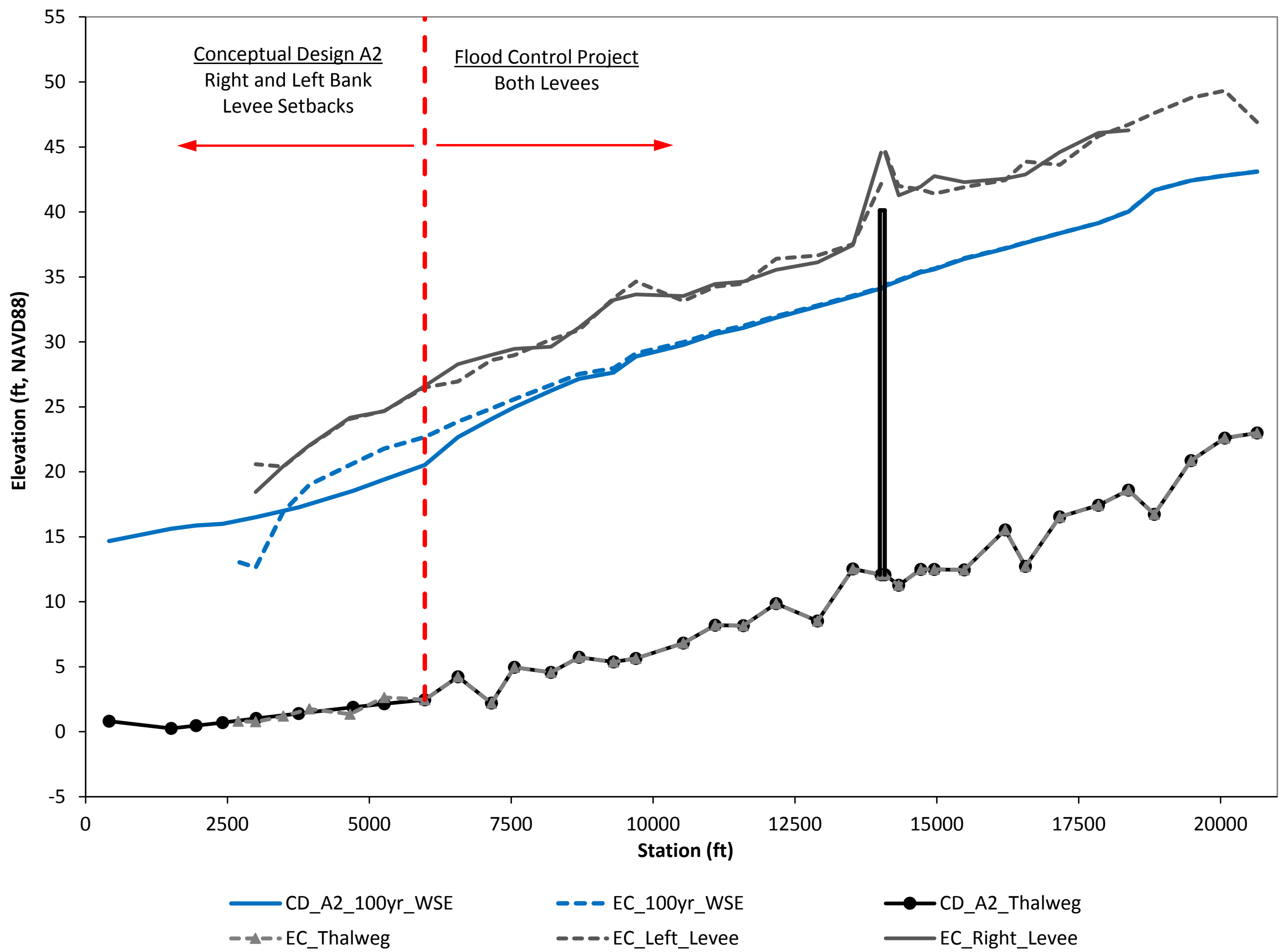


Figure 9-16. Predicted 100-yr flood profiles for existing conditions and Alternative A2. For comparison, the stationing for the existing condition was adjusted so that cross-section 3840.01 is consistent with the stationing for the Alternative A2 model at cross-section 5976.96.

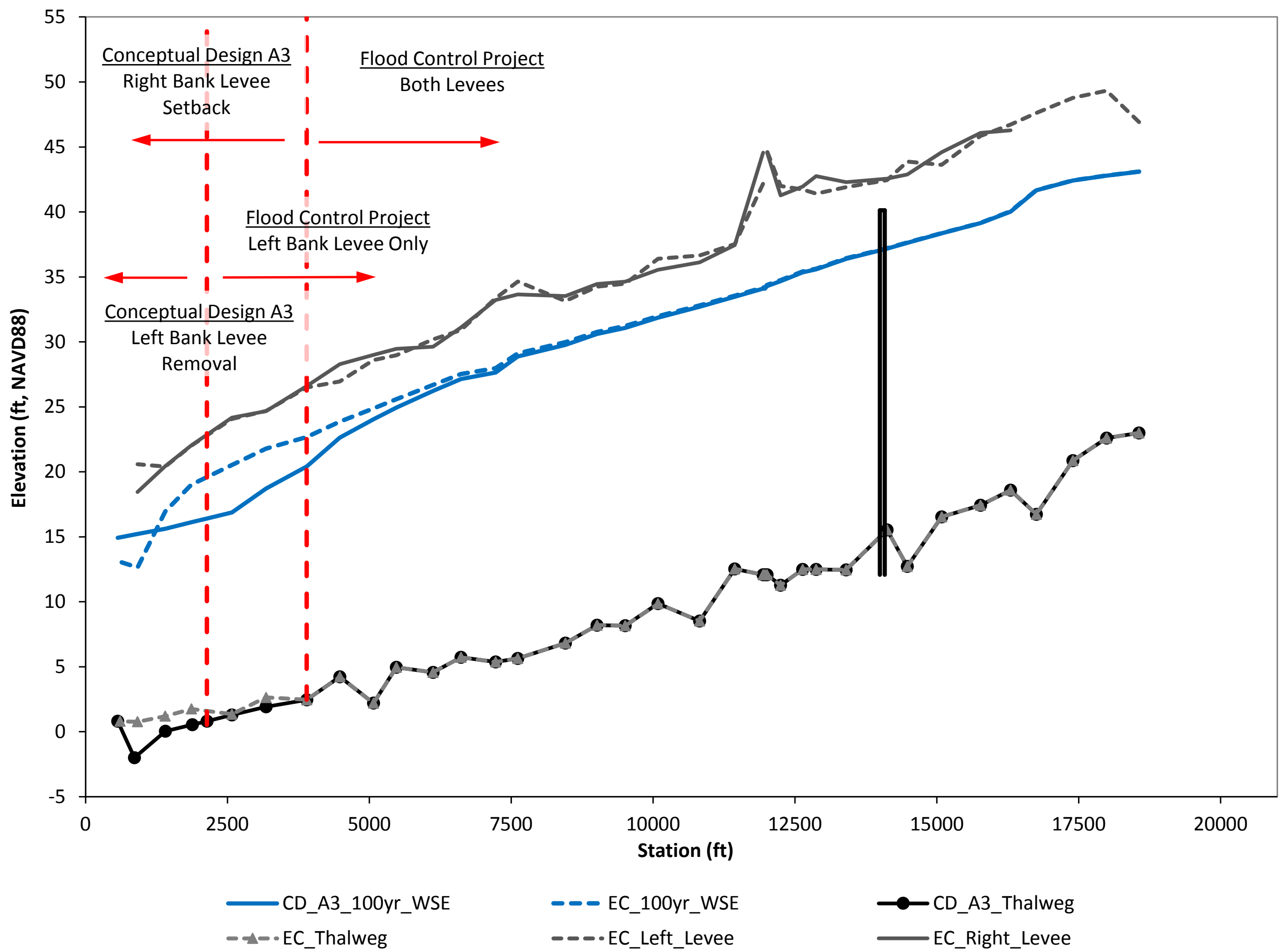


Figure 9-17. Predicted 100-yr flood profiles for existing conditions and Alternative A3. For comparison, the stationing for the existing condition was adjusted so that cross-section 3840.01 is consistent with the stationing for the Alternative A3 model at cross-section 3840.01.

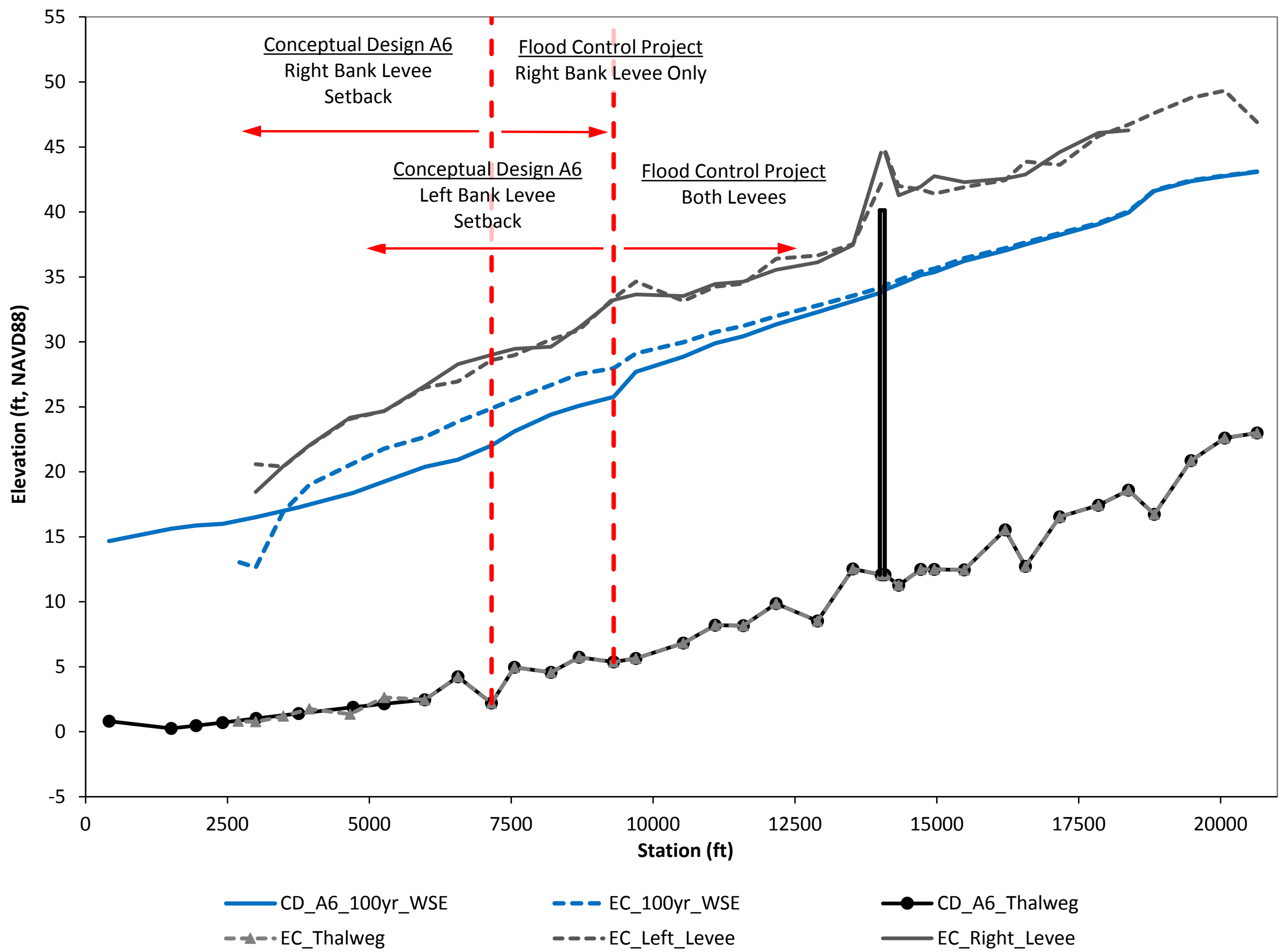


Figure 9-18. Predicted 100-yr flood profiles for existing conditions and Alternative A6. For comparison, the stationing for the existing condition was adjusted so that cross-section 3840.01 is consistent with the stationing for the Alternative A6 model at cross-section 5976.96.

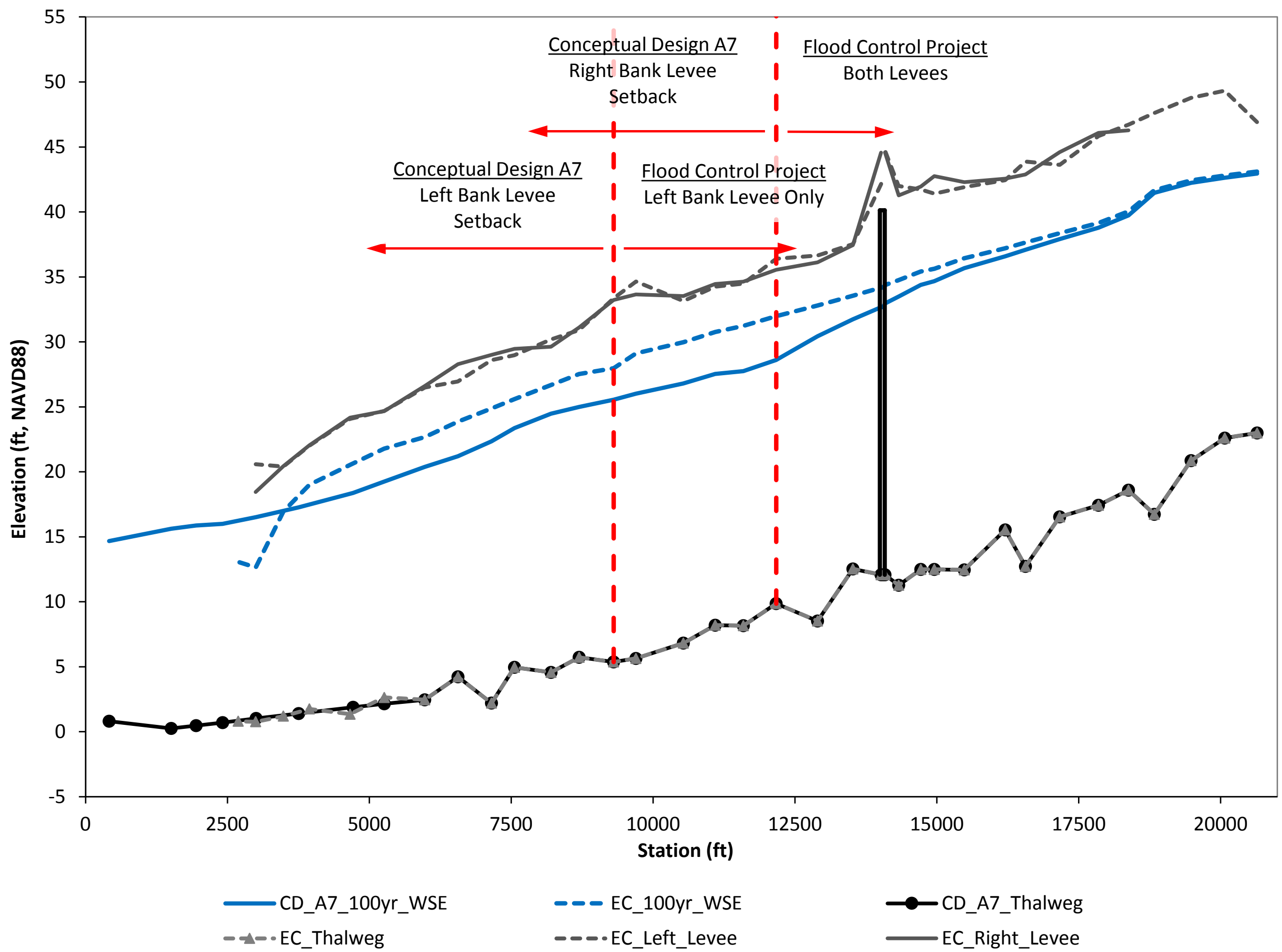
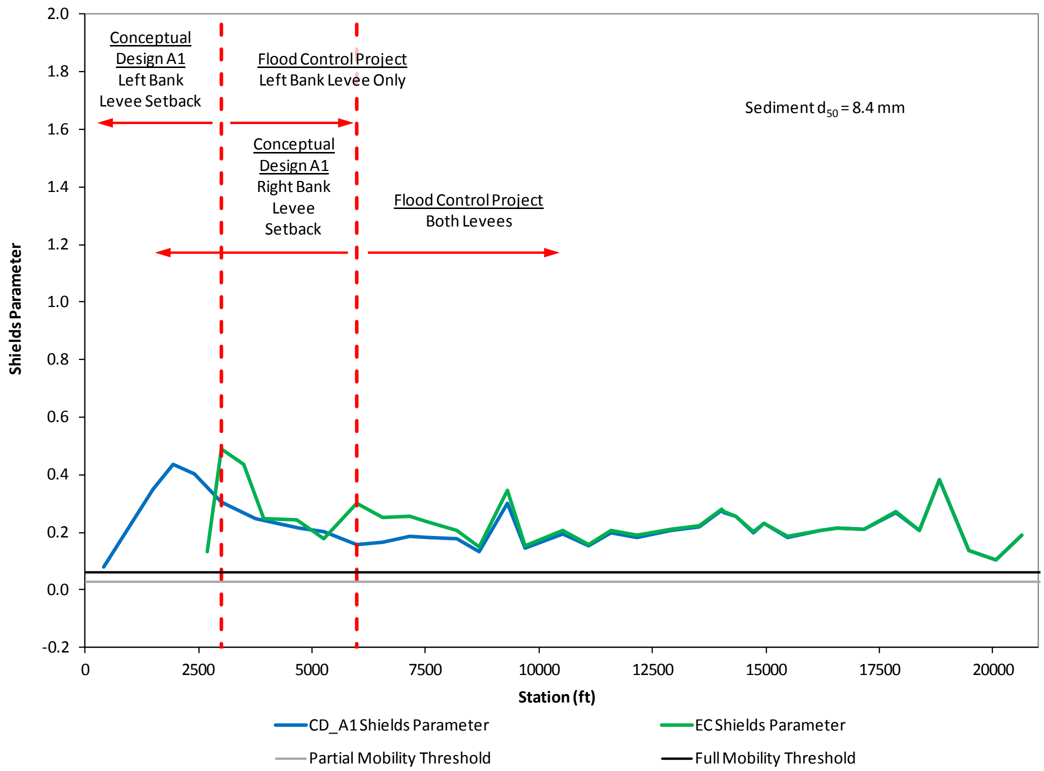


Figure 9-19. Predicted 100-yr flood profiles for existing conditions and Alternative A7. For comparison, the stationing for the existing condition was adjusted so that cross-section 3840.01 is consistent with the stationing for the Alternative A7 model at cross-section 5976.96.



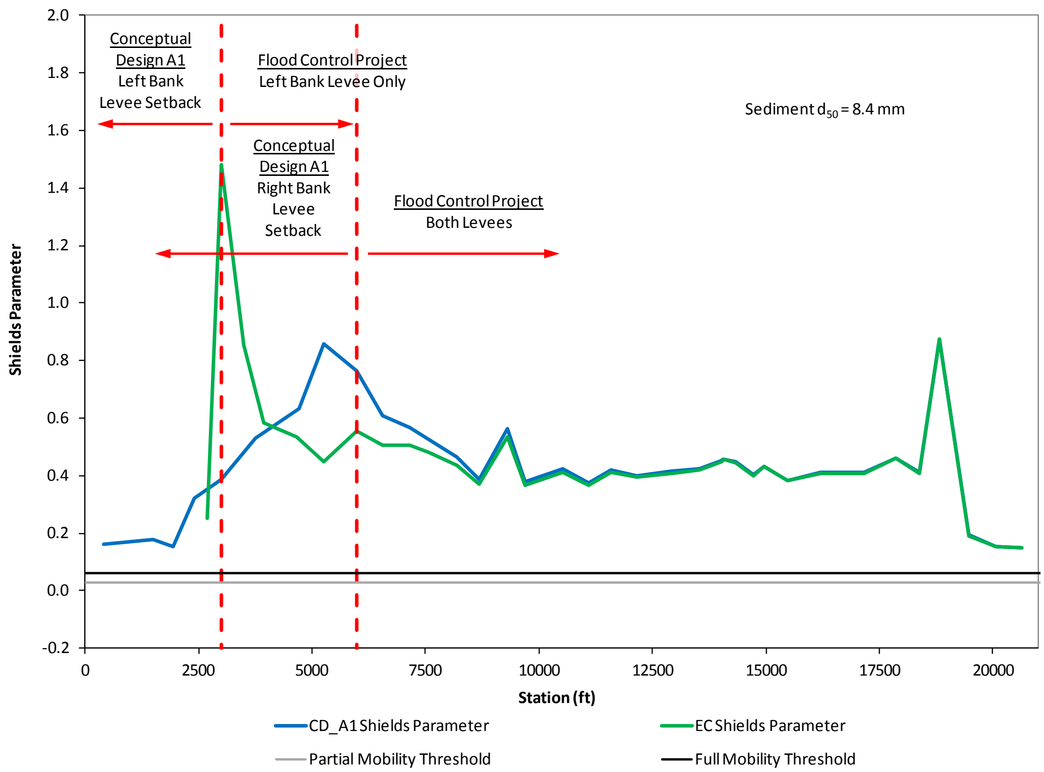


Figure 9-20. Sediment mobility results (Shields Parameter estimates) for the 1.5 (top) and 100-yr (bottom) floods for existing conditions and Alternative A1. Stationing for existing condition adjusted to be consistent with Alternative A1.

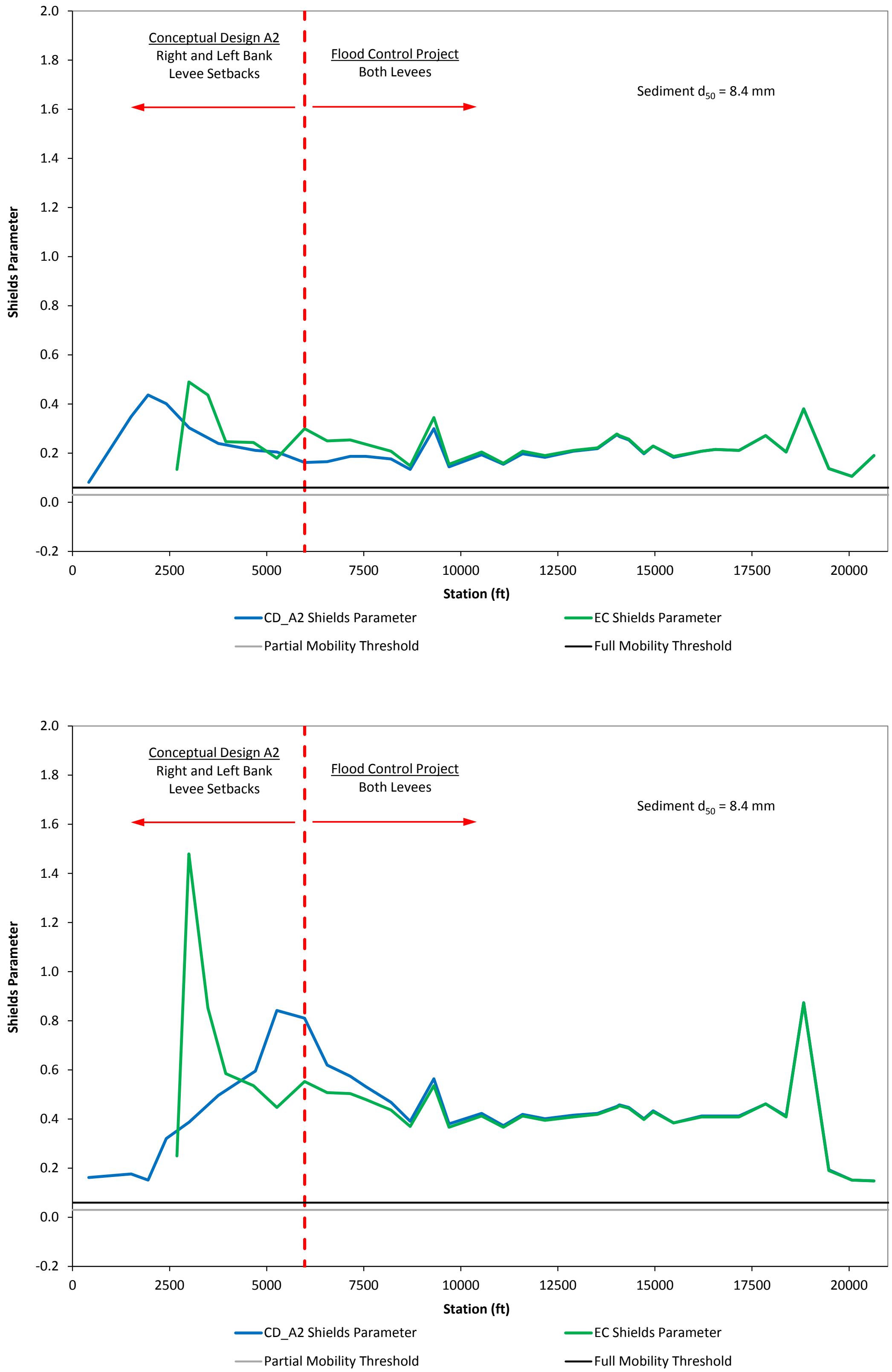
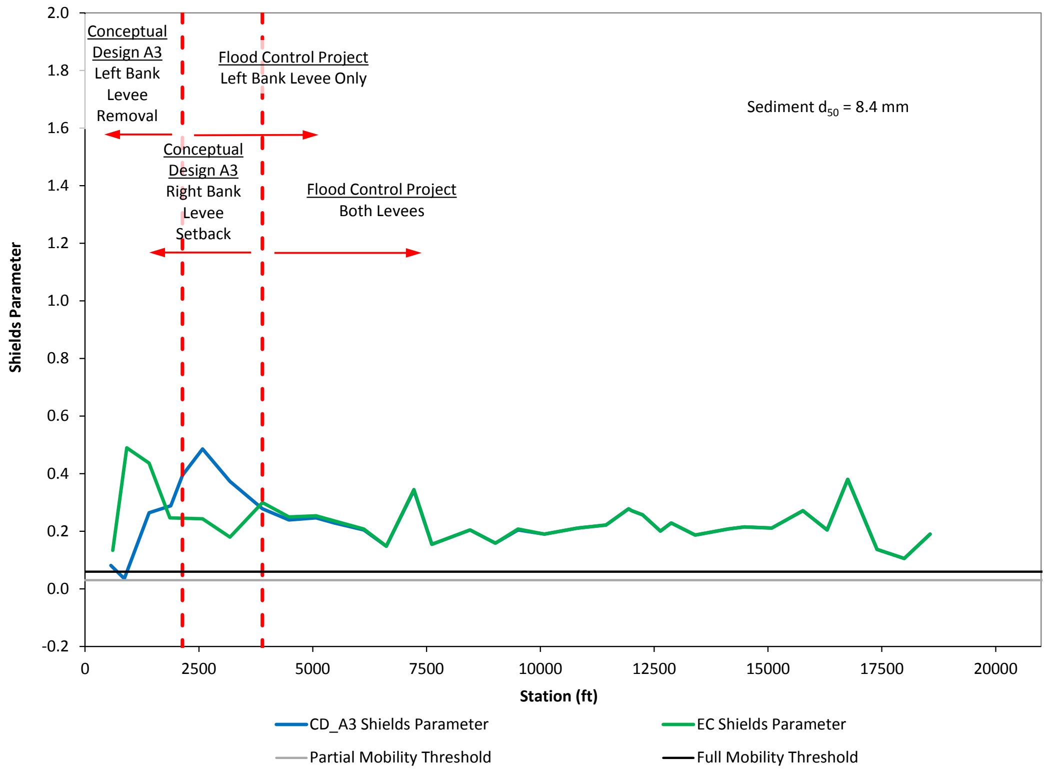


Figure 9-21. Sediment mobility results (Shields Parameter estimates) for the 1.5 (top) and 100-yr (bottom) floods for existing conditions and Alternative A2. Stationing for existing condition adjusted to be consistent with Alternative A2.



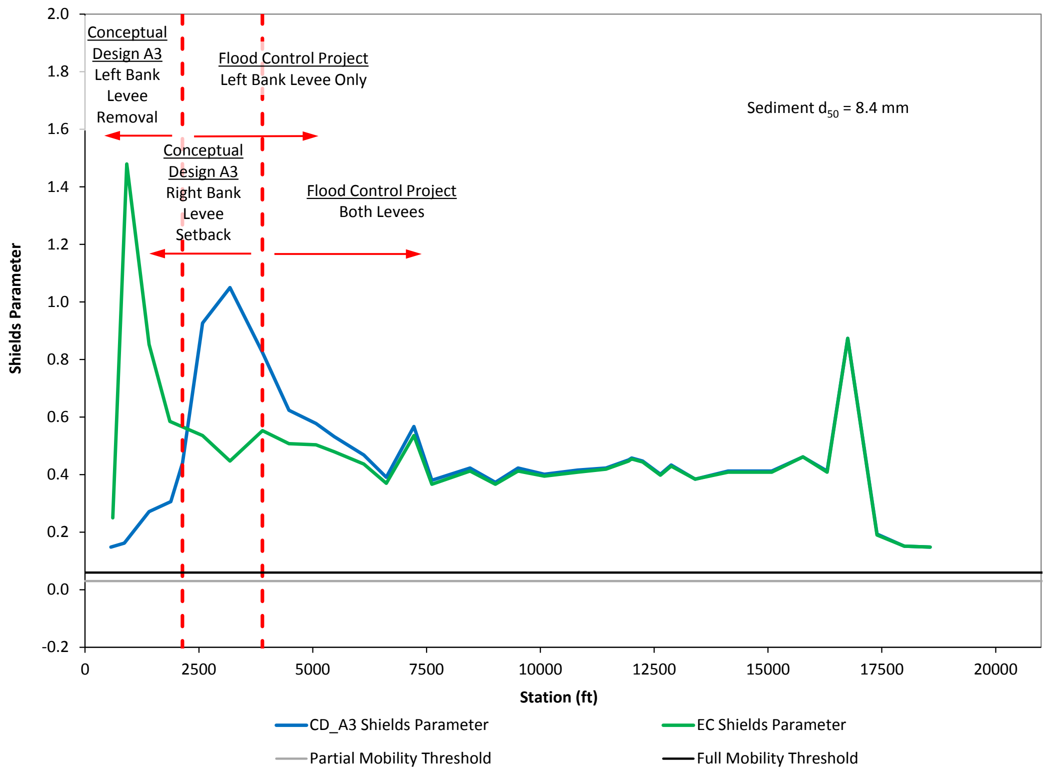
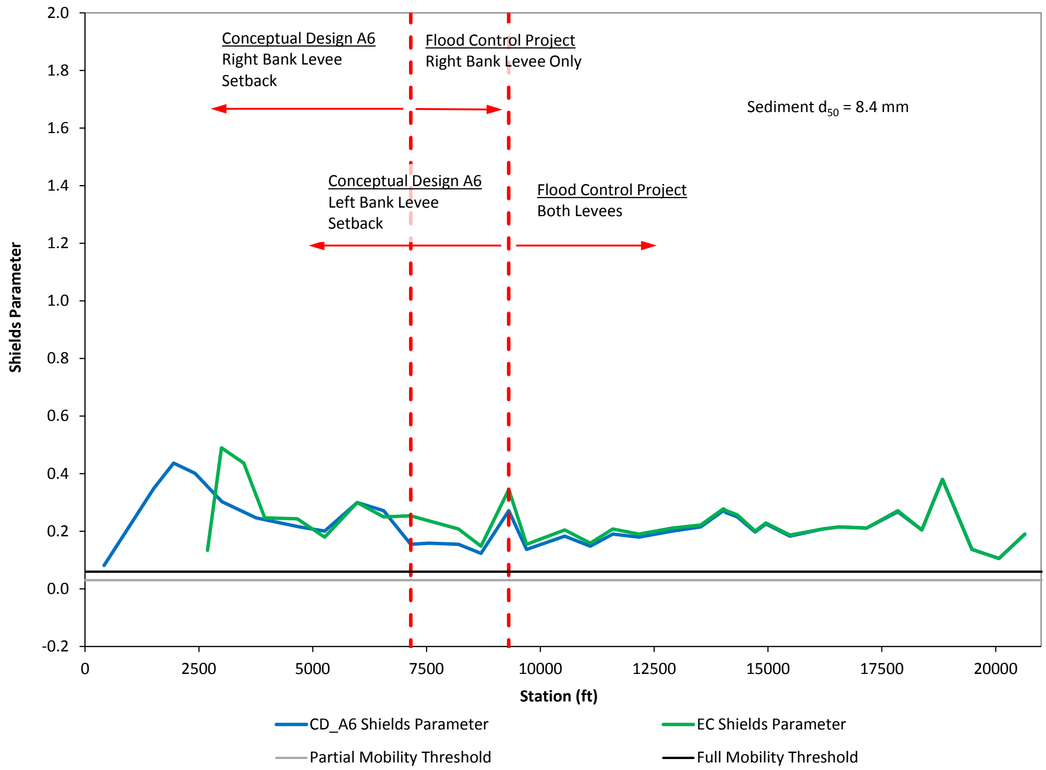


Figure 9-22. Sediment mobility results (Shields Parameter estimates) for the 1.5 (top) and 100-yr (bottom) floods for existing conditions and Alternative A3. Stationing for existing condition adjusted to be consistent with Alternative A3.



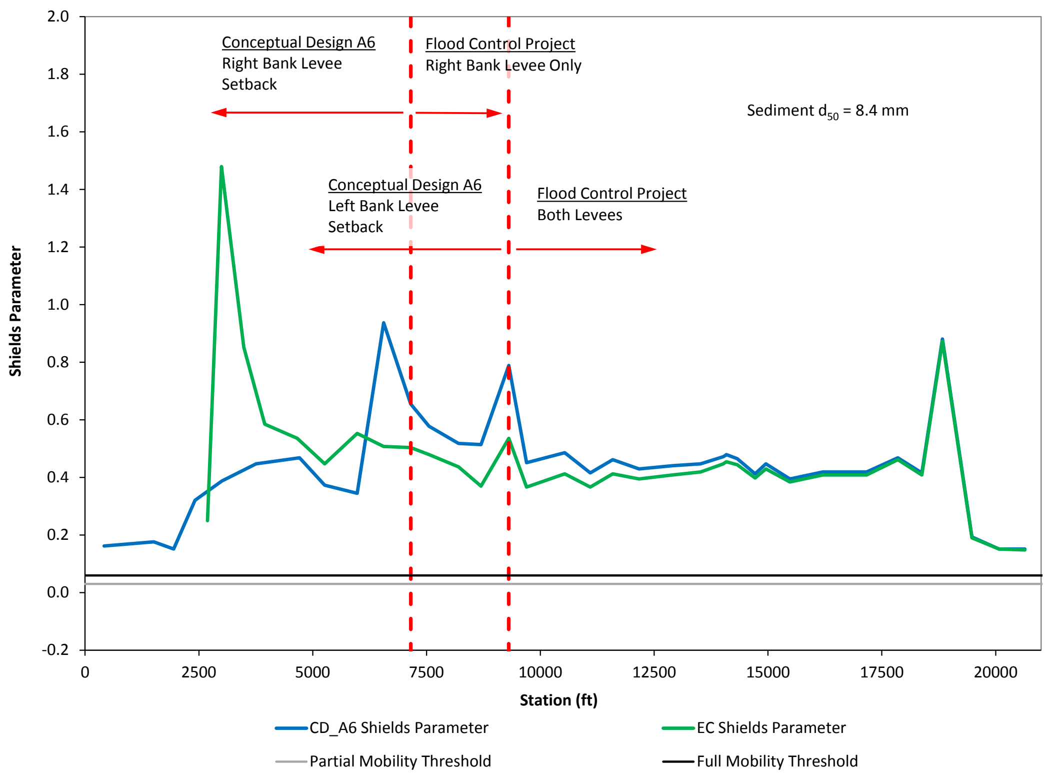
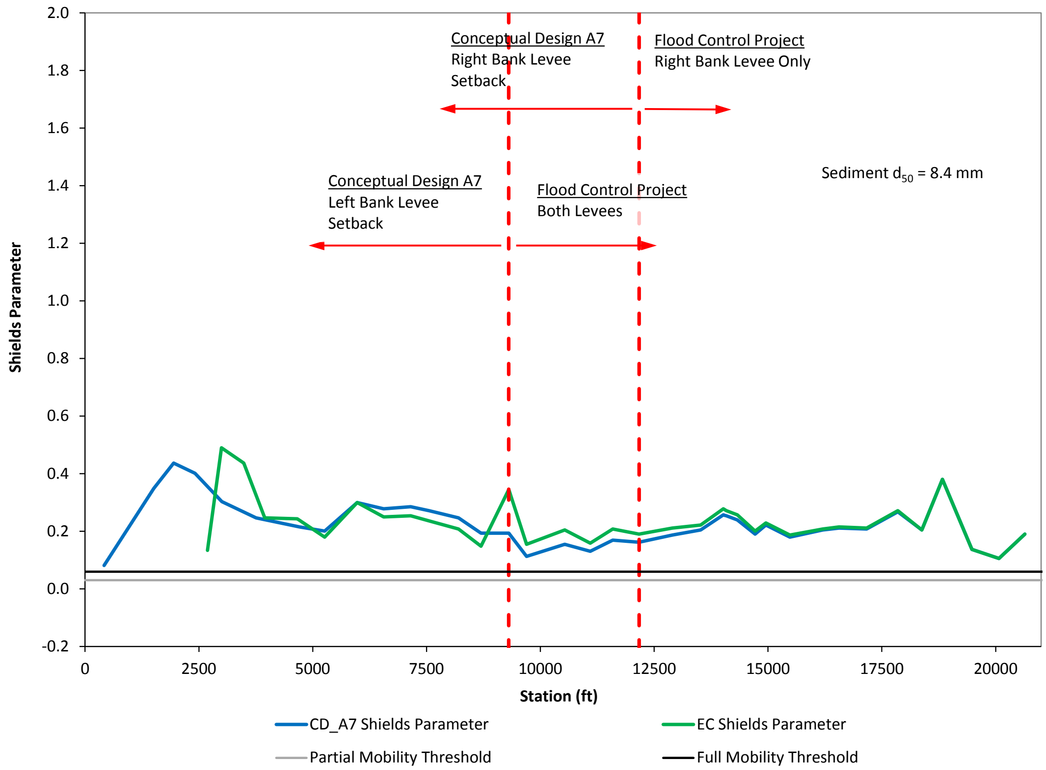


Figure 9-23. Sediment mobility results (Shields Parameter estimates) for the 1.5 (top) and 100-yr (bottom) floods for existing conditions and Alternative A6. Stationing for existing condition adjusted to be consistent with Alternative A6.



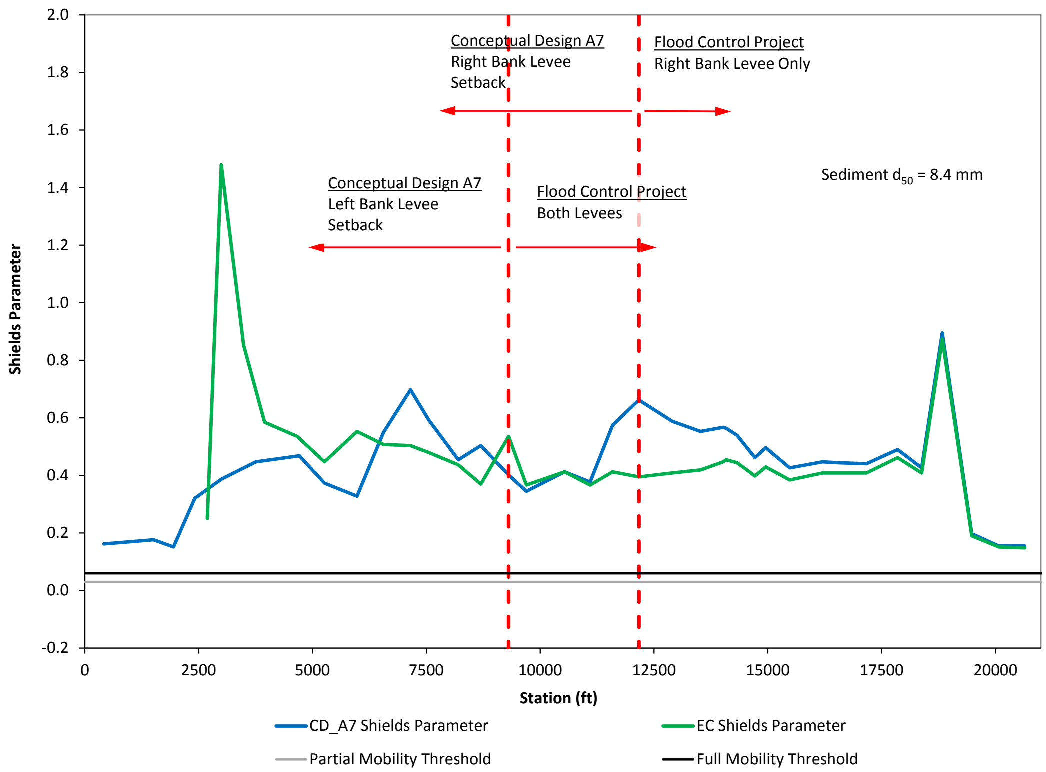


Figure 9-24. Sediment mobility results (Shields Parameter estimates) for the 1.5 (top) and 100-yr (bottom) floods for existing conditions and Alternative A7. Stationing for existing condition adjusted to be consistent with Alternative A7.

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Appendix A

Statement of Work from Grant Agreement

EXHIBIT A
Redwood Creek Estuary Restoration and Levee Rehabilitation Conceptual Design Project
STATEMENT OF WORK

Under direction of the California Department of Fish and Game (DFG), and under the following conditions and terms, the Grantee (Humboldt County Department of Public Works) will:

1. The Grantee will develop conceptual design alternatives that achieve the optimum estuary function resulting in improved salmonid survival and productivity while also rehabilitating the levee system to meet flood protection requirements of the Federal Emergency Management Administration and the United States Army Corps of Engineers. The feasibility of these design alternatives will be determined by whether they meet the needs of the adjacent landowners as well as meeting the criteria of regulatory agencies.

2. The project site is located in Township 11 North, Range 01 East Sections 32 & 33, and Township 10 North, Range 01 East, Sections 4 & 5, of the Orick 7.5 Minute United States Geological Survey (USGS) Quadrangle as depicted in Exhibit A, Attachment 1, Project Location Map, which is attached and made part of this agreement by this reference.

3. The Grantee will develop an Action Plan with description of at least three (3) preliminary conceptual designs for consideration as well as a schedule of tasks with desired completion dates relative to: 1) assessment of estuary restoration needs; 2) assessment of levee rehabilitation (flood control & maintenance) needs; as well as 3) consultation with adjacent landowners. Schedule of tasks could be in spreadsheet format.

4. The Grantee will circulate the draft Action Plan at least one (1) week prior to an initial meeting with a peer review committee including Project Team and Partners, DFG, and other agencies involved in restoration or permitting (for example – United States Fish and Wildlife Service, National Marine Fisheries Service, Army Corps of Engineers and State Coastal Conservancy). This meeting will occur within two (2) weeks of project initiation.

5. To improve salmonid production, the estuary restoration design element must at a minimum contain the objectives of: 1) improving channel connectivity and circulation with adjacent wetlands and sloughs; 2) increasing channel depth, diversity, and complexity including instream cover; and 3) identifying off-channel rearing opportunities - as described in the Redwood Creek Assessment Report (DFG 2010).

6. On a quarterly basis, the Grantee will coordinate with the peer review committee. This coordination will consist of a progress report followed by a committee meeting. The progress report will include summary information describing how conceptual designs meet estuary restoration, levee rehabilitation and adjacent landowner needs. Each progress report will be distributed to the group at least two (2) days prior to a quarterly meeting to discuss the status of community acceptance of conceptual design options and regulatory agency criteria and objectives.

7. *The grant may be terminated, with a 30 day notice if DFG concludes the project is no longer feasible due to lack of community support or inability to optimize estuary restoration and meet flood control needs in one design.*

8. The Grantee will evaluate conceptual design alternatives with respect to critical life history stages and limiting factors of salmonids and other species most likely to be affected based on literature (including DFG's Redwood Creek Assessment Report) and available information. Any additional studies that may be necessary will be identified.

9. The Grantee will evaluate conceptual design alternatives with respect to relative levee maintenance needs and identify any additional studies that may be needed.

10. The Grantee will develop an estuary enhancement/levee rehabilitation plan that:
    - Identifies project goals and desired outcomes;
    - Summarizes information in terms of adjacent landowner needs, regulatory requirements, community concerns, affected species, critical life history stages, physical processes of concern, and any conflicts in species needs, community needs and flood control requirements;
    - Describes regulatory and permitting requirements and project constraints and evaluates whether requirements can be met under project constraints;
    - Contains a summary of existing information from literature and previous studies and identifies key information gaps;
    - Contains at least three (3) viable conceptual design options for the multi-objective project that incorporate considerations for global climate change and sea level rise. Options will be illustrated with planview maps, cross-section diagrams, and narrative descriptions. Options will be supported with preliminary hydraulic modeling (HEC-RAS) results;
    - Includes proposed studies, modeling, and monitoring efforts to satisfy agency finding requirements and to understand the potential effect of estuary/levee design options on anadromous salmonids and other aquatic, riparian, or estuarine-dependent species,
    - Identifies potential easement or acquisition programs and strategies that could be used to compensate adjacent landowners for any loss of land use as a result of estuary enhancement.
    - Summarizes feasibility of enhancing species productivity through estuary restoration in view of any identified management, regulatory, physical, or biological constraints,
    - Summarizes the formal process (per 33 USC Section 408) that would be applicable for modifying a federal flood control project; and
    - Contains a phased plan for future actions – proposed studies, monitoring, etc. and preliminary cost estimates for design options and any necessary studies.

11. Any request to amend the grant for a time extension beyond the March 31, 2014 grant end date, must be submitted with a justification for the delay no later than **December 1, 2013.**

12. An annual report will submitted each year, no later than November 15, detailing work completed that season. The annual report will include, but not necessarily be limited to the following:
    - Planning start and end dates;

- Percentage of the project completed in total to date;
- Report measurable metrics for the project ***for each site individually*** and summarized for the total project by responding to the restoration project metrics listed in Appendix A, Attachment 2.

13. Upon completion of the project, the Grantee shall submit one (1) copy of a draft final report not later than **January 15, 2014** for review and comment. Within **30 days** of receipt of the draft report, the Grant Manager shall submit his/her final comments to the Grantee. **Once incorporation of changes based on comments are made to the satisfaction of the Grant Manager**, the Grantee shall submit one (1) hard copy and one (1) electronic copy, (*Microsoft Word* compatible, on a CD) of a final written report. A final report template is included as Attachment 2 to Exhibit A. The Grantee shall use this template for their final report. All data collected and created for this grant is a required deliverable of this grant and will become the property of the Department of Fish and Game, and not of the grantee. A condition of final payment on this grant shall include the delivery of all related data. Spatial data should be delivered in an ESRI-useable format where applicable and documented with metadata in accordance with minimum BIOS metadata standards (http://bios.dfg.ca.gov/metadata.asp) and FGDC metadata standards (http://www.fgdc.gov/metadata/documents/workbook_0501_bmk.pdf). The report shall not be considered final until approved and accepted by the grant manager. The report shall include, but not necessarily be limited to the following information:
    - Grant number;
    - Project name;
    - Geographic area (e.g., watershed name);
    - Location of work – show project location using U.S.G.S. 7.5 minute topographical map or appropriately scaled topographical map;
    - Geospatial reference/location (lat/long is preferred – defined as point, line, or polygon);
    - Project start and end dates;
    - A complete final Budget including: Total of each fund source, by line item, expended to complete the project, breaking down Grant dollars, by line item, and any other funding, including type of match (cash or in-kind service);
    - Total number of volunteer hours; dollar value of volunteer work; description of how the dollar value of the volunteer labor was determined; dollar value of non-volunteer donated labor (employees whose labor is not paid for by FRGP funding); and description and dollar value of non-labor in-kind contributions to the project.
    - Expected benefits to anadromous salmonids from the project;
    - Specific project access using public and private roads and trails, with landowner name and address; and
    - Report measurable metrics for the project ***for each site individually*** by responding to the restoration project metrics listed in Appendix A, Attachment 2.

14. The Grantee will acknowledge the participation of the Department of Fish and Game, Fisheries Restoration Grant Program and National Oceanic and Atmospheric Administration Fisheries funds on any signs, flyers, or other types of written communication or notice to advertise or explain the project.

Appendix B

Comments on Draft Report from Peer Review Committee

Comments on Redwood Creek Estuary Conceptual Design Report
Gayle Garman 11/26/14

Page iii – There must be a list of Figures and Tables here.

The Figures from the 12/1/14 presentation should be incorporated into the appropriate sections of the Final Report along with text summarizing the main information presented in the figures.

Page 1-1, Section 1.3 – The first few sentences of the first paragraph in this section should describe/define the Redwood Creek Flood Control Project. You could move the highlighted sentences from the paragraph below and the paragraph above. i.e. -
"The Flood Control Project consists of a system of two earthen embankment levees and associated infrastructure. Construction of the Flood Control Project included excavation and enlargement of the channel to a target geometry and placement of earthen embankments along each bank. The levee system confines approximately 3.4 miles of lower Redwood Creek."

same page and section, first sentence – *"was constructed by the Army Corps of Engineers from 1966 to 1968…"* Figure 3-10 (May 1967) doesn't show any signs of levee construction. Did the actual levee building begin summer of 1967 or '68?

Page 1-3, Section 1.6.1 – Insert (RIP) after *"the Rehabilitation and Inspection Program…"* The acronym is used on p. 2-2 and is confusing without establishing the use here.

Page 2-2, Section 2.2.2, second-to-last paragraph - It would be easier for the average reader if you would refer to "active status within the Corps of Engineers' RIP program (see Section 1.6.1)." It is difficult to know what RIP is without some association with Section 1.6.1.

same page and section, last paragraph - What is the "majority" here? Is there any estimate of a percentage of the Flood Control Project that does not meet the standard?
I see there is more information provided in Section 4.5.2. Please provide a reference to this section in parentheses after this sentence.

Page after 3-19 – is labelled as 3-1 - page numbering is messed up for the next 3 pages.

Page 4-11, Section 4.5.2, last sentence – "*freeboard capacity is near or below approximately 1 foot downstream of Highway 101 bridge…"* I think this part of the sentence is saying "freeboard capacity is at or below 1 foot in some locations downstream of the 101 bridge." If this is what you mean, insert the words 'in some locations' after the word 'foot'.

Page 4-12, Section 4.6. third paragraph end of second sentence – add "(see Figure 3-10 for comparison)."

Page 4-16, Section 4.6.3, second to last sentence under item #3 – The data in Figure 4-26 are labelled as Chinook.

Same page and section, last sentence under item #3 – Mike Sparkman - "I disagree that juvenile steelhead are especially dependent upon the estuary. My data doesn't show that, rather, the steelhead are more dependent upon riverine conditions for growth. They are probably basing this on steelhead studies in Santa Cruz besides the references they give."

Page 4-17 Section 4.6.3, second to last sentence under item #4 – Mike Sparkman believes that good overwintering habitat is also important for steelhead. also see Michelle Gilroy comments.

Page 4-41 caption under Fig. 4-26 - Data appears to be for Chinook only - "salmonids" should be replaced with "Chinook".

Page 8-5, Section 8.2.1 - Near the end of the report (p. 8-30, second to last paragraph) there is reference to determining how high levees should be raised. If increasing levee height is part of the expected design, it should be mentioned here and under the appropriate alternatives.

Page 8-5, Section 8.2.1 - As a key component, more should be said about hydraulic capacity here - such as the relationship with Army Corps specifications for active status. We will want to know how much hydraulic capacity is gained by each Alternative and how that might be interpreted with respect to meeting the criteria for Army Corps and FEMA needs.

Page 8-5, Section 8.2.2, last sentence under Seepage paragraph - Are these locations noted on an existing Figure in this document? If so, a figure reference should be given. If not, some general description of where these stations are located should be included.

Page 8-7, Section 8.3.1, third bullet in bottom paragraph - How much is hydraulic capacity increased over existing condition? Section 8.2.1 says benefits of hydraulic capacity increase may extend 3-4,000 ft. upstream. Is this the case with A1, A2, etc.? What does this translate to in terms of flood capacity and the requirements for Army Corps and FEMA?

Page 8-7, Section 8.3.1, sixth bullet - Any implications for hinge points being offset should be explained.

Page 8-7, Section 8.3.1– Does this alternative address all or most of the continuous freeboard deficiencies described in Section 4.5.2 and Fig. 4-13?

Page 8-10, Section 8.3.2 – Are there any advantages/disadvantages in having the hinge points opposite vs offset under high flow conditions?

Page 8-11, Section 8.3.2, last sentence of first full paragraph - How much more floodplain and how much does it change the sed. transition zone as compared to A1? In order to make effective comparisons it would be best to have numbers to compare. How much more pasture would be gained?

Page 8-11, Section 8.3.2, sentence above the Figure - - Add words to the effect - "This equates to about 700 more feet of levee removal and 400 more feet of levee construction than Alt. 1."

Page 8-13, Section 8.3.3 last paragraph - **A table comparing estimated total number of feet of levee removal, total footage of levee construction, and (if possible), net change in pasture acreage for at least the first 3 or 4 alternatives should be presented here.**

Page 8-20, Section 8.4, fourth line Figure references - Under the current Figure numbering these should be 8-15 and 8-16.

Page 8-21, Section 8.4.2, first full paragraph Figure reference 8-12 - Under current Figure numbering, this should be Fig. 8-17.

Page 8-21, Section 8.4.2, second paragraph, first sentence – This is a run-on sentence and should be divided into two sentences. Figure reference should be Figure 8-17, under this first draft convention. There appears to be something missing in the third line. The first sentence should end after the Figure reference and the second sentence could be "All three alternatives provide a substantial increase in the amount of inundation surface area during backwatering periods as compared to the existing levee configuration.

Page 8-21, Section 8.4.2, second paragraph, rest of paragraph from line 4 on and Table 8-6 - These rough estimates assume the only factor affecting juv. Chinook capacity is surface area and volume. There would need to be a literature citation supporting this supposition. Most literature indicates that there is more to estimating juvenile capacity in estuaries than just surface area and volume (habitat quality, food, predation, etc.).

The estimates in Table 8-6 and paragraph are oversimplified. The basic message is - "The increase in the area and volume of the estuary with any of the three alternatives is likely to contribute to an increase in juvenile Chinook production. A resulting increase in smolts entering the ocean, in turn, could increase the number of returning adults."

After the 12/1/14 meeting, I understand this to a first step toward establishing a benefit in terms of a rough estimate of increased fish production as part of the cost/benefit estimate, but it doesn't help in comparison of alternatives. The area/volume comparisons of Tables 8-4 and 8-5 are more useful.

Pages 8-23, 25 and 27 – The Figure number is off for these three Figures. Based on current numbering they should be 8 -15, -16, and -17.

Page 2-28, Section 8.5 – This paragraph must begin with definitions of what is meant by "persistence and resilience."

Page 8-28, Section 8.6 second line of first paragraph and Page 8-29, first line under Design Deficiency Study – "*Corps of Engineers (1982)*…" This citation is not found in the Reference

Section. Other entries are listed as US. Army Corps of Engineers, but there are no publications dated 1982 or 2007.

Page 8-29, Section 8.6, last line of paragraph under Special Legislation – "*is*" should be replaced by either "have been" or "are". The sentence subject is plural – Congressman Huffman and his predecessor have been very supportive.

Page 8-30, section 8.7 – This section should be better developed and more specific since the plan for next steps is one of the most important deliverables (refer to page A-2 of grant agreement "phased plan for future actions –proposed/necessary studies, and preliminary cost estimates." These should be complete sentences. The "Who" is missing in each of the lead sentences.

Page 8-30, section 8., first paragraph, first sentence – "*perform more detailed technical studies (hydraulic modeling and fish habitat evaluation…*" Does the hydraulic modeling get at predicted sedimentation rates as well as spatial-temporal patterns? Is 2-D modeling the only or best way to get at this? This section needs more specifics - what are the objectives for the modeling and evaluation and when do we know it is done? The "iterative approach" sounds like studies will be done over and over without a solid endpoint. What fish habitat evaluation is necessary? It seems that modeling to predict sedimentation rates and patterns would aid in the prediction of potential fish habitat gains. The last line of section 8.5 has at least a little more detail.

One of the burning questions is – If A1-3 are the alternatives most likely to be accepted by landowners, will it be enough of an improvement as far as estuary functioning and persistence/resilience to be worth the effort and expense?

Page 8-30, section 8.7, fifth paragraph, first sentence – "*additional technical studies (hydraulic modeling)*" - How does this differ from the technical studies mentioned in the first paragraph?

Page 8-30, section 8.7, fifth paragraph, second sentence – *"…vertical and longitudinal extent of levee raising needed…"* **The need for levee-raising is not obvious in the document before now. This aspect needs to be explained - at very least in 8.2 (Levee Rehabilitation Concepts).**

Grant Agreement requirements that need to be completed or added –

- Summarizes information in terms of adjacent landowner needs, regulatory requirements, community concerns, affected species, critical life history stages, physical processes of concern, and any conflicts in species needs, community needs and flood control requirements;
- Describes regulatory and permitting requirements ** and project constraints and evaluates whether requirements can be met under project constraints;
- Contains a summary of existing information from literature and previous studies and identifies key information gaps;

*** list of the likely permits that would be needed*

- Includes proposed studies, modeling, and monitoring efforts to satisfy agency finding requirements and to understand the potential effect of estuary/levee design options on anadromous salmonids and other aquatic, riparian, or estuarine-dependent species;
- Identifies potential easement or acquisition programs and strategies that could be used to compensate adjacent landowners for any loss of land use as a result of estuary enhancement;
- Contains a phased plan for future actions – proposed studies, monitoring, etc. and preliminary cost estimates for design options and any necessary studies.

Performance Measures that need to be listed (per Final Report template –Grant Agreement p. A-6):

- Acres of land area affected by the planning/assessment activity
- Miles assessed that contain anadromous salmonids;
- Miles assessed that are in need of restoration;
- Acres assessed that are in need of restoration;
- Miles assessed to establish regulations or protective measures for salmonids;
- Number of potential fish passage barriers assessed;
- Number of barriers to fish passage identified;
- Number of plans/assessments completed;
- If the project involves restoration planning or coordination:
    - Type(s) of planning activities conducted, select from: development of a recovery plan; coordination/implementation of a recovery plan; coordination of watershed conservation and restoration; watershed council support; tribal infrastructure support; support to local entities or agencies involved in salmonid restoration planning and coordination; developing monitoring plans or sampling protocols; conducting habitat restoration scoping and feasibility studies; evaluation/prioritization of restoration plans and projects; designing and maintaining restoration data systems; engineering/design work for restoration projects; or developing restoration/action plans;
    - Name of the plan developed by the project, in the format Author, date, title, name, source, source address;
    - Describe extent, purpose and application of the plan;
- If the project involves stream surveys or assessments:
    - Type(s) of assessment activities conducted, select from: salmonid presence/absence survey; instream habitat condition assessment; habitat use by salmonids; or fish passage barrier inventory;
    - Name of the assessment document developed by the project, in the format Author, date, title, name, source, source address;
    - Acres of habitat assessed to determine habitat conditions affecting salmonids;
    - Miles of stream assessed;

    - Miles of road assessed;
- If the project involves watershed habitat surveys or assessments:
    - Type(s) of assessment activities conducted, select from: riparian condition; road condition/inventory; upland habitat conditions; wetlands; estuarine/nearshore habitat conditions; LiDAR or other remote mapping; landscape mapping; invasive species; floodplain mapping; forest inventories; overall watershed condition assessment or mapping; or stream typing;
    - Name of the assessment document developed by the project, in the format Author, date, title, name, source, source address;
    - Acres of habitat assessed to determine habitat conditions affecting salmonids;
    - Miles of stream assessed;
    - Miles of road assessed.

+ A final Budget including a column for cost-share must be included with the Final Report with all comments addressed.

+ I will also need a Final Invoice once all the billable work is completed.

Additional Comments based on 12/1/14 meeting –

I look forward to the write-up on the Sediment Mobility Estimates as it seems that the Shields Parameter graphs show values in the existing condition as well as all the alternatives that are well above the 0.06 full sediment mobility value. Since we know that channel aggradation in the existing condition is a problem, I'd like to understand more about what this information tells us.

Open discussion Questions

a. Based on the presented information, alternatives that provide the most ecological value as well as being compatible with adjacent ag land use are worth pursuing. From the perspective of what historically was most persistent/resilient and from the near-term fisheries resource perspective, <u>Alternatives 1 & 2</u>, which restore main channel flow into the South Slough are most desirable. Concerns were raised about Alt. 2 in that the current diagram shows a loss of established riparian habitat around Strawberry Creek. If Alt 2 is advanced, ways to maintain established riparian habitat on either side of the creek, should be explored so that the lower portion of Strawberry Creek does not become choked with reed canary grass and retains habitat value equivalent to its existing condition.

   As was pointed out in the meeting - while Alt. 3 could provide a smoother transition to the ultimate desired estuary conditions provided by Alt. 6 or Alt 7. However, the minimal connection to South Slough in Alt 3 does not demonstrate an appreciable improvement in resilience and ecological function estuary in the next 10 to 15 years.

   Since Alternatives 6 and 7 would provide the most flood capacity, resiliency, and ecological function it is recommended that at least one of them would be included in

Tables 8-3, 8-4, and 8-5 as well as the Cost Estimate table and other diagrammatic comparisons from the slide presentation. It seems wording could be crafted to minimize concerns that these Alternatives would be forced through without maintaining agricultural values.

b. Uncertainties:

1. Most obvious – whether sufficient pasture opportunities can be found and risks to ag production can be minimized to the point that adjacent landowners would be willing participate with one of the Alternatives that provides the most ecological function.

2. Do any of the alternatives that might work for landowners provide the necessary reduction in maintenance that the County requires?

3. We need to know more about temporal and spatial sedimentation – both fine sediments and gravels.

4. What is the most expedient approach to modifying the Federal Flood Control project? Is it safe to say that any or all of the Alternatives might meet the requirements for reactivation?

5. What are the needs for raising the existing levees (p. 8-30)? This was not discussed.

e. Next steps

- address uncertainty #1 and select an alternative that meets the Overall Purpose;

- talk to other entities about their experiences with getting projects through the necessary Corps of Engineers process for modifying Federal Flood Control project – groups involved in projects mentioned on San Lorenzo R., Sacramento R. or others?;

- figure out how much pastureland would be made unproductive or inundated to the point where there is a significant loss in productivity;

- search for grazing lease opportunities as a means of meeting current ag production levels;

- once there is an alternative that adjacent landowners could support and a way to meet the ag productivity needs, apply for an FRGP grant to work on design details;

f. CDFW role going forward

– permitting: CEQA review, Lake and Streambed Alteration Agreement, CESA Incidental Take Permit;

- potential source of grant funding for design planning and implementation (although implementation will require multiple funding sources);

- supply of fisheries data from ongoing monitoring programs in riverine environment.

Redwood Creek Estuary Restoration Conceptual Design Project Comments
– Michelle Gilroy and Mike Sparkman 11/25/14

Page 2-2, Section 2.2.2:
Define RIP

Page 3-8, Section 3.3
"Pacific" lamprey

Page 4-15, Section 4.6.1
If water temperatures have been collected since 1997, why are only 2002 and 03 selected to be reported on here?

Section 4.6.2
Add cutthroat trout in parentheses as well. Suggest mentioning presence of New Zealand Mud Snail in Lower Redwood Creek now. There is a Redwood Creek specific study by Darren Ward, HSU.

Page 4-15, section 4.6.2
M. Sparkman: In summer, there is also the problem of low water depths. I totally agree that carrying capacity has been reduced (data driven response by Mike Sparkman and Dave A), and at least for Chinook smolts, they don't stay in the estuary very long.

M. Sparkman: Regarding 'poor growing conditions upstream': that may have been the case, but mid to upper Redwood Creek is back to pre-flood bedload levels, and conditions are improving.

Page 4-16, Section 4.6.3
#2. 1st sentence…reduced because of "decrease" and simplification of habitat, …

Page 4-16
M Sparkman: Habitat carrying capacity: they should mention the lack of complexity in the form of pool/riffle sequences, and more importantly, lack of large woody debris, and large amounts of sediments. I agree that estuary is deficient compared to upstream production. The estuary is the biggest limiting factor, but there is always the worry of landslides and increased sedimentation due to logging and road building (particularly legacy).

M Sparkman: I disagree that juvenile steelhead are especially dependent upon the estuary. My data doesn't show[MG1] that, rather, the sh are more dependent upon riverine conditions for growth. They are probably basing this on steelhead studies in Santa Cruz besides the references they give.

M Gilroy: SH are probably more dependent on river conditions than the estuary and it may be overstating that "SH are especially dependent on estuaries". More sampling is necessary in the Redwood Cr estuary Jan-April/May when SH smolts are most likely to be present. I believe Dave Anderson's estuary work (which targets yoy Chinook) starts later in the spring after most SH have moved through. Also, based on the photos and Dave Anderson talks, the historic Redwood Cr estuary did become a lagoon and likely provided similar habitat to the lagoons studied in Santa Cruz. Bottom line, stating SH are especially dependent on estuaries is an over statement, however, restoring estuarine/lagoon function to Redwood Cr estuary will benefit all salmonids and SH would be more likely to use the estuary than they do presently.

M. Sparkman: Steelhead trout are even more dependent on good overwinter conditions b/c they can spend 2 years in freshwater before going to the ocean. Most coho spend 1 yr in freshwater[MG2].

M. Gilroy: overwinter stream conditions are critical to both species no matter how many winters each rears in the stream. Also, I believe Redwood Creek is one of the waters where 2 yr freshwater phase for coho has been documented.

Page 4-29
Figure 4-14. Add month of NAIP imagery.

Page 5-2, Section 5.1.3
Add early fall into first bullet

Page 7-6, Table 7-1

Add Ecological Objective – reduce canary grass

Ecological
#5 add DIDSON metric for lower mainstem Redwood Creek to measure adult fish populations

Page 8-2, Section 8.1.3
2nd paragraph, last sentence: delete especially Chinook salmon and steelhead. Restoring estuarine/lagoon function to Redwood Cr estuary will benefit all salmonids.

From: Roemer, Dave <dave_roemer@nps.gov>
Sent: Wednesday, December 03, 2014 4:29 PM
To: Seemann, Hank
Cc: Darci Short; Vicki Ozaki; David G Anderson; Mary Ann Madej
Subject: Redwood National Park comments on Conceptual Design Project draft

VIA ELECTRONIC MAIL: NO HARD COPY TO FOLLOW

IN REPLY REFER TO:
N1621

December 3, 2014

Redwood National Park
121000 Hwy 101 South / P.O. Box 7
Orick, California 95555

Hank Seeman
Deputy Director
Humboldt County Department of Public Works
1106 Second Street
Eureka, CA 95501

Dear Hank:

Thank you for all of the effort and progress made towards developing a restoration vision for the Redwood Creek estuary that respects the livelihoods and values of agricultural producers in Orick. It bears reaffirming that any project involving private lands depends upon the willingness of private landowners to participate as stakeholders with full and fair consideration of their long-term interests. The National Park Service recognizes the key role of our neighbors and fully supports processes that respect their interests and that seek to achieve across-the-board benefits for the estuary and landowners. I believe that there are solutions that have the potential to be a “win-win” for the rich natural and cultural heritage of the estuary and lower valley.

Staff at Redwood National Park participated in the Peer Review Committee and have reviewed the Nov. 14, 2014 draft of the Redwood Creek Estuary Restoration and Levee Rehabilitation Conceptual Design Project. The purpose of our evaluation is to offer suggestions for improvements to the document to increase its utility as a stepping-stone towards the future discussions and designs that will be necessary to advance a restoration project.

In addition to general and detailed comments offered below, we wish to highlight several key points from our review:

1) Restoration design concepts should include reconnection of the South Slough with the main channel of Redwood Creek, unlike in Alternative A3 where the main flow remains in the present channel and South Slough would only backfill. It is a key uncertainty that estuary function could be restored, or self-maintaining, without re-integration of the South Slough.

2) Realignment of a riparian vegetation portion of Strawberry Creek, as included in the concepts for Alternatives A2 and A4, would provide more ecological harm than benefit and likely incur maintenance costs to manage reed canary grass. The riparian vegetation of the existing segment contains characteristics that would be difficult to quickly re-establish in a new channel.

3) The document would benefit from inclusion and analysis of a more full range of restoration design concepts. The three alternatives selected for comparison in the scoring matrix provide only a narrow range of benefits and costs. While respectfully recognizing that large-footprint concepts like Alternatives A6 and A7 do not enjoy landowner support – and that landowner support is necessary for any project to be implemented – those concepts still provide valuable points for comparison and context. Further analyses of costs and benefits for the estuary and for agricultural production, which will be necessary in the future, should encompass a wide spectrum of alternative design concepts.

Thank you for the opportunity to work with you as Peer Review Committee members during the preparation of these conceptual designs. This project, and the communication with landowners and stakeholders that you have fostered, will provide a fresh starting point for future discussions. Redwood National Park is committed to working with the County and with everyone involved, to achieve broad benefits in the Redwood Creek watershed and estuary.

Sincerely,

/s/ David M. Roemer

David M. Roemer
Chief, Resources Management and Science

cc: Stephen Prokop, Superintendent
Darci Short, Geologist
David Anderson, Biologist
Vicki Ozaki, Geologist

Redwood National Park comments on the Nov 14, 2014 Draft of the Redwood Creek Estuary Restoration and Levee Rehabilitation Conceptual Design Project, Orick, Humboldt County, California.

General comments:
* Include an Executive Summary.
* The alternatives have been selected based on evaluations of either "near future" or "short-term" viability or feasibility. It would be helpful to have standard definitions for "viable" and "feasible" and for the timeframe that is being used to evaluate the alternatives.
* Restoration of the estuary and setting back levees also has the potential benefit to reducing tsunami impacts for large distant source tsunami.
* Include a statement that describes what a successfully functioning flood control project would look like (e.g., Alternative A7).

Specific Comments:

Section 1.1, page 1-1: Please describe the products that are required by conditions of the FRGP grant. For example, were three conceptual design alternatives specified? The first mention of three conceptual alternatives occurs toward the end of the document in Section 7.2, page 7-5, paragraph 1. Here, or elsewhere towards the beginning of the document, would be a better place to introduce the project goals, rather than deferring to Section 7.1.

Section 1.2, page 1-1: “Land in the vicinity of the lower Redwood Creek and estuary includes privately owned agricultural land and a portion of Redwood National and State Park.” Here, and throughout the document, the land at the mouth of Redwood Creek may be said to be within the boundary of Redwood National and State Parks (RNSP), or perhaps more directly, Redwood National Park (RNP) managed by the National Park Service (NPS). No state park properties are within the estuary or levee project footprint.

Section 1.5.1 page 1-2, paragraph 2: “due to the presence of listed species, their listed critical habitat, and environmentally sensitive habitat areas.”

Section 1.8, page 1-4, paragraph 1: “endangered species recovery” – There are no federal or state listed endangered salmonids in the estuary, not counting the endangered tidewater goby which is now extirpated in the estuary. A better term might be “threatened and endangered species recovery.”

Section 1.8, page 1-4, 2nd Bullet: Add that the NPS provided additional information – “provided digital copies of it photographic archive and estuary documents.”

Section 1.8, page 1-5, paragraph 2: Please add the National Park Service to the Peer Review Committee list.

Section 1, page 1-6, Figure 1-1. Label the Redwood Creek Estuary on the watershed map.

Section 3.2.1, page 3.5, paragraph 2: The text states that when the historic barrier beach was narrower and reworked, it allowed for increased seepage rates during low flow/inlet closure. If so, how “would (this) allow the lagoon to stabilize at higher levels during periods…” One would assume the water elevations would be lower than what occurs now, if there was more seepage.

Section 3.3, page 3-9: This document is salmonid centric, but in this section it should include how historic conditions benefitted other fish species (freshwater, brackish, and marine) found in the estuary such as the Threespine stickleback, staghorn sculpins, shiner surfperch, and tidewater goby. Also, not mentioned are coastal cutthroat trout that utilize the estuary.

Section 4.1, page 4-1, paragraph 1: Redwood Creek is about 65 miles long based on RNP GIS data; not 56 miles as stated in Janda et al. 1975.

Table 4-1, page 4-3: Define TBD with a footnote.

Section 4.3.1, page 4-8, paragraph 3: “Suspended sediment and bedload measurements have been routinely made at the Highway 101 Bridge near the Redwood Creek at Orick gaging station….”

Section 4.3.1, page 4-8, paragraph 4: The term SSC is used once; spell out suspended sediment concentration.

Section 4.5.2, page 4-10: When referring to station numbers, denote that the station numbers are also distances in feet from the end of the levees. The same for in Table 4-6. It allows the reader to do distance calculations.

Section 4.5.3: Different methods of determining levee structural stability were used and each had different results. How is the reader to interpret these findings? Please explain.

Section 4.6.1.1, page 4-13, paragraph 4: Creek mouth migration in the document is described as “generally confined to a much smaller barrier beach located directly west of the levee end(s)”, however during the mouth closure process during late June-early July, the mouth migrates to the south, sometimes as far the visitor center, before ocean processes close and fill the outlet channel with sand. The difference is that the barrier beach is not reworked as the channel is on the ocean side of the barrier beach. Creek mouth migration and location is restricted to a smaller area at high flows.

Section 4.6.1.2, page 4-14, paragraph 1: Flow in Sand Cache and Strawberry Creeks is described as being “tidally dependent”, use tidally influenced.

Section 4.6.2, page 4-15, paragraph 2: Include “and limited available rearing habitat” within the sentence ”High water temperatures and low dissolved oxygen during the summer limit salmonid production.”

Section 4.6.3, page 4-15, paragraph 1: Include that a functioning estuary is also critical to recovery of federally listed Threatened and Endangered fish species in Redwood Creek.

Section 4.6.2 and 4.63: Coho presently are not using the estuary embayment for summer rearing. Coho smolts leave the estuary before the mouth closes in late June/early July. Our seining data show we capture them in June as smolts, but in July and later, smolts and young-of-the-year are not found. Coho juveniles are found in Strawberry Creek, and would potentially be found in any backwater habitats in a restored estuary.

Figure 4-6, page 4-23: Label the bridge as the legend suggests that it is ground.

Figure 4-26, page 4-26: Could not discern the vertical lines on the graphs that are noted in the figure caption.

Section 5.1.3, page 5-2, bullet 2: During the summer with the creek mouth closed, estuary water depth is greater than when the mouth is open to the ocean. With restoration and scour, water depth would increase in summer, but also be important in spring and early summer when fish are migrating downstream to the estuary. During spring and early June, at low tide with present estuary conditions, water depth is so low (knee deep) a person can walk across the creek at the ends of the levees, and the creek is a large riffle almost to the mouth. This is not conducive for fish rearing.

Section 5.1.3, page 5-2, bullet 3: The bullet mentions that re-establishment of riparian forests and grasslands. Is there a historic basis for grasslands in the pre-vegetation clearance Orick Valley? Historic photos show a Sitka spruce/redwood forest with shrubs. Grasslands were mainly upland prairies.

Section 6.3, page 6-2: Describe landowners as both private and public, “acceptable to the landowners, both private with appropriate compensation for impacts and conversion of any land to non-agricultural use and public with trust responsibilities.” The inference that landowners refers to only private landowners, and the park (representing citizens of the United States) is not a landowner occurs in other portions of the document.

Section 8.1.4, page 8-3, paragraph 3: The last sentence refers to the “few days of the year” when high flows make the channels inhospitable and is critical for juvenile salmonid survival. Are you able to estimate how many is a ‘few’ days and at what flows? Is this comparable to the number of days a year when flood protection is critical?

Section 8.2.1, page 8-5. Capacity: first bullet – “Levees are normally raised by widening the embankment fill prism to maintain the angle of repose.”

Section 8.3.1, page 8-6. Alternative A1: Add discussion to the overview paragraph that details why the south levee location was placed where it was. Was the intent to maximize pastureland on the east side while still achieving connection of Redwood Creek to South Slough? Additional narrative describing why constructed elements are placed as they are will help the reader to understand the intent of the alternative.

Section 8.3.1, page 8-6, paragraph 3: Does bank stabilization along portions of the re-connected South Slough mean rip-rapped banks?

Section 8.3.1, page 8-8, Figures 8.2-8.3, 8.6-8.6, 8.9-8.10: Please include more information in the map legend to describe the action taken (e.g., For the Proposed Demolition include in the legend: remove levee, remove fill, remove riparian, etc.).

Section 8.3, Figures 8-1 and 8-2 and all alternative figures: We suggest the figures be full page. The figures almost work on half page, but not really. The legends are very small and difficult to read.

Section 8.3.1, page 8-10, Table 8-3: The alternatives that have been evaluated in this table are not very different from each other; the similarity is reflected in the scores, e.g., “medium” values across all alternatives for tidal prism volume, slough channel scour, increase in fish populations, etc. As in the Peer Review Committee meetings, where

Alternatives A6 and A7 were presented and shown to differ significantly from A1, A2, and A3, inclusion of a more comprehensive restoration alternative in this matrix would be helpful. Scoring Alternative A6 or A7 would improve the utility of the table and allow for a full range of objective benefits and costs to be compared.

Section 8.3.1, page 8-10, Table 8-3, Estuary-Physical Processes: In terms of improving water circulation, there is very little difference between Alternative A1 and A2. Alternative A3 restores less circulation to the south slough then the other two alternatives. It seems that there should not be a difference of “Improve water circulation patterns” between Alternative A1 and A2. Alternative A3 would have a lesser value than both Alternatives A1 and A2. Perhaps score Alternative A1 and A2 as medium and Alternative A3 as low.

Section 8.3.2, page 8-10, Alternative A2 (and Alternative A4). “This alternative includes a re-alignment of Strawberry Creek...” Explain the reason for re-aligning Strawberry Creek versus leaving it in its original channel within an established riparian zone. We question the true gains of relocating Strawberry Creek under this alternative. The present channel appears to occupy the same location as shown in the earliest airphotos. The channel possesses characteristics that have evolved over time and are not easily constructed. While flood plain channels and off channel habitat are recognized as limiting features in lower Redwood Creek, it appears that a good amount of that type of habitat will be restored/connected in the estuary area in the Sand Cache Creek area and around the “island”. Will the length of new Strawberry Creek downstream of the levees with this alternative have greater benefit than the loss of the decades- (centuries-) old Strawberry Creek channel? Also since Reed Canary is highly invasive, a newly excavated channel will require annual maintenance to keep the grass out of the channel until riparian vegetation can shade it out. Additionally the channel will require some sort of cattle exclusion for the riparian zone and stream channel. Relocating the channel would provide additional contiguous pasture land at the county-owned property – an agricultural land benefit. But, if Strawberry Creek were kept in the current channel, a riparian swath of about 30 feet wide on each side could be retained along the channel and the remainder of the county site converted to pasture. A pathway through the riparian zone could be constructed to allow for cattle management. This would protect the habitat integrity of existing Strawberry Creek while still affording working pastureland in the immediate area.

Section 8.3.2, page 8-11, paragraph 3: In addition to the levee construction and demolition, include estimates of length of Strawberry Creek to be excavated (realigned) and filled, and the riparian acreage to be converted to pasture.

Section 8.3.3, page 8-13, paragraph 1: The culverts through the south levee between Redwood Creek and the South Slough are not tidal gates; they are manually operated culvert gates. (They are also described as tide gates on page 8-16 paragraph 1.) These gates are opened in the spring after the last large storm events and closed in the fall after the mouth breaches and before the next large storm events. If the gates are left open during the winter, sedimentation occurs in the South Slough where the flow widens out.

Section 8.3.3 Alterative A3: At the final Peer Review meeting several benefits of the A3 design relating to future potential for levee/estuary restoration were discussed, and should appear in the text.

Section 8.3.4, page 8-15, paragraph 1: Read as follows: “Based on numerous meetings, input, and noted concerns of the adjacent private landowners, Alternatives A1, A2, and A3, were ultimately selected by the County to represent a suite of potentially feasible alternatives….”

Section 8.3.4, page 8-16, paragraph 1: The South Slough gates have been seasonally effective in improving water quality and water circulation. When the gates are open and the estuary is tidal (i.e., the mouth is open) there is more exchange of water with the creek than if the gates did not exist. Also, when the mouth breaches, there is greater drainage of stagnant water out of the South Slough than if the gates did not exist. The gates were completed in 1989.

Section 8.4, page 8-19, paragraph 2: Report the elevation of MHHW you used to model summer low flow barrier beach backwater (i.e., with the mouth closed). As you know, when the mouth closes off, the water elevation of the embayment peaks and slowly declines during the summer, from barrier beach seepage and evaporation, until it again rises prior to breaching, the results of barrier beach overwash or a flow event. During the closure period, the South Slough and North Slough can be connected to the estuary embayment.

Section 8.4.2, page 8-21, paragraph 1: The sediment accumulation at the mouth of the south slough does not restrict backwatering once the embayment is closed off mid-summer. Also, South Slough is backwatered via the open South Slough culverts, the inlets which are lower in elevation than the South Slough outlet channel.

Section 8.7, page 8-30, paragraph 1: Read as “These studies would apply an iterative approach based on feedback from the adjacent private landowners, the park and resources and permitting agencies.”

Section 8.7, page 8-30: Include “Continued involvement and consultation with private land owners.”

Section 9, References:

* Anderson, D. 1991 – 2005. Redwood Creek Estuary Monitoring Annual Reports. Redwood National Park, Orick, CA.
* Anderson, D. 2006 – 2014. Redwood Creek Estuary Monitoring Data. On-file at Redwood National Park, Orick, CA.
* Hofstra, T. 1984 – 1988. Redwood Creek Estuary Monitoring Reports. Redwood National Park, Orick, CA.

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David M. Roemer
Chief of Resource Management and Science
Redwood National and State Parks
707-465-7700 office
707-951-7818 mobile
dave_roemer@nps.gov

Seemann, Hank

From: Madej, Mary Ann <mary_ann_madej@usgs.gov>
Sent: Thursday, December 04, 2014 12:46 PM
To: Roemer, Dave
Cc: Seemann, Hank; Darci Short; Vicki Ozaki; David G Anderson
Subject: Re: Redwood National Park comments on Conceptual Design Project draft

Hank,
I have a few more comments to add to those submitted by Redwood National Park. I appreciate the amount of work and energy devoted to this project so far. I support an alternative that would restore hydrologic connectivity to the South Slough, as well as enhance connectivity with tributaries entering lower Redwood Creek. The success of any restoration alternative depends in large part on the balance of sediment input, sediment transport, and sediment output from Redwood Creek. It was probably outside the scope of work to model sediment transport, but a short discussion of what would be involved would be useful. On P. 2-2, the draft states that the Corps of Engineers 2008 report suggests that 430,000 cubic yards would need to be removed to restore the levees to design conditions and similar quantities would need to be removed annually. Assuming a bulk density of 1.35 tons/cubic yard (100 lbs/ft^3), that is equivalent to almost 600,000 tons of sediment needing to be excavated. In contrast, on P. 4-8, the report states that about 174,000 tons of bedload is transported annually past the Orick USGS gage - quite a difference in estimates. During gravel excavation in 1987 (related to the Highway 101 Bypass construction project), surveys indicated that 102,000 cubic meters were excavated and the winter floods redeposited 49,000 cubic meters (about 87,000 tons of sediment) (Collins and Dunne, 1990). So, a very wide range of estimates regarding bedload transport exist at this point.

The discussion of mobility of the channel bed at our last meeting was interesting but I'm concerned that the bed material size modeled (a D50 of 8.6 mm) is smaller than actual current conditions. I've attached two photographs of the channel bed at the upstream end of the levees taken in September, 2014 and one can see that the channel bed is considerably coarser. We have seen a coarsening trend in bed material for several years now throughout lower Redwood Creek. This area is the source area for sediment entering the levee system, because little sediment is contributed by Prairie Creek. There are, of course, patches of sand and fine gravel in the levee system, but an acknowledgement that bed material may be coarser than modeled may be warranted.

Also on P. 4-8 is a discussion that suspended sediment concentration decreased
3.5 mg/L/yr since 1971. Considering that Redwood Creek commonly has winter flow concentrations of over 2000 mg/L (7000 mg/L is not uncommon), is such a small decrease physically significant?

Ricks (1995) is cited several times in the report. Be aware that, although the USGS Professional Paper was published in 1995, Cindy Ricks collected most of the data when she was working on her master's thesis, which was completed in 1983. So, estimates of sediment deposition are older than you may realize.

References:
Collins, B. and T. Dunne. 1990. Fluvial geomorphology and river-gravel mining: A guide for planners, Case studies included. California Dept. of Conservation Sepecial Publication 98.

Ricks, C. L. 1983. Flood history and sedimentation at the mouth of Redwood Creek, Humboldt County, California. Oregon State University. Corvallis, OR. Master's thesis.

Mary Ann

From: Michael Cipra <m.cipra@ncrlt.org>
Sent: Tuesday, December 02, 2014 10:19 AM
To: Seemann, Hank
Subject: RE: Redwood Creek PRC meeting #5 slides

Hank,
Great meeting yesterday, and the report is excellent.

My main comment is that the analysis of Alternative A3 seems to demonstrate that it is a scenario that falls short of providing adequate ecological benefits that define an estuary restoration. In addition, this scenario represents uncertainty and potential heightened risk to the adjacent pasture. I understand that for the county it is more attractive than A1, A2, or A4 because of the potential long-term decrease in levee maintenance cost. However, I would recommend a different direction. The worst-case outcome is inaction, as Jeff Anderson stated. Trying to advance A3 will very likely lead to inaction.

As for next steps and the role of the land trust, I would be happy to continue working with you on landowner outreach. For the future of agriculture and the ecosystem, the Redwood Creek situation is too important to ignore.

My best,

Michael Cipra
Executive Director
Northcoast Regional Land Trust
(707) 822-2242
PO Box 398
Bayside, CA 95524
www.ncrlt.org

From: Golightly, Paula <paula_golightly@fws.gov>
Sent: Wednesday, December 03, 2014 1:55 PM
To: Seemann, Hank
Subject: Re: Redwood Creek PRC meeting #5 slides

Hi Hank, I am sorry I couldn't make the meeting on Monday. I had to be in a meeting and on a conference call. I did review the report and the slide information. Thank you so much for sending. I have provided some comments below in response to the questions you have asked:

2. Feedback on draft report: The report is very well written and methodical. The one question I was left with though was given the various approaches outlined on page 8-28 "Approaches for Modifying the Federal Flood Control Project", how will the conceptual design planning process influence decision making of the Army Corps to allow for modification of the levee system in a reasonable time frame. Is the Section 408 Modification Process with the Army Corps the route you are hoping to best influence? It seems like by the time the Crops would allow any alternatives to occur via the approaches described the project area may need to be assessed again as existing conditions used for modeling and landownership may change in 5, 10 or 20 years. Such a challenging situation. Yikes!!

3. Open discussion on questions such as:

a. Are Alternatives A1, A2, and/or A3 worth pursuing? Yes- I think it is important to choose the alternative that best allows the system to deposit sediment as far upstream of the estuary as possible. Alternative 2 or 3 seems the best when trying to balance the human needs with fish and wildlife benefits but Alternative 6 is interesting as well. I wonder if Alternative 6 or 7 could be a fallback option if landownerships change or other factors allow for a greater opportunity. I can see though that having a seemingly more drastic back up option would likely be of concern to the Orick community.
b. What are the key uncertainties that should be evaluated further? Is there any way to evaluate potential changes in agricultural productivity with greater inundation and sediment deposits? Could the UC Ag Extension folks possible help with this question? In some areas greater deposition provides the best soil for growing grass and grazing livestock but the time period for grazing. Are there any historical records or accounts from families or others about how productive the grazing land was before the levees were built?
c. Are there opportunities to reduce costs? Not sure.
d. What are some considerations for phasing?e Not sure
e. What should happen next? I was wondering if one of the next steps is to engage with NRCS to talk with landowners about easement programs that may be of benefit to them Maybe this has already been done.

Is the next step then to finalize the report? How will it be used by the Corps? I can give you a call to answer these questions if it is easier.

Thanks for the opportunity to review this. Take Care, Paula

Paula Golightly
Supervisory Fish and Wildlife Biologist
Partners for Fish and Wildlife and Coastal Programs
U.S. Fish and Wildlife Service
1655 Heindon Road
Arcata, CA 95521
(707) 825-5123

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
West Coast Region
1655 Heindon Road
Arcata, California 95521-4573

In response refer to:
151401SWR2014AR00289

DEC 03 2014

Hank Seemann
Deputy Director - Environmental Services
Humboldt County Public Works Department
1106 Second Street
Eureka, CA 95501

Dear ~~Mr. Seemann~~ HANK:

Thank you for the opportunity to provide comments on the draft report for the Redwood Creek Estuary Restoration and Levee Rehabilitation Conceptual Design Project (report), dated November 14, 2014. NMFS commends you for providing detailed information, a comparative analysis and alternative development in the report, and for hosting numerous peer review committee meetings to discuss draft analyses and conceptual design progress. NMFS provides our comments below, which have been reviewed and agreed upon by the NOAA Restoration Center.

As noted by several participants in the December 1, 2014 meeting, and as described in the report, alternatives 6 and 7 clearly provide the greatest amount and the highest quality salmonid habitat. As such, these alternatives have the greatest potential to promote listed species recovery in Redwood Creek. Alternatives 6 and 7 also restore natural sediment routing processes, and construction of these alternatives would move the sediment transition zone upstream of the estuary allowing for a self-maintaining sediment regime in the lower estuary. Moving the sediment transition zone upstream of the estuary and encouraging sediment transport through the lower river system is a critical component of a functional Redwood Creek Flood Control Project (project). The sediment routing component of alternatives 6 and 7, when combined with re-authorization of the project to a more realistic flood level design, provides for the needed rehabilitation of the levee system and could become part of the solution to the ongoing maintenance needs of the project by addressing current design deficiencies. We encourage the County to fully evaluate alternatives 6 and 7 in the report, and to include these alternatives in the scoring matrix, and in the analysis of productivity and capacity described in section 8.4 of the report.

We understand that alternatives 1, 2, and 3 are currently more palatable to adjacent landowners. However, we believe that Alternative 3 does not provide enough salmon and steelhead habitat relative to the other options, as this alternative does not re-capture the South Slough. Re-capturing the South Slough is an important design element for many reasons, including providing flushing flows for sediment scour, providing additional habitat during backwater events, extending the length of the main channel, and providing additional habitat. In addition, Alternative 2 proposes to move Strawberry Creek out of much needed, functional riparian habitat and to re-align Strawberry Creek adjacent to Highway 101. We recommend that Strawberry Creek remain in its current location in order to maximize current riparian habitat benefits.

We are interested in discussing with you the pros and cons of different approaches to estuary restoration and levee rehabilitation, as we may be able to provide additional incentives to landowners that would help encourage their consideration of alternatives 6 and 7. In addition, we think that a more developed section in the report regarding potential negative effects and benefits to landowners would improve the report and could help in discussions with landowners. Specifically, for each alternative we recommend that you better quantify metrics such as the number of grazing days lost in the floodplain areas, dollar value of lost livestock production (if any), and potential benefits to the grazing areas of overbank flooding on agricultural soils and grasses, etc. The report should also include potential solutions to mitigate seasonal inundation of agricultural lands if needed, such as fence maintenance or feed supplementation. We also recommend that the report fully describe the benefits of estuary restoration to steelhead, as steelhead is not only a listed species, but also provide an instream fishery in Redwood Creek. Increases in steelhead abundance could encourage tourism and economic development in the Orick area.

We look forward to working with the County and other partners to restore the Redwood Creek estuary and to rehabilitate the Redwood Creek Flood Control Project. Please contact Leslie Wolff at (707) 825-5172 if you have questions, and to discuss next steps.

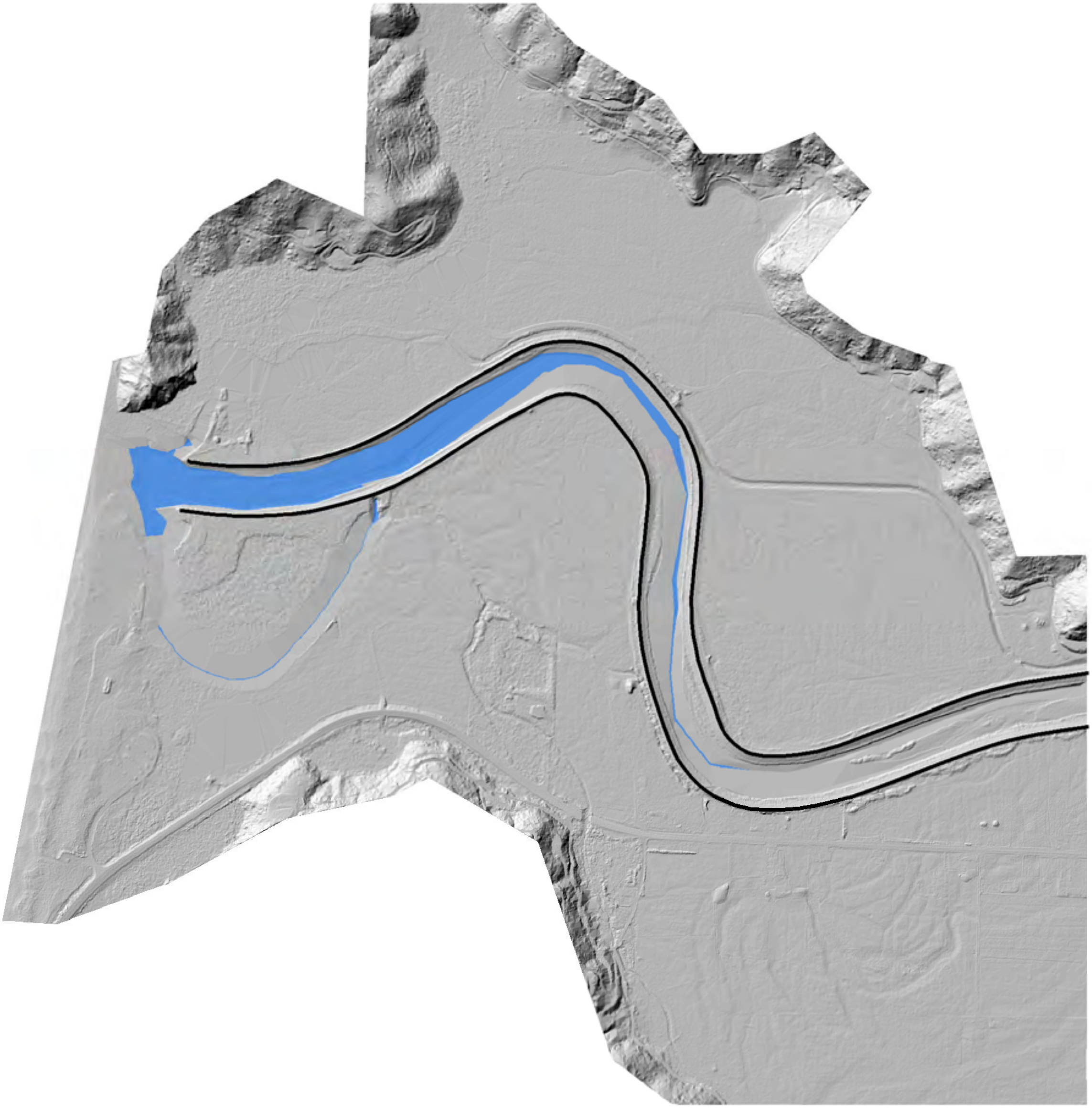
Sincerely,

for Irma Lagomarsino
Assistant Regional Administrator
California Coastal Area Office

Cc: Gayle Garman, Grant Manager, California Department of Fish and Wildlife

Appendix C

Inundation Maps



Redwood Creek, CA **Existing Condition Inundation MHHW**

Inundation area

Levee alignment

Proposed levee setback

Data sources:
LiDAR data: Humboldt Co
Inundation: NHE

0 500 1,000 2,000 Feet
0 125 250 500 Meters

N

Stillwater Sciences
www.stillwatersci.com

Redwood Creek, CA

Existing Condition Inundation Q1.5yr (16,000 cfs)

- Inundation area
- Estimated inundation area
- Levee alignment
- Proposed levee setback

Data sources:
LiDAR data: Humboldt Co
Inundation: NHE

0 500 1,000 2,000 Feet
0 125 250 500 Meters

N

Stillwater Sciences
www.stillwatersci.com

Redwood Creek, CA

Existing Condition Inundation Q5yr (32,000 cfs)

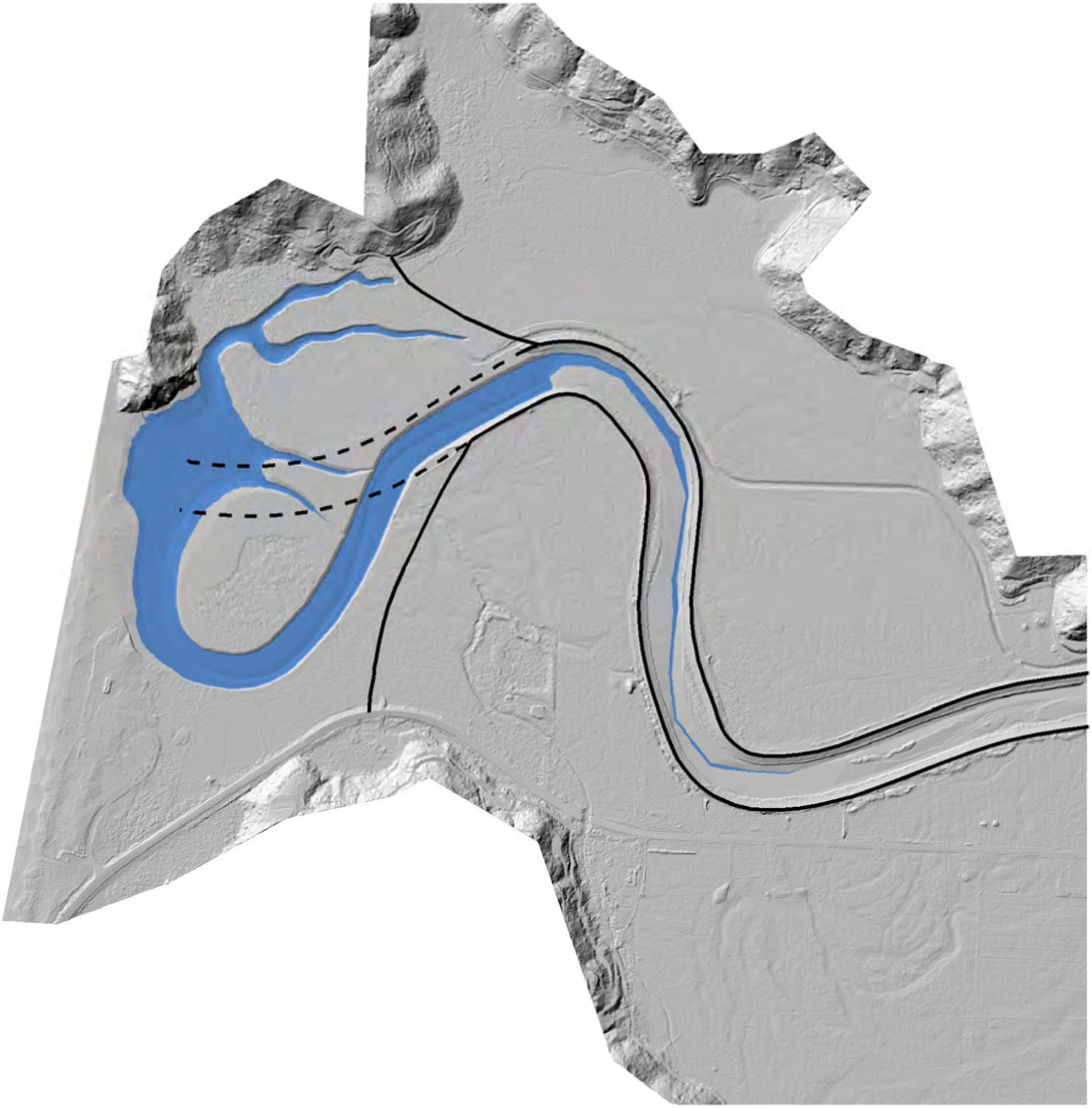
- Inundation area
- Estimated inundation area
- Levee alignment
- Proposed levee setback

Data sources:
LiDAR data: Humboldt Co
Inundation: NHE

0 500 1,000 2,000 Feet
0 125 250 500 Meters

N

Stillwater Sciences
www.stillwatersci.com



Redwood Creek, CA

A1 Inundation MHHW

Inundation area

Levee alignment

Proposed levee setback

Data sources:
LiDAR data: Humboldt Co
Inundation: NHE

0 500 1,000 2,000 Feet
0 125 250 500 Meters

N

Stillwater Sciences
www.stillwatersci.com

Redwood Creek, CA

A1 Inundation Q1.5yr (16,000 cfs)

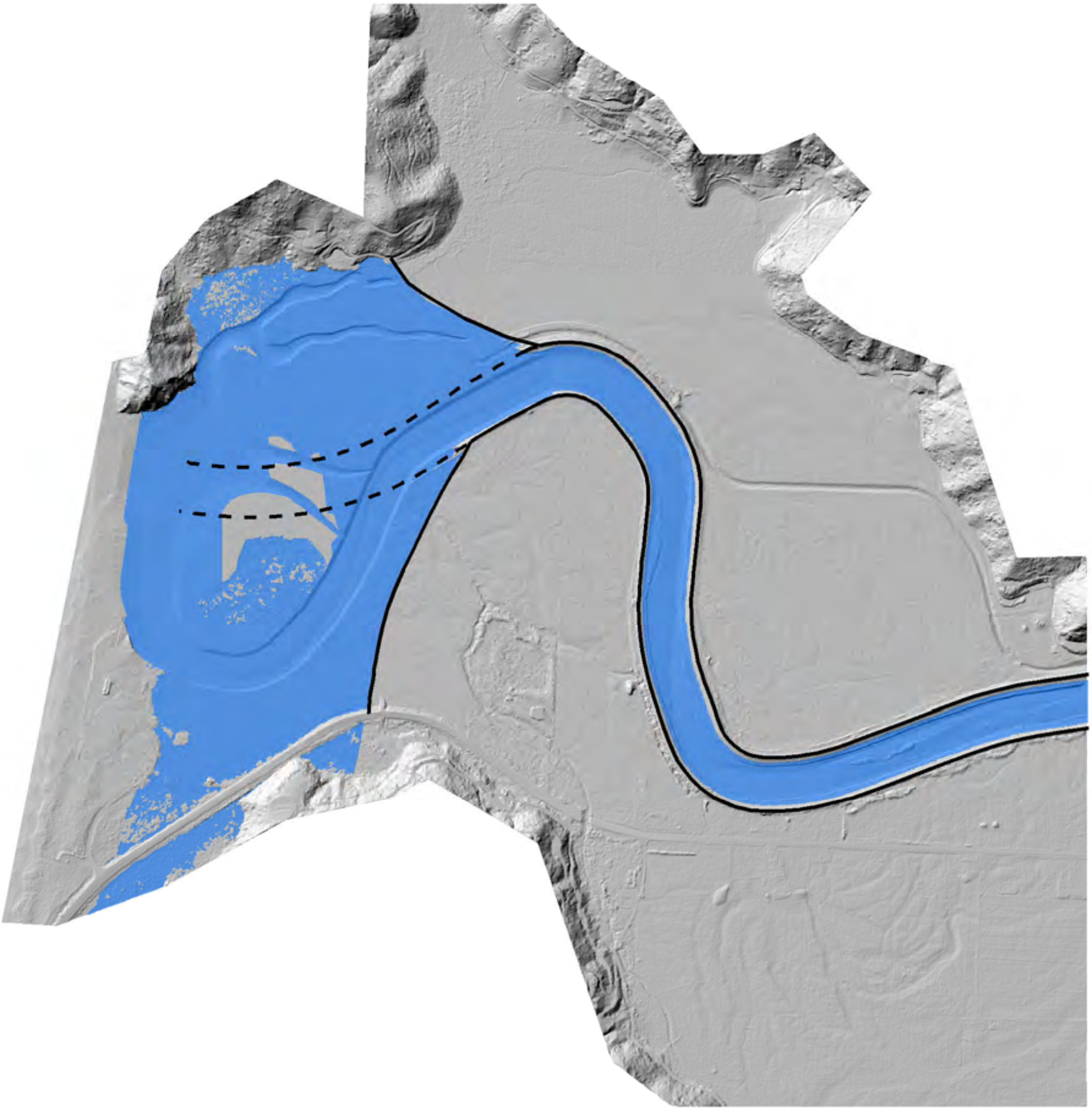
Inundation area

Levee alignment

Proposed levee setback

Data sources:
LiDAR data: Humboldt Co
Inundation: NHE

Stillwater Sciences
www.stillwatersci.com



Redwood Creek, CA

A1 Inundation Q5yr (32,000 cfs)

Inundation area

Levee alignment

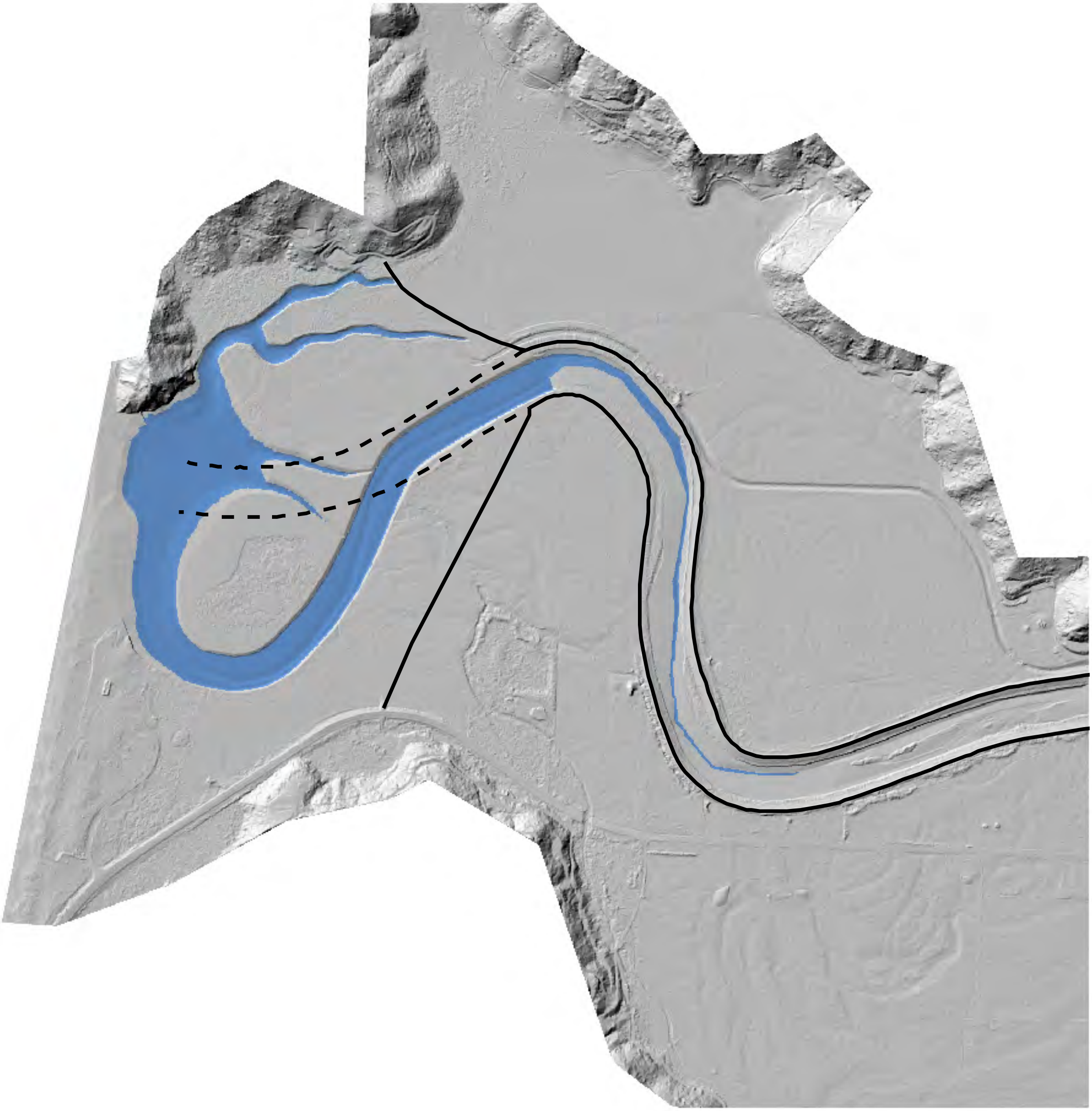
Proposed levee setback

Data sources:
LiDAR data: Humboldt Co
Inundation: NHE

0 500 1,000 2,000 Feet
0 125 250 500 Meters

N

Stillwater Sciences
www.stillwatersci.com



Redwood Creek, CA

A2 Inundation MHHW

Inundation area

Levee alignment

Proposed levee setback

Data sources:
LiDAR data: Humboldt Co
Inundation: NHE

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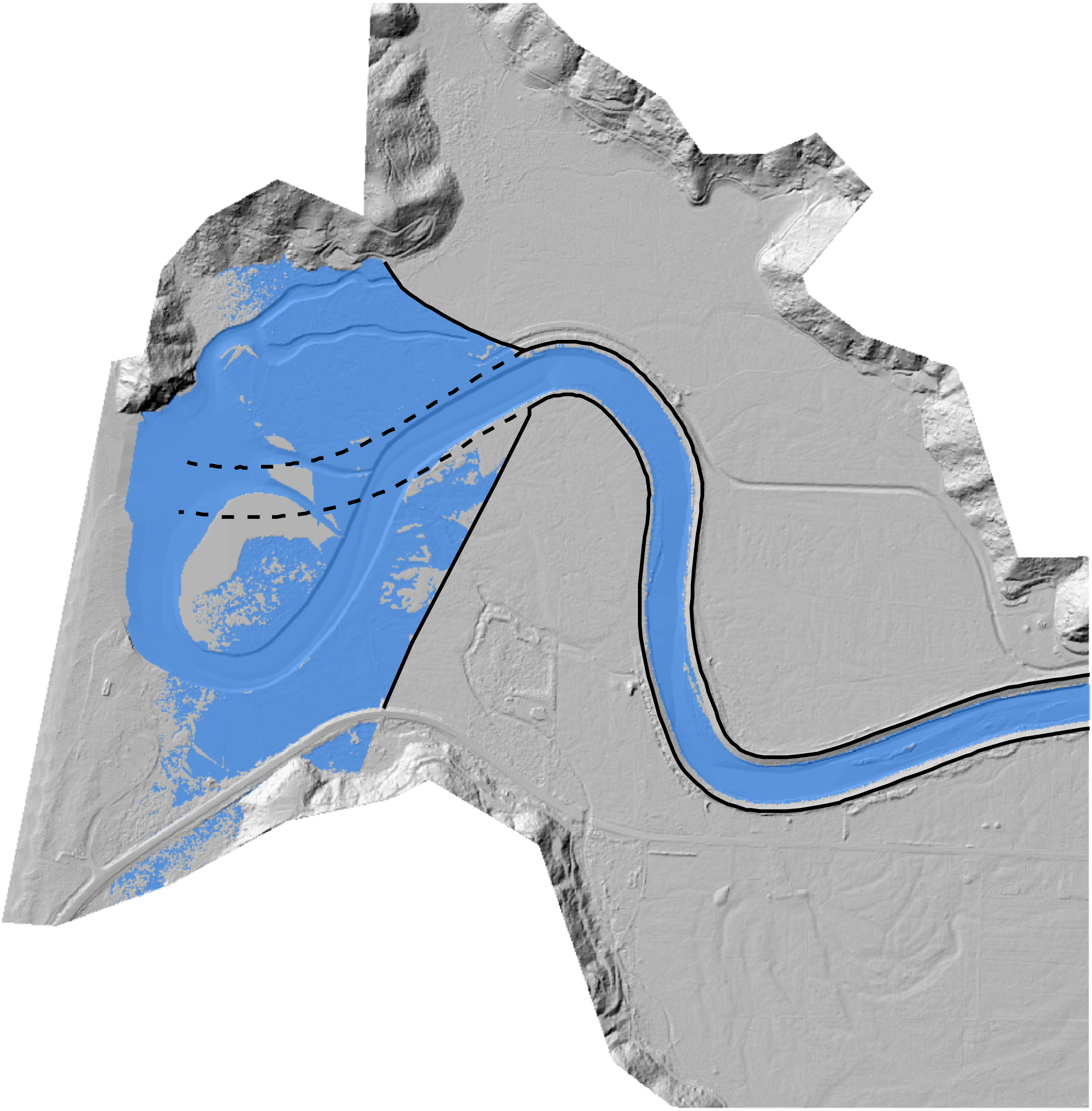


Redwood Creek, CA

A2 Inundation Q1.5yr (16,000 cfs)

Inundation area

Levee alignment

Proposed levee setback

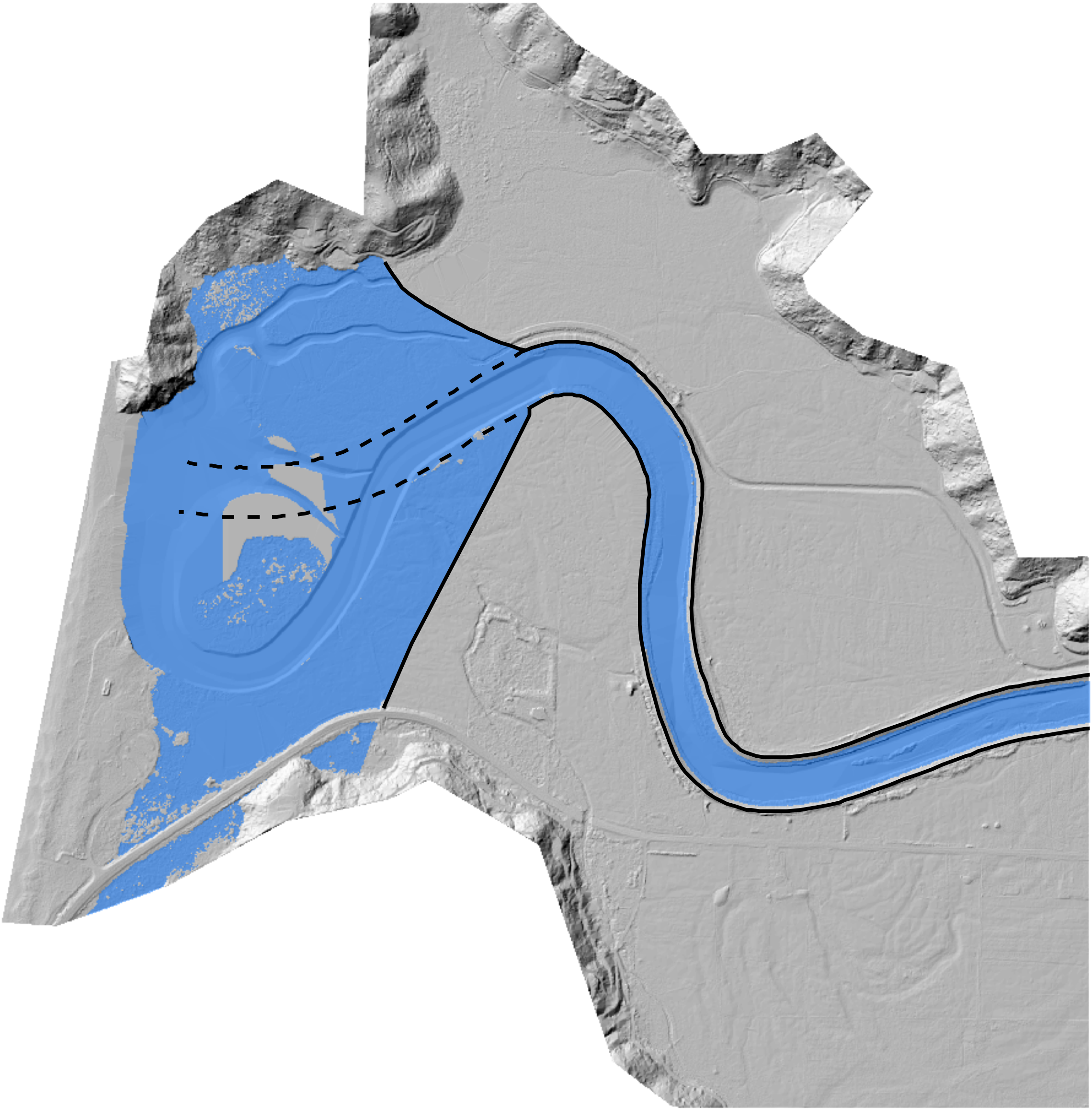
Data sources:
LiDAR data: Humboldt Co
Inundation: NHE

0 500 1,000 2,000 Feet

0 125 250 500 Meters

N

Stillwater Sciences
www.stillwatersci.com



Redwood Creek, CA

A2 Inundation Q5yr (32,000 cfs)

Inundation area

Levee alignment

Proposed levee setback

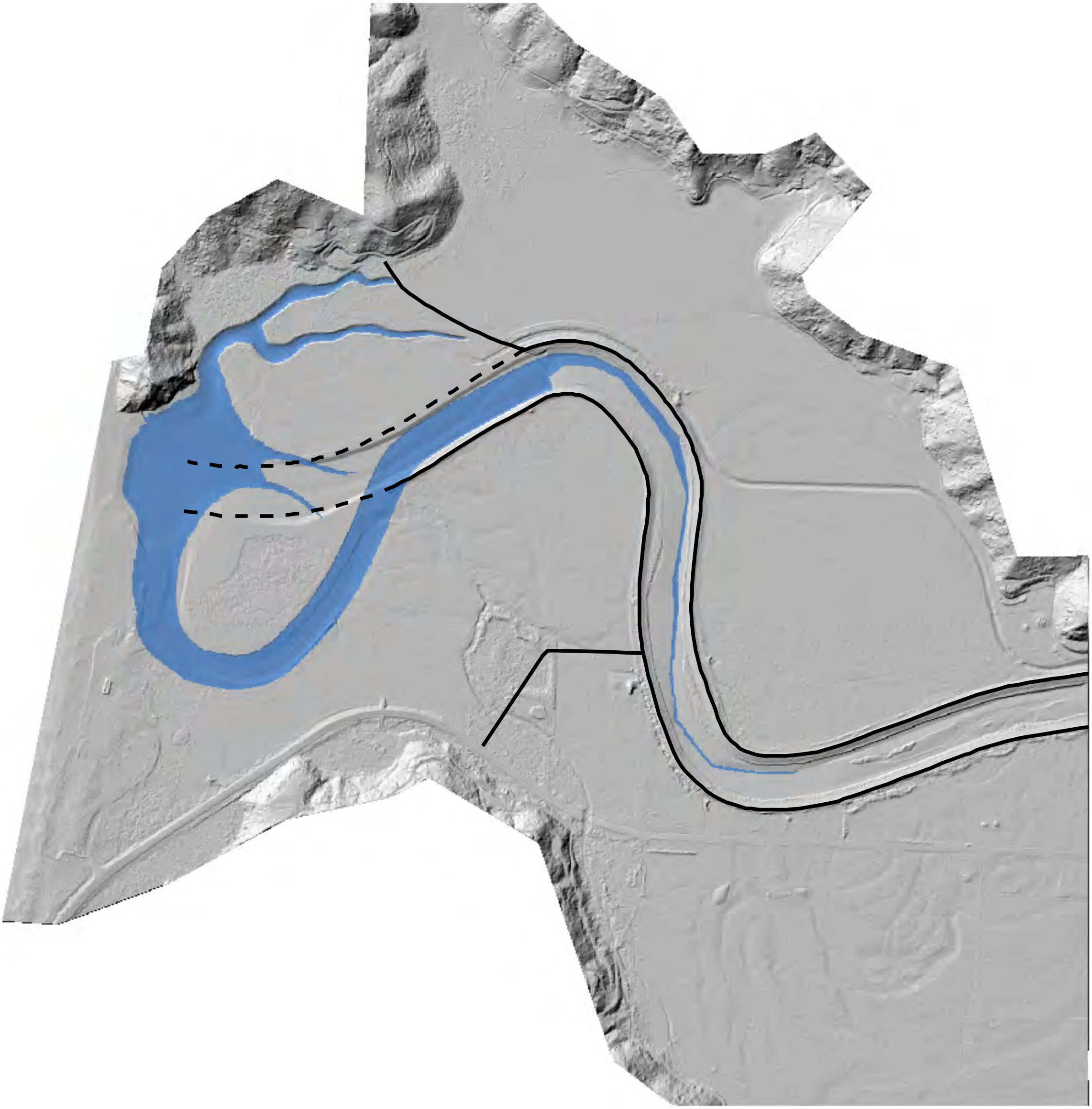
Data sources:
LiDAR data: Humboldt Co
Inundation: NHE

0 500 1,000 2,000 Feet

0 125 250 500 Meters

N

Stillwater Sciences
www.stillwatersci.com



Redwood Creek, CA

A3 Inundation MHHW

Inundation area

Levee alignment

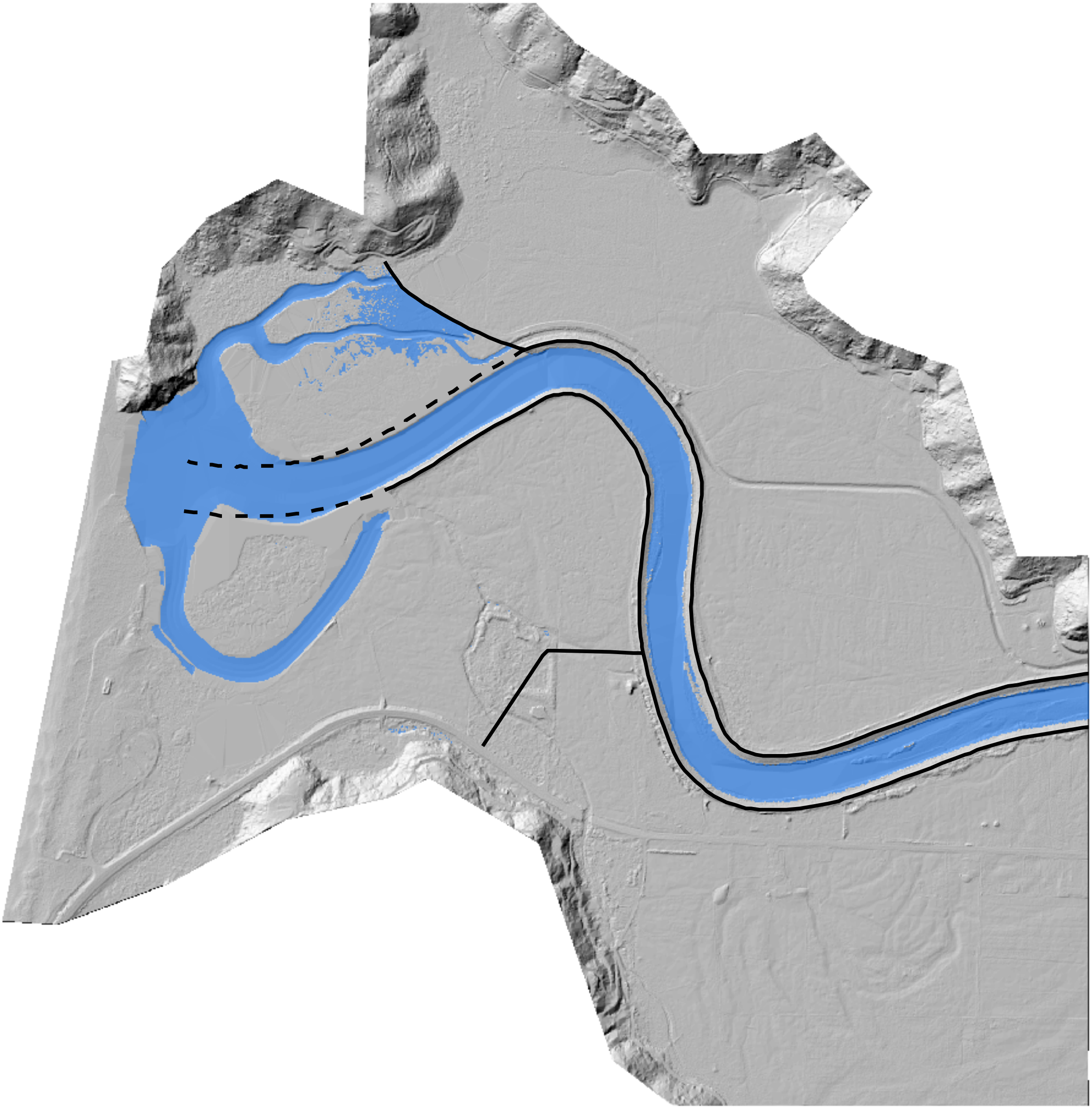
Proposed levee setback

Data sources:
LiDAR data: Humboldt Co
Inundation: NHE

0 500 1,000 2,000 Feet
0 125 250 500 Meters

N

Stillwater Sciences
www.stillwatersci.com



Redwood Creek, CA

A3 Inundation Q1.5yr (16,000 cfs)

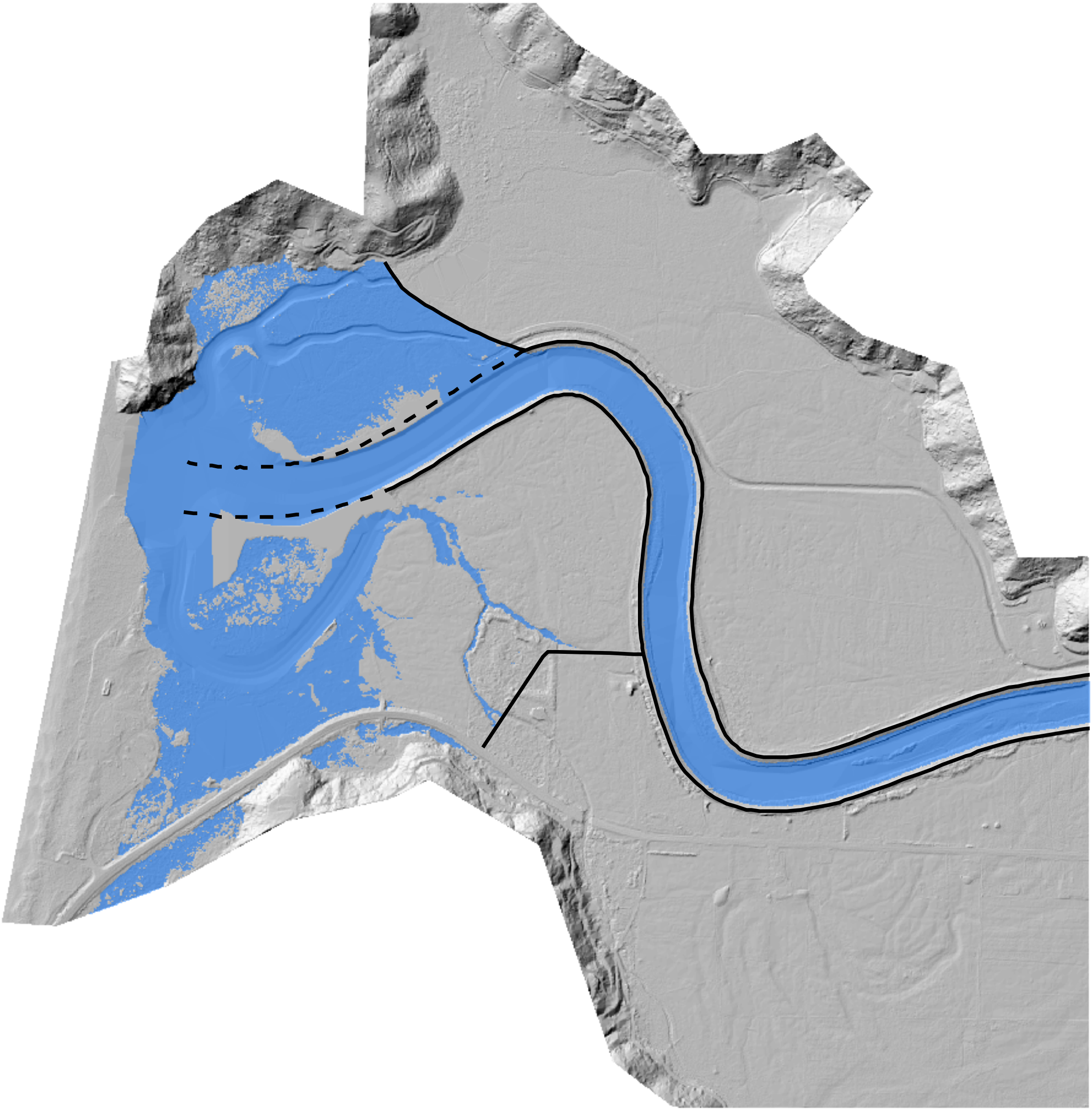
Inundation area

Levee alignment

Proposed levee setback

Data sources:
LiDAR data: Humboldt Co
Inundation: NHE

Stillwater Sciences
www.stillwatersci.com



Redwood Creek, CA

A3 Inundation Q5yr (3**2,0**00 cfs)

Inundation area

Levee alignment

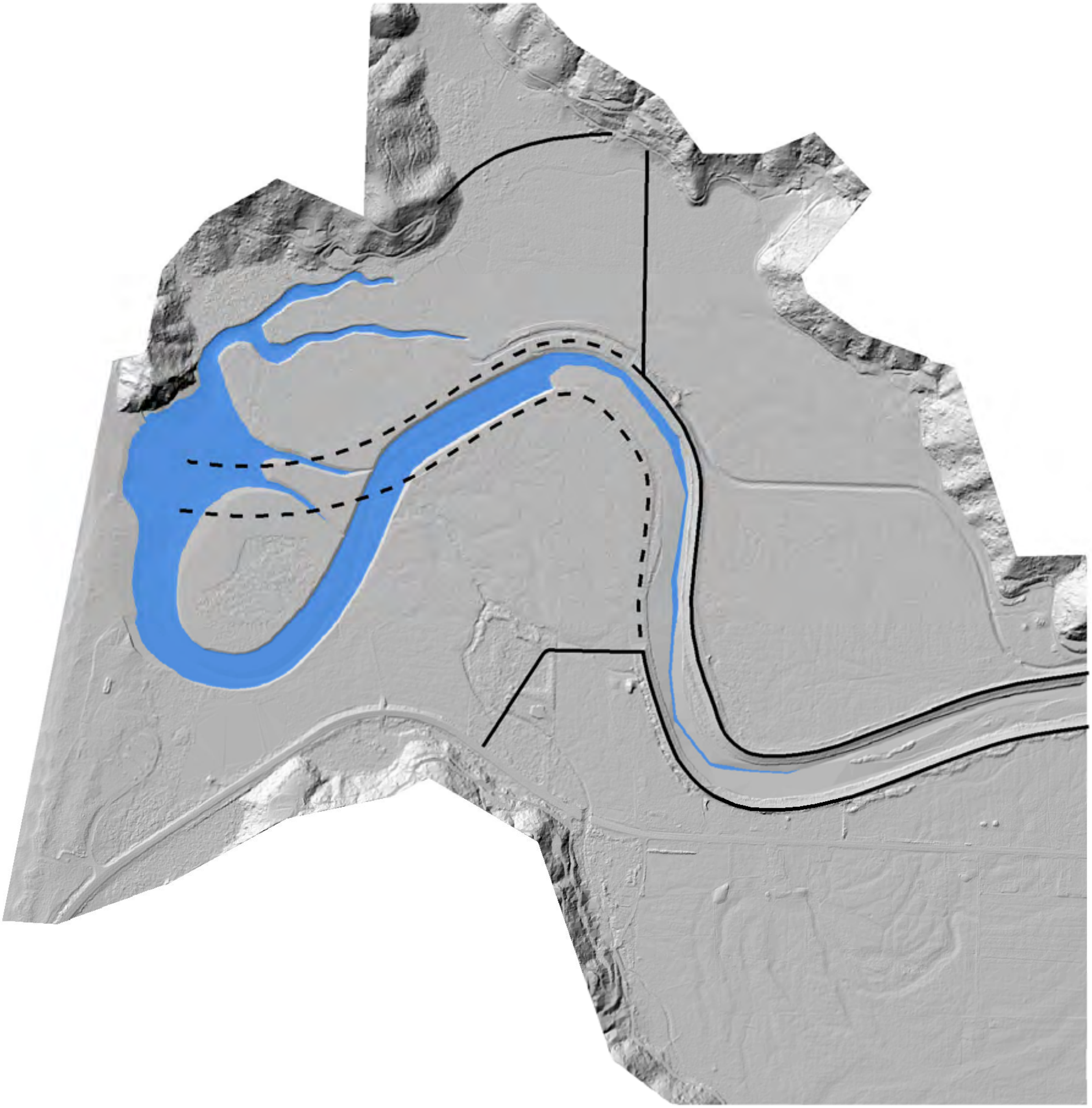
Proposed levee setback

Data sources:
LiDAR data: Humboldt Co
Inundation: NHE

0 500 1,000 2,000 Feet
0 125 250 500 Meters

N

Stillwater Sciences
www.stillwatersci.com



Redwood Creek, CA

A6 Inundation MHHW

Inundation area

Levee alignment

Proposed levee setback

Data sources:
LiDAR data: Humboldt Co
Inundation: NHE

Stillwater Sciences
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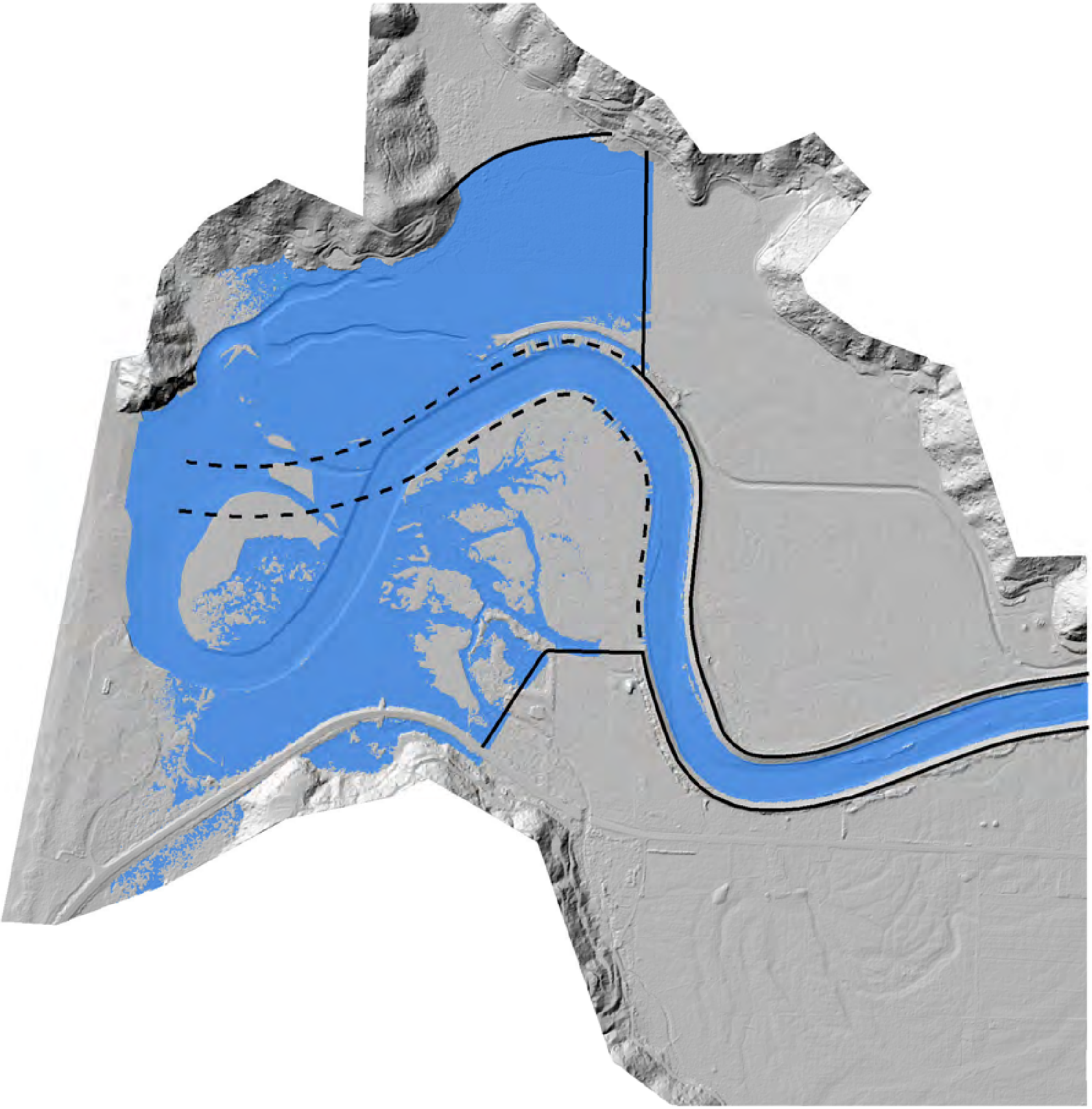


Redwood Creek, CA

A6 Inundation Q1.5yr (16,000 cfs)

Inundation area

Levee alignment

Proposed levee setback

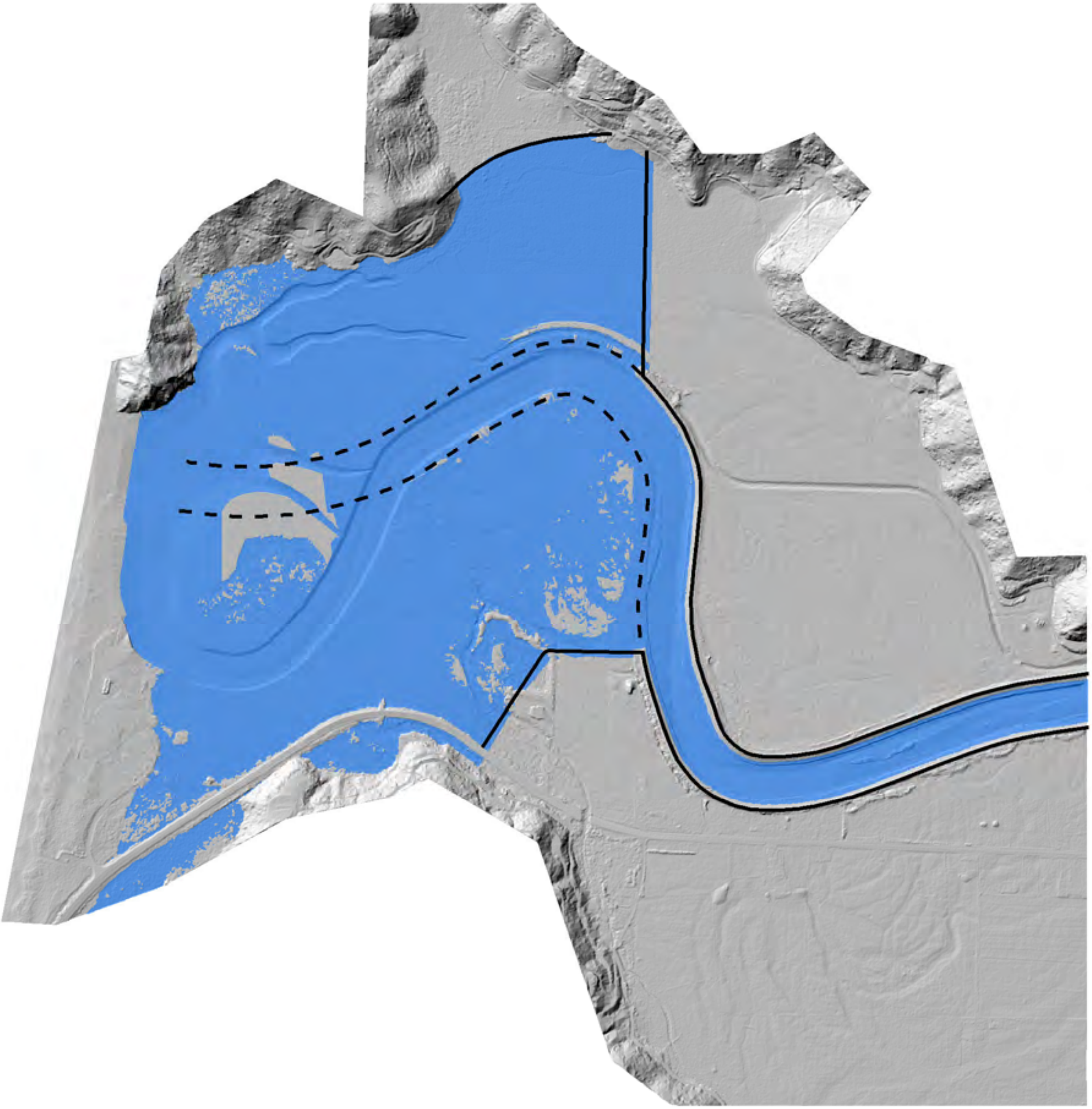
Data sources:
LiDAR data: Humboldt Co
Inundation: NHE

0 500 1,000 2,000 Feet

0 125 250 500 Meters

N

Stillwater Sciences
www.stillwatersci.com



Redwood Creek, CA

A6 Inundation Q5yr (32,000 cfs)

Inundation area

Levee alignment

Proposed levee setback

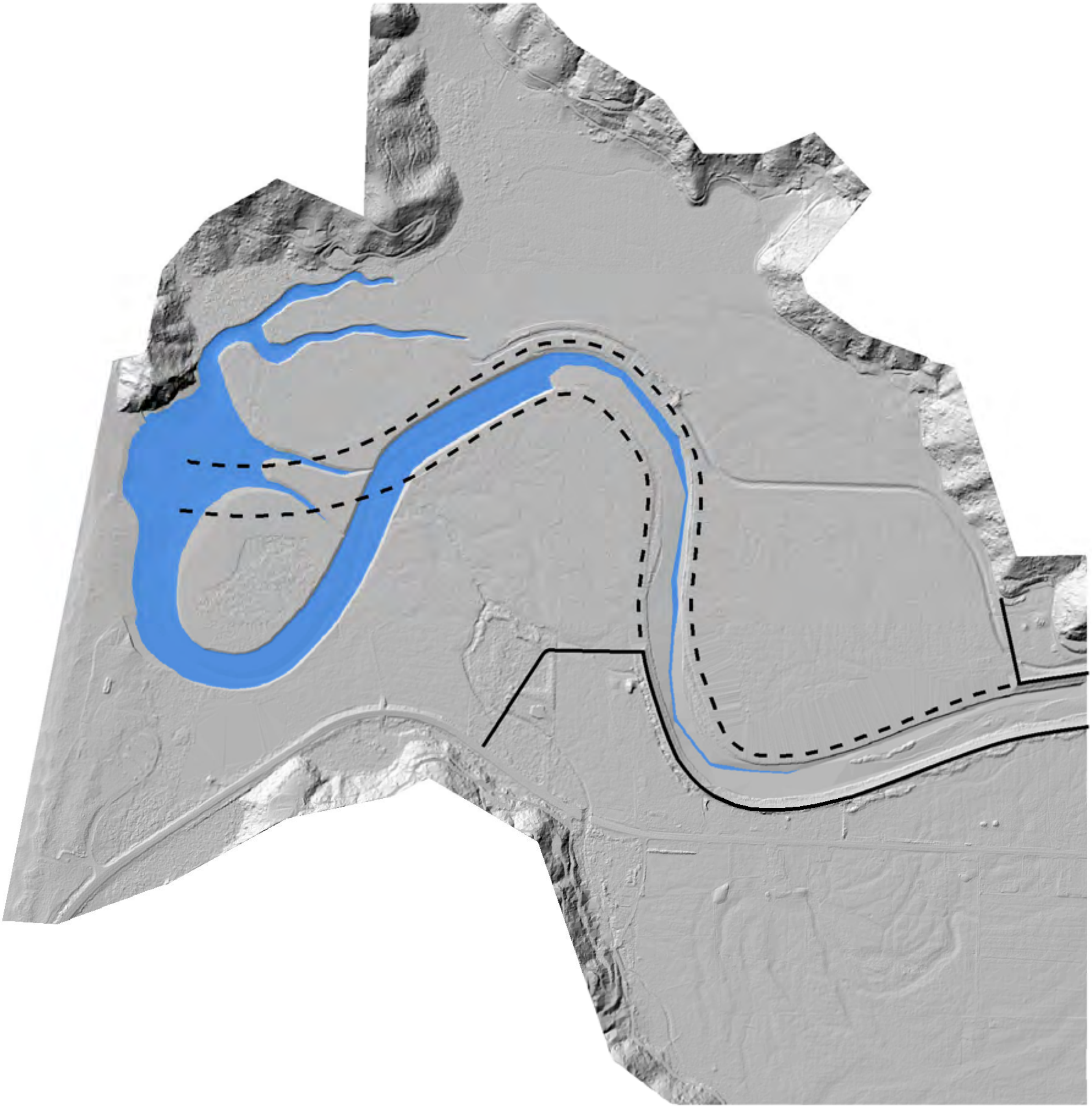
Data sources:
LiDAR data: Humboldt Co
Inundation: NHE

0 500 1,000 2,000 Feet

0 125 250 500 Meters

N

Stillwater Sciences
www.stillwatersci.com



Redwood Creek, CA

A7 Inundation MHHW

Inundation area

Levee alignment

Proposed levee setback

Data sources:
LiDAR data: Humboldt Co
Inundation: NHE

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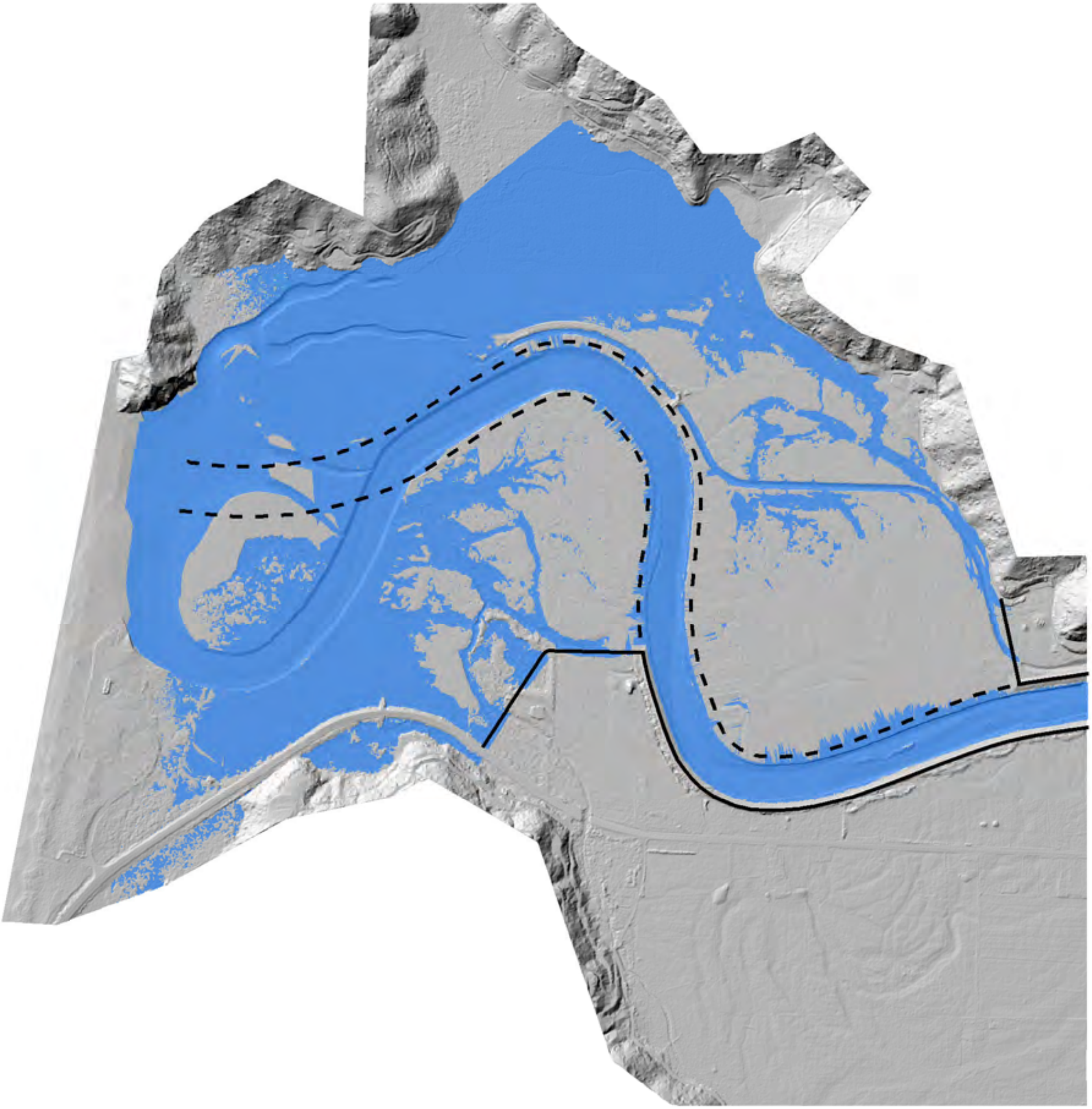
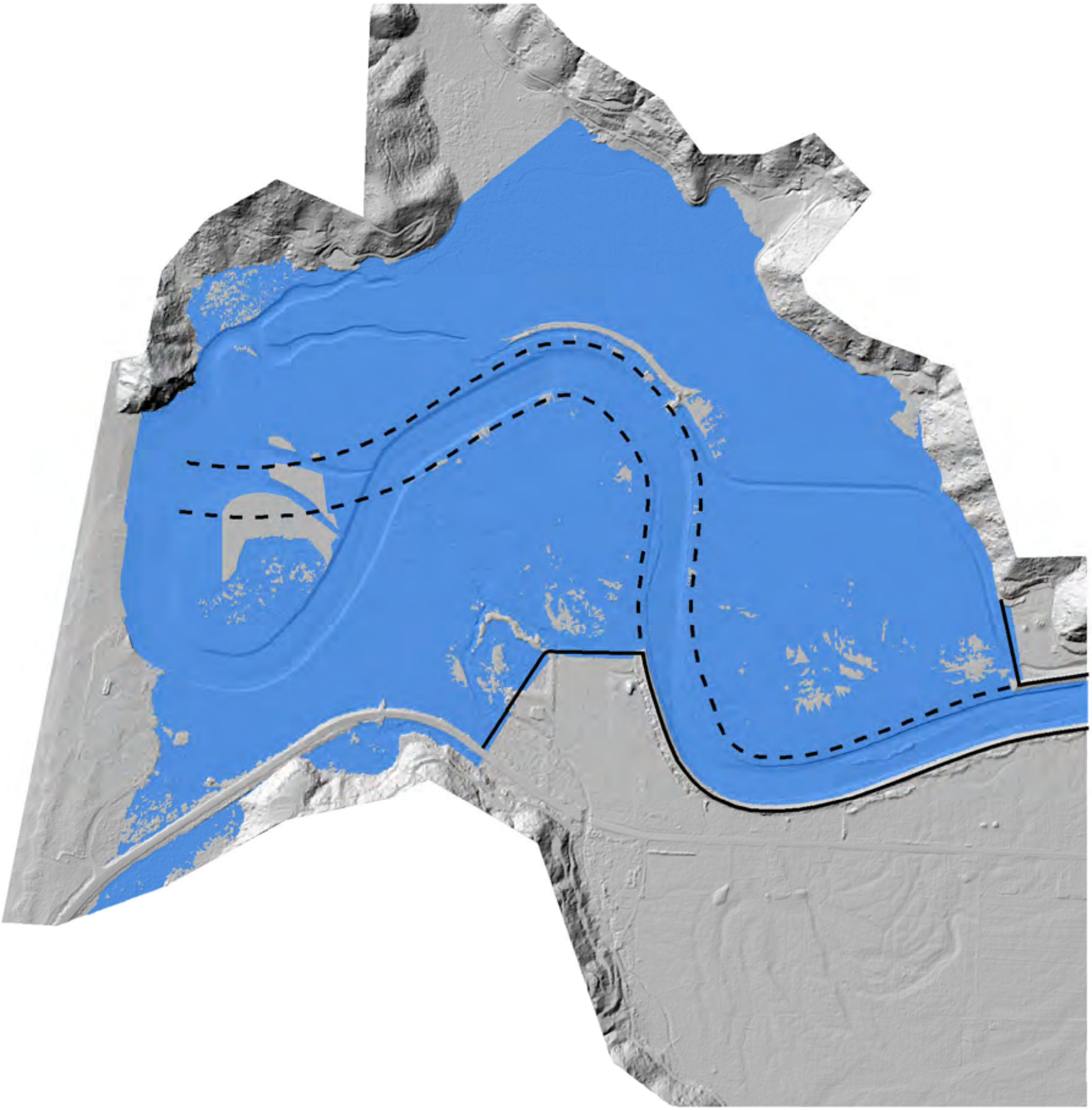


Redwood Creek, CA

A7 Inundation Q1.5yr (16,000 cfs)



Redwood Creek, CA

A7 Inundation Q5yr (32,000 cfs)

Inundation area

Levee alignment

Proposed levee setback

Data sources:
LiDAR data: Humboldt Co
Inundation: NHE

0 500 1,000 2,000 Feet
0 125 250 500 Meters

N

Stillwater Sciences
www.stillwatersci.com