Strawberry Creek Restoration Project
At Redwood National Park

Final Basis of Design Report

March 30, 2012

Prepared for:

Pacific Coast Fish, Wildlife and Wetlands Association

Redwood National Park

California Department of Fish and Game
Fisheries Restoration Grant Program
CDFG Agreement #P90910510

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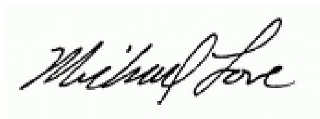

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Table of Contents

1. BACKGROUND

Strawberry Creek historically flowed through an expansive wetland system supported by several tributaries (Figure 1-1). The wetland system was located adjacent to the Redwood Creek estuary and helped support healthy salmonid populations within the basin. Existing and historical land use activities and introduction of invasive wetland vegetation has severely degraded the function and productivity of the wetland and affected fish access and geomorphic processes within Strawberry Creek and its tributary channels. The impetus for restoration of Strawberry Creek and adjacent wetland results from a desire on the part of both private landowners and Redwood National Park (RNP) to restore the stream to once again support coho salmon, as well as coastal cutthroat and steelhead trout.

1.1. Planning Report Recommendations

A report was prepared in 2008 by Michael Love & Associates, Inc. (MLA) for Pacific Coast Fish, Wildlife and Wetlands Restoration Association (PCFWWRA), the U.S. Fish and Wildlife Service (USFWS), and Redwood National Park (RNP), entitled *Lower Strawberry Creek Restoration Planning Report* (Planning Report). The Planning Report summarized the historical and present conditions of Strawberry Creek, extending from the South Slough estuary upstream 9,000 feet, ending upstream of the now abandoned South Operations Center (SOC) on the RNP property (MLA, 2008). The Planning Report focused on developing recommendations that would lead to achieving an overall project goal of restoring self-sustaining stream channels and wetlands within Strawberry Creek with suitable fish habitat and access, water quality, and biological productivity to support non-natal rearing of salmonids.

The Planning Report characterized the hydraulic, hydrologic, topographic, geomorphic and biological aspects of Lower Strawberry Creek at a planning level and made implementation recommendations for restoration. The Planning Report outlined specific restoration implementation objectives for the Strawberry Creek Watershed, including:

1) Removal and control of invasive reed canary grass from portions of the stream channel, wetland, and floodplain;
2) Revegetation of the riparian corridor with appropriate native species;
3) Fencing riparian corridors to inhibit riparian area cattle grazing and associated streambank erosion;
4) Replacement of undersized stream crossings that impede fish passage and natural geomorphic processes;
5) Restoration of portions of the stream channels to re-establish natural geomorphic processes; and
6) Continued elimination of critical erosion and sediment delivery from the upland watershed to the stream and wetland.

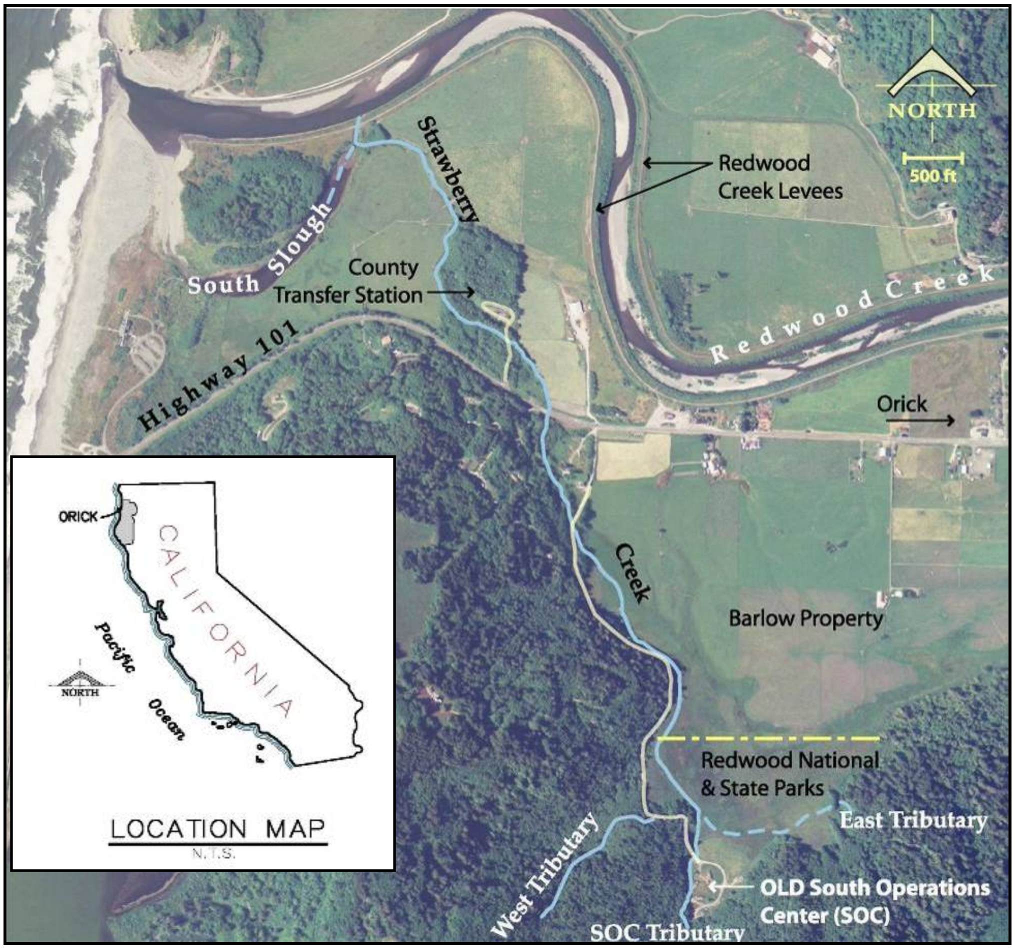


Figure 1-1. Location of Strawberry Creek as it flows from south to north along the western edge of the Orick Valley and into the South Slough of Redwood Creek.

The Planning Report included recommended phasing of implementation to best achieve restoration objectives. The recommended restoration sequence proceeded from downstream to upstream. The Phase 1 recommendations are currently being implemented by PCFWWRA with USFW-provided funding. Phase 1 consists of removal of in-channel reed canary grass *(Phalaris arundinacia*) along a 3,270-foot stretch of Strawberry Creek from Highway 101 upstream to the boundary with RNP, followed by aggressive planting of 5 acres of riparian vegetation and construction of 4,000 feet of livestock exclusion fencing. The objective of the reed canary grass removal and riparian restoration is to shade-out the reed canary grass along and within the stream channel. The reduction of reed canary grass presence will eventually increase flow conveyance and sediment transport, lower seasonally high water elevations, maintain an open channel for unimpeded fish access, and improve channel water quality.

Phase 2 recommendations encompass sections of Strawberry Creek, the West Fork Tributary and a small portion of the vast wetlands located on the RNP property. This report presents the basis of design for Phase 2 of the project.

Final engineering design of Phase 3, replacement of an undersized and perched culvert at the Humboldt County Waste Transfer Station, has been funded and design is underway. It is expected that Phase 3 will be constructed in 2012 or 2013.

1.2. Phase 2 Project Components and Objectives

RNP, through PCFWWRA, has retained the services of Michael Love & Associates to develop preliminary through final design drawings for Phase 2 of the Strawberry Creek Restoration Project, located within the boundaries of RNP upstream of Highway 101 (Appendix A and Figure 1-1). Redwood National Park provided funding for a portion of the project design development. Additionally, the project has been awarded funding from the California Department of Fish and Game (CDFG) Fisheries Restoration Grant Program (Agreement P90910510) to prepare a geologic assessment of the project area and to develop final engineering plans and specifications in 2011/2012. It is anticipated that implementation of the project will occur in the summer and fall of 2012.

Phase 2 of the Strawberry Creek Restoration Project includes the following components:

- Restoration of approximately 3 acres of wetland area to create non-natal rearing and foraging area for juvenile salmonids;
- Construction of 1,113 linear feet of slough channel with 578 feet of interconnected side channels in the restored wetland areas to improve fish access and create off-channel foraging and rearing areas;
- Channel realignment and restoration of 387 feet of Strawberry Creek and the West Fork Tributary upstream of the wetland area to restore fish habitat, improve fish passage and access to upstream habitat, and facilitate stable geomorphic processes;
- Replacement of an undersized culvert on the West Fork Tributary to improve fish passage and conveyance of water, sediment and debris; and
- Removal of invasive plant species and re-establishment of 1.5 acres of riparian area restored wetland and along the restored stream channels to improve fish access, improve water quality, and create riparian diversity.

The selection of project components and project extends was determined through discussions with RNP, CDFG and working with a Project Advisory Group. Further discussion of how project components were selected is presented in the following section.

1.3. Project Development

1.3.1. Initial Project Components

In March 2010 MLA prepared preliminary design drawings and a technical design memorandum for the project (MLA, 2010a and 2010b) at the direction of RNP. The design plans included restoration of approximately 1,700 feet of the Strawberry Creek, extending from the southern RNP property line, through a wetland area, to upstream of the SOC area, and included the replacement of the undersized Strawberry Creek culvert on the SOC Access Road. The design plans also detailed replacement of the of West Fork Tributary culvert on the SOC Access Road and channel restoration upstream and downstream of the culvert.

In the 2010 plan set, the project limits on Strawberry Creek extended further than originally proposed in the 2008 planning report due to the identification of a long-stringer bridge that forms a 6-foot drop in the channel profile and creates a total blockage to fish movement. The design plans included removal of the log stringer bridge and restoration of the channel reach a short distance upstream of the bridge to provide fish access to upstream habitat.

The excavated material from the channel restoration and culvert replacements was specified to create elevated planting mounds within an approximately 3-acre wetland area. Riparian vegetation planted on the mounds would shade-out and outcompete two invasive plant species present in the wetland (*Phalaris arundinacea and Glyceria fluitans).*

1.3.2. Project Advisory Group

A project advisory group composed staff from RNP, CDFG, USFWS, National Marine Fisheries (NMFS), PCFWWRA, MLA and Pacific Watershed Associates (PWA) met on October 28, 2010 for a field visit to the project area and to review the design plans. The intent of the meeting was to solicit comments from the advisory group regarding the project and to identify any additional studies necessary for the project.

Numerous valuable comments were received at the meeting and through written comments after the meeting. These comments were incorporated into the design as appropriate. Several critical questions were identified that suggested additional studies or analyses were necessary to establish the final scope of the project. These questions included:

1. What is the extent and quality of the fish habitat upstream of the failing long stringer bridge, and would it support coho salmon?
2. Does the benefit of fish access to Strawberry Creek upstream of the SOC Access Road culvert merit the high construction cost for the culvert replacement and channel restoration upstream of the culvert?
3. Should the restored reach of Strawberry Creek upstream of the SOC access road be in a different location than proposed?
4. What are the uncertainties associated with channel avulsion and subgrade conditions given that project construction will occur on an alluvial fan and in an aggraded channel upstream of the failing stringer bridge?

The group agreed that restoring the wetland and fish access to the West Fork Tributary would provide ample non-natal rearing habit to merit their costs. Both NFMS and USFWS indicated that they felt that the West Fork Tributary provided suitable coho rearing habitat.

1.3.3. Results of Additional Studies

Subsequent to the October 2010 meeting, personnel from USFWS performed a fish habitat assessment of Strawberry Creek upstream of the culvert crossing using CDFG protocols. Additionally, a geologic investigation of the project area was performed by PWA.

Fish Habitat Assessment

The fish habitat assessment, conducted by USFWS, identified approximately 900 feet of continuous channel upstream of the Strawberry Creek culvert that may provide suitable spawning and rearing habitat for coho salmon, though the habitat is more suitable for cutthroat trout. The habitat assessment also noted that fish access would be limited within this 900-foot reach due to numerous large drops and debris jams, including the 6-foot drop at the failing log stringer bridge. The assessment found that habitat ended at the upstream end of this 900-foot reach due to the small size of the channel and heavy choking with woody debris. Details of the fish habitat assessment are presented in Appendix B.

Geologic Assessment

The geologic assessment and report confirmed that the upper reaches of Strawberry Creek are located on an active alluvial fan that is functioning as a flooding fan (PWA, 2011). The assessment found that there is a high likelihood of potential channel avulsion on the upper alluvial fan, upstream of the project area. A channel avulsion on the upper fan could cause the stream to abandon the restored channel reach and new culvert. Preventing a channel avulsion would necessitate construction activities higher on the fan than planned, and would require substantial forest clearing and grading of equipment access routes.

Additionally, the geologic report indicated that there are uncertainties associated with excavation of a new channel and stable tie-in through the slash and stored sediment that could increase project costs or reduce the effectiveness of the project. These uncertainties include the difficulty of excavation and compacting backfill around large pieces of slash, potential for loss of baseflow, and potential release of stored sediments associated with construction activities.

The geologic report also provided information on the geologic context of the project area and subgrade conditions to be expected during the construction process. Recommendations from the geologic report were incorporated into the current design as appropriate.

1.3.4. Alternatives Analysis and Resolution of Project Components

A second meeting was held on February 7, 2011 to discuss the results of the additional studies and to identify the final scope of the project for Strawberry Creek. Attendees at the meeting included staff from Redwood National Park, PCFWWRA, PWA, and staff from CDFG. In preparation for the meeting, MLA prepared four alternative channel alignments and profiles, along with a matrix of considerations that reflected the ability of each alternative to meet project objectives and constraints and address risks and uncertainties (Appendix C).

The meeting attendees agreed that the cost and uncertainties associated with replacing the Strawberry Creek culvert and restoration or relocation of the Strawberry Creek upstream of the culvert does not merit the benefit of establishing fish access to a maximum of 900 feet of channel with suitable habitat. Therefore, it was concluded that the upper limit of restoration of Strawberry Creek would end at the outlet of the existing Strawberry Creek culvert and the existing Strawberry Creek culvert will remain as a barrier to fish passage.

It was agreed that the scope of the culvert replacement and restoration of the West Fork Tributary and wetland area will remain unchanged, but will reflect comments from the 2010 design plans and subsequent meetings. Meeting minutes for the February 7, 2011 meeting are presented in Appendix C.

2. HISTORICAL AND CURRENT CONDITIONS

Restoration of Strawberry Creek requires an understanding of the historical geomorphic and hydrologic conditions throughout the project area. The current project, Phase 2, is confined to RNP property. It involves a portion of the existing wetland complex and the lower portions of the Strawberry Creek mainstem and West Fork Tributary channels as they enter the valley bottom. The following sections briefly describe the historical and current geomorphic conditions and land use history for each of the main project areas. These descriptions are based on findings documented from the Planning Report, as well as additional interpretation during the detailed field investigations associated with the Phase 2 design development. Further detail of historical aerial photograph analysis is also presented in the project geologic report (PWA, 2011).

2.1.1. Wetland Complex

<u>Summary of Historical Wetland Conditions</u>

The wetland complex lies within the historical floodplain of Redwood Creek, which is now constrained by flood control levees (Figure 1-1 and Figure 2-1). Based on topography, the existing wetland complex is formed by a series of depressions that are likely remnant channels formed by Redwood Creek, possibly during large overbank flood events. These depressions follow the base of adjoining hillslopes along the southern and western edges of Orick Valley.

The 2008 Planning Report provides an interpretation of the historical wetland complex found in the low gradient portions of Strawberry Creek on what is now RNP property. The historical interpretation was based on a sequence of aerial photographs dating back to 1936, when the wetland complex within the southwestern corner of Orick Valley was relatively undisturbed. These interpretations were combined with RNP-documented descriptions of the area from local residents who were involved in the original clearing of the land. The following is a description of the wetland complex provided in the Planning Report:

> "Historic accounts indicate that the project area was dominated by large salmonberry and Sitka Spruce "big enough to hold a dance on" (RNP, 1986). Spruce forests were described as extending from the hillslopes to downstream of Highway 101. Residents indicate that when land was cleared for agriculture, at least 160 large spruce trees were cleared from the floodplain on what is currently the RNP property (RNP, 1986). In fact, small patches of higher ground within the existing wetlands still contain Sitka spruce snags, stumps, and saplings [Figure 2-2]. By the time of the 1962 aerial photograph, nearly all of the historic wetland area had been cleared and drained for cattle pasture and the forested upland areas behind the old SOC had been recently logged."

A 1968 aerial photograph (Figure 2-1) shows nearly all the wetland complex on the current day RNP property as cleared and drained for cattle pasture, and Strawberry Creek ditched. Interviews with residents living in the area before the forest was cleared indicated that, to make pasture, the slough channels in the spruce wetland were filled, the trees felled, the stumps dynamited, and the wet area ditched (RNP, 1986).

The constructed ditches captured flows from the various tributaries of Strawberry Creek as they intersected the valley floor and routed the water north along the base of the hillslope until discharging into the Redwood Creek estuary. Near the current day northern RNP property boundary, a raised and graveled berm (referred to as the Ranch Road Levee in the Planning Report) was constructed to provide a dry path for cattle to cross a low-lying area where the West Fork Tributary enters the valley (Darci Short, RNP, Personal Communication, 2010). The ditched Strawberry Creek channel was located along the eastern toe of this berm.

Summary of Current Wetland Condition

Following acquisition of the property by Redwood National Park in the early 1980's, cattle were removed from the drained wetland and the land has remained unmanaged since then. Currently, the entire ditched channel and floodplain in this area is seasonally inundated approximately 2 to 3 feet deep. The wetland area is colonized with a floating mat of water mannagrass (*Glyceria fluitans)* (L. Arguello RNP, Personal Communication, 2010) and reed canary grass (*Phalaris arundinacea*), both highly invasive non-native grasses (Figure 2-2). These grasses block flow conveyance in Strawberry Creek, inhibit fish access, and are believed to create extremely low summer dissolved oxygen levels due to organic decomposition (RNP, 2006).

The stream channel flows into a deep pond immediately downstream of the RNP property, which directly influences water levels in the wetland complex on the RNP property. The pond outlet and downstream channel are currently choked with reed canary grass, impeding stream flows and raising the seasonal water level (MLA, 2008). During wet periods water levels on the RNP property rise to high enough to flow across low-lying ground on the adjacent pasture. Gaining control of the reed canary grass downstream of RNP through shading by riparian vegetation (Phase 1 implementation, currently underway) is expected to improve flow conveyance and lower seasonal high water levels within the upstream wetland areas.

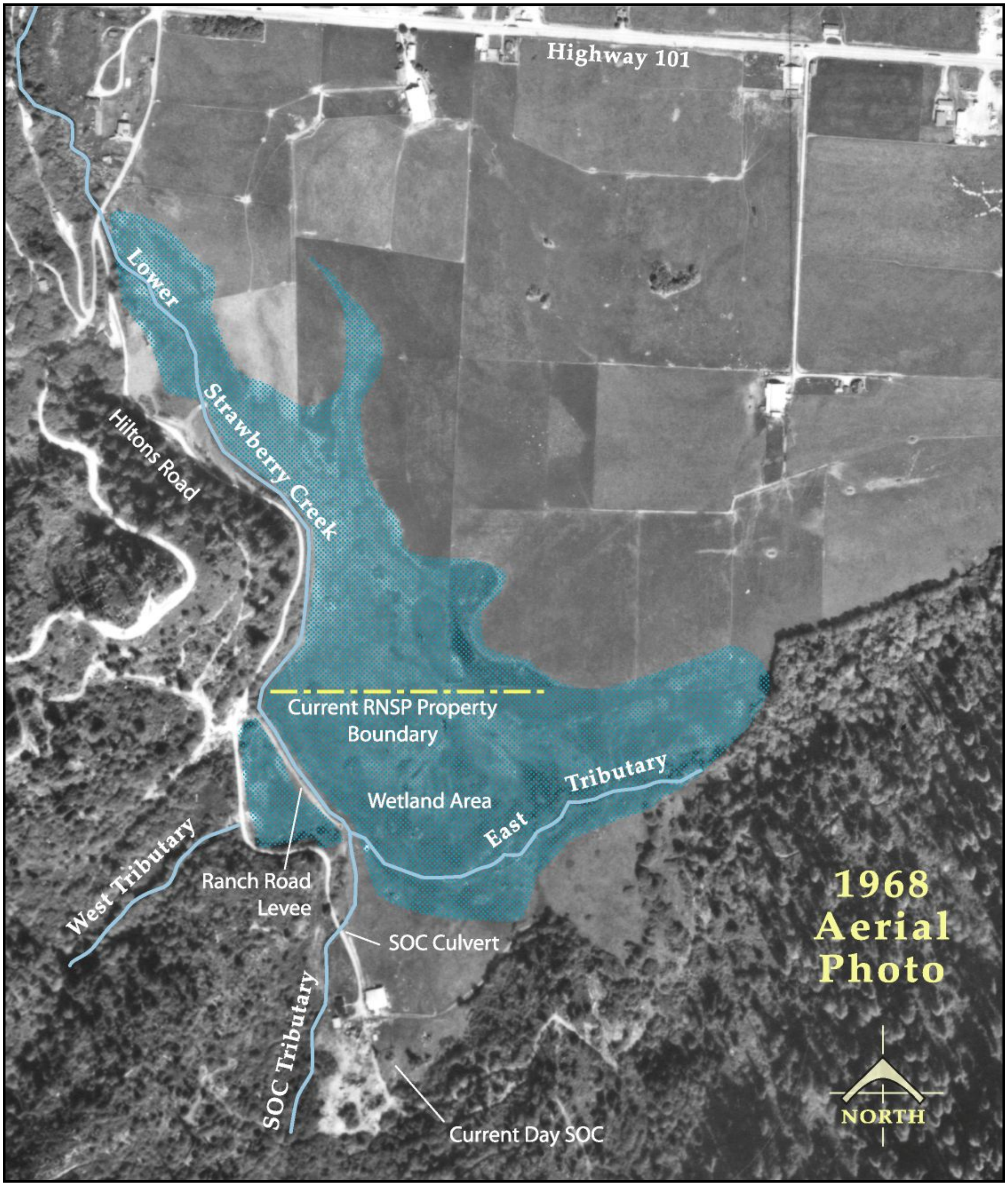


Figure 2-1. 1968 aerial photograph of Lower Strawberry Creek. Shading indicates approximate limits of historical wetland area. From the Planning Report (MLA, 2008).

Figure 2-2. Strawberry Creek wetland complex covered with reed canary grass and a mat of water mannagrass, floating approximately 2 feet above the ground surface. Note the small spruce tree on a hummock in the wetland area.

2.1.2. Strawberry Creek Upstream of the Wetland Complex

Historical Conditions

At the southwestern corner of Orick Valley, the mainstem of Strawberry Creek originates from steeply sloping hills. It flows down the hillslopes through a confined valley and onto an alluvial fan before reaching the valley floor. The 1936 aerial photograph shows the alluvial fan being densely forested with conifers; likely a combination of Sitka spruce and coastal redwoods (several large redwood snags are still located on the fan). Based on recent topographic surveys, the alluvial fan within the SOC area is nearly 1,000 feet in length, more than 750 feet wide at its base, and has an overall slope of about 4.5%.

The location of the stream channel is not evident in the 1936 or 1948 aerial photographs. The overall channel slope would have been similar to the slope of the alluvial fan. At these steep slopes in densely forested watersheds, the prevalent channel type is typically wood forced step-pool morphology (Montgomery et. al., 1995; Montgomery and Buffington, 1997). Based on the steepness and erodibility of the contributing forested hillslopes, it is reasonable to assume that the historical channel morphology was one dominated by large wood in the bankfull channel and on the floodplain, combined with episodic delivery of sediment and large woody debris associated with mass wasting events. On a forested fan such as this, large sediment pulses, large wood recruitment, and extensive debris jamming commonly cause channel avulsions. Over time, the shifting channel builds the fan.

By the time of the 1968 aerial photograph, the alluvial fan had been cleared and Strawberry Creek within the project area appears to have been moved to the toe of the western hillslope, providing a relatively flat upland area to construct a ranch house and several outbuildings (Figure 2-1). This land was acquired in the 1980's by Redwood National Park. Their South Operations Center (SOC), consisting of numerous mobile buildings, was sited on the alluvial fan. In the late 1990's the SOC was relocated to a new facility in Orick, but many of the old structures remain on site.

Current Conditions

Strawberry Creek flows along the toe of the western hillslope through the SOC area. It crosses under the SOC Access Road through a 24-inch culvert. The 500-foot reach of channel upstream of the culvert has an overall average slope of approximately 4.0%. Near the upstream end of this 500-foot reach is a failing log stringer bridge crossing, consisting of large logs and dirt placed in the channel to allow logging access. The channel drop across the stringer bridge exceeds 6 feet.

Upstream of the log stringer bridge, the channel slope decreases and the bed consists of fine sediment stored behind the crossing for approximately 250 feet. The channel along this reach is flowing at a sharp angle to the slope of the alluvial fan, suggesting that it was moved to this location. Upstream of this point the channel becomes dominated by large wood steps and pools, which was used as a reference reach (3.4) for channel design. For about 150 feet downstream of the log stringer bridge, the channel is relatively stable, with several small wood/root forced steps and several riffles. Channel substrate is characterized by small to medium sized gravels mixed with sands and silts. Downstream of this short stable reach, to within about 50 feet of the SOC Access Road, the channel is actively incising into clay due to a complete lack of wood or other grade controlling features. There is little riparian vegetation, except for some young alders and a dense thicket of invasive Himalaya berries (*Rubus armeniensis*).

About 50 feet upstream of the culvert the channel slope decreases and the morphology changes from a transport reach to a depositional reach. The channel bed shows signs of sediment aggradation, which continues downstream of the SOC Access Road.

Throughout much of the channel reach in the vicinity of the SOC area, a small berm separates the channel from the adjacent floodplain and the abandoned SOC buildings. The berm has deteriorated in the absence of routine maintenance activities. RNP personnel note that during large runoff events, the stream has flowed flows out of the bank upstream of the existing buildings, flooding some of the buildings.

The existing SOC Access Road crossing consists of a 24-inch diameter corrugated metal culvert (CMP). The inlet, barrel and outlet of the culvert are filled to near capacity with sediment and the outlet is partly buried. Ross Taylor and Associates (2009) assessed the culvert crossing and described it as a barrier to fish passage and extremely undersized. The Taylor report recommended that the culvert be replaced to improve capacity and sediment transport as part of an overall channel and riparian restoration project.

Strawberry Creek between the culvert crossing and the confluence with the East Tributary is approximately 350 feet long and appears to have been routed into a ditch along the base of the adjacent hillslope rather than following the gradient of the alluvial fan. The average channel slope within this reach is currently 2.3%.

This channel reach can be characterized as a depositional reach. The channel is poorly defined with bank heights of only a few inches. Isolated areas of recent fine sediment deposition and observations of out-of bank flows during high baseflow indicates that the channel frequently spills onto the adjacent floodplain/alluvial fan. The channel bed in this reach consists of sands and a few areas of pea-gravels. It is relatively featureless, with no large wood present in the channel. The entire length of this reach is choked with a dense thicket of invasive Himalaya berries (*Rubus armeniensis*) transitioning to reed canary grass approaching the East Tributary confluence.

2.1.3. West Fork Tributary to Strawberry Creek

The West Fork Tributary flows under the SOC Access Road through an 18-inch diameter CMP before entering the wetland complex. Extensive aggradation has formed immediately upstream of the culvert inlet, causing the channel profile to drop nearly two feet immediately upstream of the culvert inlet. There is also evidence of excavation associated with unplugging the culvert inlet. The outlet of the culvert is completely buried downstream of the SOC Access Road and there is no defined channel connecting the West Fork Tributary to the mainstem channel of Strawberry Creek. Dense floating mats of reed canary grass and water mannagrass cover the wetland area. Given that the outlet is buried, the culvert is assumed to be a complete barrier to all fish.

Approximately 220 feet upstream of the SOC Access Road, two channels join to form a single channel of the West Fork Tributary that then drains to the culvert under the SOC Access Road. The two stream channels upstream of the confluence are characterized by low banks and numerous wood-controlled drops and pools with several shallow, less defined overbank channels present on the floodplain.

Downstream of the confluence, the 170-foot long main channel has a slope of 1.8% and flows through a large wetland area before entering the culvert under the SOC Access Road. In addition to the single main channel, the wetland area is characterized by numerous shallow overbank channels. The wetland area appears to have developed in an extensive area of sediment aggradation, evidenced by the abrupt change in channel gradient from upstream and current ground elevation of 2-feet above the existing culvert inlet.

Field evidence suggests most of the sedimentation immediately upstream of the SOC Access Road did not occur recently due to the presence of larger alder trees and a mature shrub understory within the aggraded areas. The sedimentation source to the West Fork Tributary has likely been substantially reduced as active logging operations in the watershed have been stopped, and the harvested areas revegetated. Historical air photos indicate that this area and the surrounding hill slopes were clear-cut shortly before 1968 and that the area immediately upstream of the SOC Access Road may have been a pasture (Figure 2-1).

A second 18-inch diameter culvert, located about 170 feet to the north of the West Fork Tributary culvert, drains overbank flows from the West Fork Tributary. Its inlet also shows signs of plugging, localized aggradation and excavation.

3. DESIGN SUPPORT INFORMATION

3.1. Topography

A planning-level topographic survey of the greater Strawberry Creek project area was conducted in 2006 and 2007 for analysis and preparation of the Planning Report (MLA, 2008). The detail of the survey was limited in some areas because of the planning-level nature of the study and difficulty with access due to the floating mat of grasses and invasive berry bushes. A more detailed survey was necessary to prepare a restoration design for the RNP project area. MLA performed a supplemental topographic survey of the project area on RNP property in October 2009. It included a field-run topographic survey of the project area and longitudinal profiles and cross section of the Strawberry Creek and West Fork Tributary channels. A detailed survey of the wetland area to the west of the current channel alignment was also conducted using a series of transects and spot grade points. The survey was conducted with a total station and tied to the same coordinate system as the planning level survey (California State Plane Zone 1 horizontal datum and NAVD 1988 vertical datum).

The results from both the restoration design and planning level surveys were combined to create a single digital elevation model (DEM) of the project area showing topography at 1-foot contour intervals (Appendix A).

3.2. Project Area Peak Flows and Wetland Water Levels

3.2.1. Peak Flows

Estimation of the 100-year peak flow was used to size the new West Fork Tributary culvert replacement and for calculating forces on proposed channel wood structures. For this project, it was assumed that the geomorphic "bankfull" flow in Strawberry Creek and the West Fork Tributary, outside of the wetland complex, has a return period of approximately 1.5 years. Bankfull flows have been found to commonly have a return period between 1.2- and 1.5-years and serve as the dominant "channel forming" flow, which shapes the active channel of a stream system (Leopold et al., 1964).

Figure 3-1 shows the USGS topographic map with sub-drainage areas of Strawberry Creek and its tributaries. The Planning Report (MLA, 2008) presented detailed methodology and predicted peak flow estimations for each of the sub basins based on peak flow estimates from nearby gaged streams scaled by drainage area. Table 3-1 presents the drainage areas of Strawberry Creek (SOC Tributary) and West Fork Tributary, and the estimated peak flows associated with various return periods.

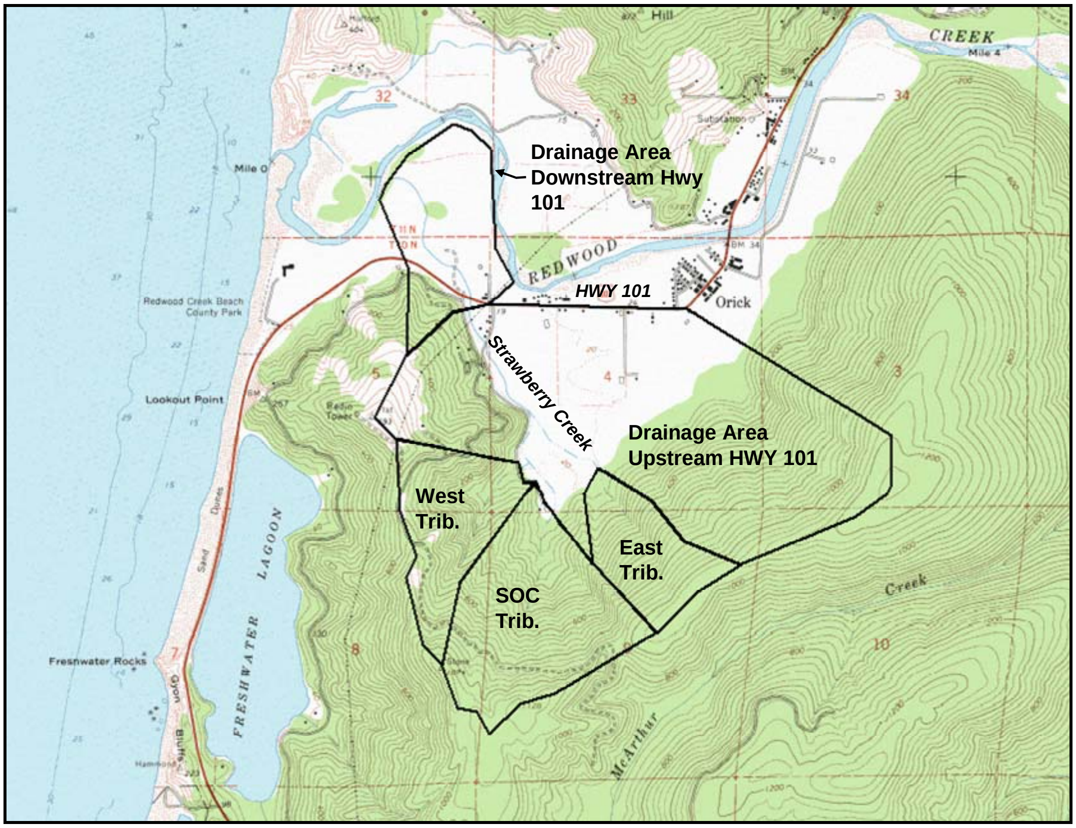


Figure 3-1. Sub-drainage areas of Strawberry Creek on the 1:24,000 USGS topographic map (Orick Quadrangle). Alignment of Redwood Creek is prior to the Flood Control Project. The Strawberry Creek drainage at the SOC Access Road is labeled as the SOC Tributary.

Table 3-1. Peak flow estimates for the Strawberry Creek watershed from MLA (2008).

Location	Drainage Area (mi^2)	Strawberry Creek Recurrence Intervals and Estimated Peak Flows (cfs)						
		1.5 Year	2 Year	5 Year	10 Year	25 Year	50 Year	100 Year
West Fork Tributary at SOC Access Road	0.21	12	17	31	41	55	67	78
Strawberry Creek (SOC Tributary) at SOC Access Road	0.38	22	31	55	74	99	120	140

3.2.2. Wetland Water Levels

RNP installed two continuously recording water level gages in Strawberry Creek and adjacent wetland near the downstream limits of the project area (Randy Klein, RNP, personal communication). The water level gages were installed on April 27, 2010 and will remain in place throughout the duration of project and for post-project monitoring. The water level gages were installed to assess seasonal water levels in both the stream and wetland and to record any changes in water levels associated with Phase 1 and 2 implementation. Available water level data was used to establish planting mound elevations and planting zones within the wetland and stream channel (Section 4.1.3). As additional is collected, planting zone elevations will be adjusted as necessary.

RNP provided MLA with the results of water level monitoring results from April 27, 2010 through October 19, 2011, along with an analysis of the 14-day minimum, maximum and average water levels for the monitoring period. The 14-day minimum water level in the wetland at the end of the dry season (late August through early October), is approximately 19.8 feet (NAVD88). During the wet season, maximum 14-day water levels in the wetland peaked near 20.3 feet (NAVD88).

A plot of available water level readings and 14-day analyses prepared by NPS is presented in Appendix D.

3.3. Existing Utilities

Information regarding location of existing utilities, including water, telephone and electric lines, were obtained from the relevant utility agencies and from the survey. Locations of known utilities are shown on the design drawings (Appendix A). A 6-inch municipal water line buried approximately 3-feet deep runs along the SOC Access Road under all of the existing culverts. The water line provides service to the park ranger's residence and to two fire hydrants. A telephone line also runs along the SOC Access Road. Electricity is provided to the SOC area and the park ranger's residence via a combination of overhead and buried power lines.

3.4. Reference Reach Survey

The restoration design for the Strawberry Creek channel upstream of the wetland complex and the West Fork Tributary upstream of the SOC Access Road was based in part on characteristics of a selected reference channel reach located approximately 1,000 feet upstream of the project area on the mainstem of Strawberry Creek. The surveyed reference reach was a stable channel 120 feet in length and characterized by wood-forced steps and pools, low banks and a broad floodplain with a mature alder dominated riparian forest.

3.4.1. Stream Channel Hydraulic Geometry and Profile Characteristics

The reference reach of Strawberry Creek had a gently sinuous channel with low, nearly vertical banks formed by a dense network of roots. A series of 8 log steps were located within the reference reach, each forming discrete drops. The log drops formed scour pools that transition to short glides followed by riffles before encountering the next drop. The glides and riffles typically acted as tailwater controls at each log drop, reducing the amount of drop between each log structure.

The overall channel slope controlled by the log steps was 6.6% and the average bankfull channel width was 6.3 feet. Riffles comprised approximately one-half the length of the channel between each log drop and the average riffle slope was slightly less than the overall slope of the stream channel.

Table 3-2 summarizes the measured hydraulic geometry of the reference reach. Figure 3-2 presents photographs of the reference reach.

3.4.2. Bed Material Characterization

The reference reach channel bed was formed of loosely packed small gravels and occasional patches of exposed soft clays. A sample of the channel bed material was collected and sieved to characterize the size gradation of material. The median particle size (D_{50}) was 7.5 mm and the D_{84} was 18 mm. Streamflows were slightly elevated at the time of the survey from a rainfall event the previous night, and portions of the bed material were in transport.

3.4.3. Log Feature Characterization

The steps within the reference reach were comprised of single and double old growth redwood logs/slash that fully spanned the channel at angles ranging from nearly perpendicular to approximately 60 degrees relative to the direction of flow. Pitch of the log crests ranged from nearly flat to gently sloping. The channel generally widened up to two feet as it flowed over each log step, then narrowed to the measured bankfull widths within approximately 10 feet of the step, forming an hourglass shape when observed from above. Log features spacing ranged from 8 to 22 feet with an average of 16 feet, which is on average approximately every 2.5 bankfull channel widths.

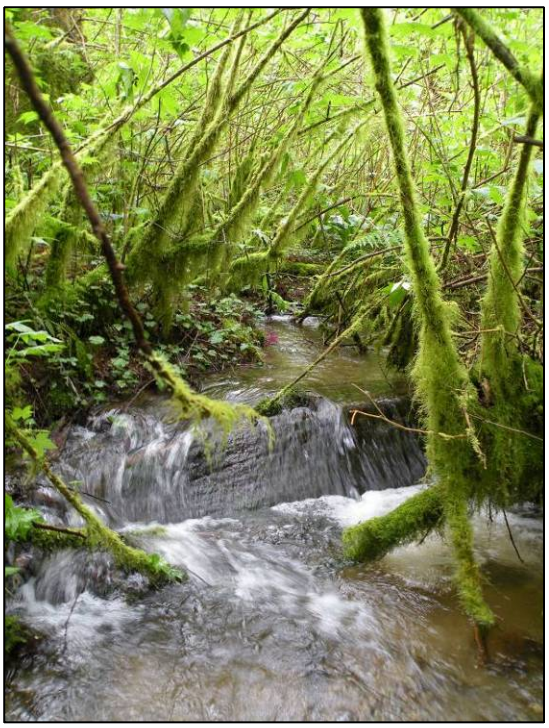
3.4.4. Floodplain Characterization

The reference reach of Strawberry Creek was located in the middle of a broad floodplain that extended a minimum of 100 feet to either side before encountering the toe of the adjacent hillslope. The floodplain vegetation was dominated by mature 12 to 18-inch alders, and a dense understory of salmonberry and other well established native shrub species. The floodplain surface was hummocky and dense with fallen trees and thick groundcover vegetation, including sorrel, skunk cabbage, and ferns.

Table 3-2. Measured Strawberry Creek channel characteristics within the 120-foot long reference reach upstream of the project reach. The 6.6% sloped channel was dominated by eight log steps interspersed with small gravel pools, glides, and riffles.

Measured Feature	Range	Average
Bankfull Width	4 to 8 feet	6.3 feet
Bankfull Depth	1.4 to 1.6 feet	1.4 feet
Log Feature Spacing	8 to 22 feet	16 feet
Log Feature Spacing / Average Bankfull Width	1.3 to 3.5 ft/ft	2.5 ft/ft
Riffle Length	3 to 16 feet	7.8 feet
Riffle Slope	1.67 to 10%	5.4%
Water Surface Drop Height between Log Features	0.3 to 2.2 feet	1.0 feet
Water Surface Drop Height from Log Feature to Tailwater Control	0.3 to 1.2 feet	0.7 feet
Scour Pool Depth Downstream Drop	0 to 1.4 feet	0.8 feet
Scour Pool Length Downstream Drop	5 to 8 feet	6 feet


(a)


(b)

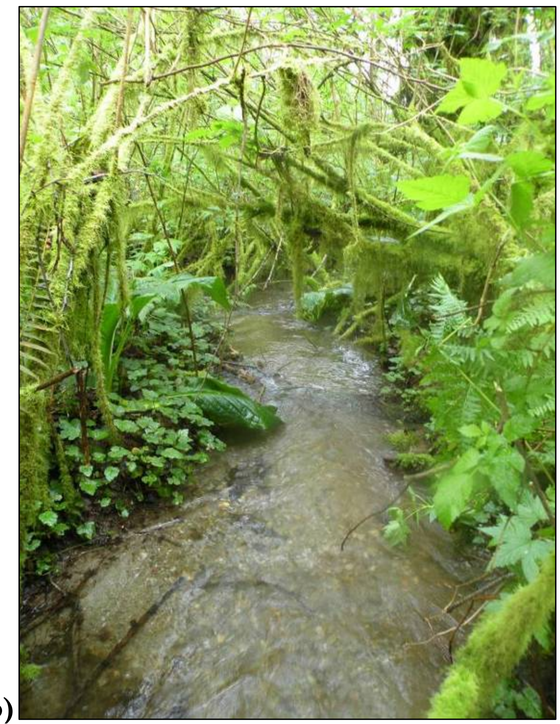

(c)

Figure 3-2. A typical log step spanning the stream channel within the Strawberry Creek reference reach (Photos a. and b.). Crest of the log is fairly flat and the log is slightly skewed to the flow. The water surface drop across this step is approximately 8 inches. Typical channel cross sections between log steps (Photo c) consisted of glides and riffles. Note the low vegetated streambanks and dense riparian canopy.

4. DEVELOPMENT OF RESTORATION DESIGN

4.1. Wetland Restoration Design

Design plans for the wetland restoration are provided in Appendix A.

4.1.1. Overall Design Approach

The portion of the wetland located on the RNP property is vast and restoring the entire wetland in the near-term was viewed by RNP staff as cost prohibitive; both initial cost and ongoing vegetation maintenance cost. A smaller-scale wetland restoration project was viewed as a starting point, providing an opportunity to refine restoration approaches and improve the effectiveness of future restoration within the wetland.

The design objectives of the approximately 3-acre wetland restoration include:

(1) Creation of open, slow velocity wetland slough channels with numerous side channels;

(2) Control of invasive grass species through riparian shading; and

(3) Restoration of areas of seasonal overbank inundation that provide biologically productive areas supporting native aquatic species, including foraging coho salmon.

As recommended in the 2008 Planning Report, the proposed design realigns Strawberry Creek out of its existing ditch within the wetland complex. The new alignment routes the channel to the west, through an existing 3-acre wetland that is partially isolated from the larger wetland complex due to the adjacent hillslopes and the existing raised and graveled berm (formally referred to as the Ranch Road Levee). Moving the channel towards the west facilitates improving the connection of Strawberry Creek with the West Fork Tributary. This connection will improve fish access to the steeper, upstream coldwater stream habitat in the West Fork Tributary, which is not affected by invasive grasses due in part to the shade provided by the dense multistory riparian vegetation.

The Strawberry Creek channel, as it enters the wetland complex from upstream, will transition from a single-thread, riverine channel morphology to a wetland slough channel with a smaller side channel and numerous dead-ended channels extending into the wetland area. A flow-through and numerous dead-end wetland slough channels will be constructed within the wetland area to increase habitat complexity and provide off-channel refugia areas. The West Fork Tributary channel will also flow through the wetland area to Strawberry Creek in a defined slough channel.

The existing ground within the wetland is currently located below the seasonal high wetland water levels, and is too saturated to support the desired riparian species. Spoils from excavation of the Strawberry Creek and West Fork Tributary channels and other sources will be used to construct planting mounds adjacent to Strawberry Creek and the West Fork Tributary within the limits of the seasonal wetland high water. The planting mounds raise the ground surface to re-create the Sitka spruce hummocks that were likely once prevalent within the wetland complex and are characteristic of these environments (Diefenderfer et al, 2008). The mounds will be planted with Sitka spruce and other native riparian trees and shrubs. The riparian vegetation supported on each mound and the mounds themselves are intended to create dense shade to inhibit the regrowth of reed canary grass and water mannagrass in the adjacent slough channels. The Planting Mounds installed along the eastern side of Strawberry Creek will be an integral part of the wetland restoration, creating a vegetation buffer between the restored and un-restored wetland areas.

Log crib-walls will form narrow openings between the planting mounds at the locations of channel crossings. Nurse logs consisting of old growth redwood root wads planted with Sitka spruce seedlings will be placed on the floodplain in some locations where planting mounds are not specified to create additional shade, support growth of riparian trees and create floodplain complexity.

The multiple channel network and planting mounds were designed to restore the wetland area to a more dissected, hummocky spruce, willow and alder wetland described by historical accounts, evidenced on aerial photographs, and similar to existing "spruce swamps" within the Pacific Northwest as described in various technical papers (Diefenderfer, et al., 2008; Diefenderfer and Montgomery, 2009; Brophy, 2009). The slough channel construction and wetland restoration will ultimately provide an open water area that allows fish and other aquatic organisms to freely move year-round. Similar to current day conditions, during the wet season, water levels would persist above the streambanks and across the entire floodplain/wetland; while during the dry season most of the standing water would be contained within the slough channel banks.

4.1.2. Wetland Channel Network Shape and Profile Design

Strawberry Creek Wetland Slough Channel

The Strawberry Creek wetland slough channel will extend from just upstream of the East Tributary confluence to the RNP property boundary, for a total length of 985 feet. The new channel downstream of the confluence with the East Tributary will follow a gently sinuous planform alignment along the west side of the gravel berm before meeting the existing Strawberry Creek stream channel approximately 100 feet upstream of the property boundary, and continue to the property boundary. The location of the channel alignment within the wetland was designed to create channel sinuosity and maximize the length of gravel berm that can be incorporated into the planting mounds, reducing overall fill volumes.

Wide channels with steep banks have been found to inhibit the recolonization of reed canary grass within the channel (MLA, 2006). Therefore, the cross-sectional shape for the wetland slough channel designs will be trapezoidal with a wide bottom and steep slide slopes. The channel will be trapezoidal, with a bottom width of 10 feet and side slopes of 1.5H:1V. Channel side slopes are based on recommendations in PWA (2011). The top width is similar to the top width of Strawberry Creek downstream of the RNP property. The design bottom elevation of the slough channel is lower than the lowest water levels during the dry season, and matches the elevation of the East Tributary thalweg at its confluence with Strawberry Creek and the elevation of the existing channel at the RNP property boundary. The channel slope transitions from 2% at the upstream end to 0.1% at the downstream end, with a grade break at the Strawberry Creek confluence with the East Tributary.

West Fork Tributary Wetland Slough Channel

The West Fork Tributary wetland slough channel will extend upstream from Strawberry Creek to the downstream end of the new West Fork Tributary culvert for a total length of 205 feet. The planform alignment of the West Fork Tributary was established to maximize its length while maintaining a rough east-west orientation so that the planting mounds completely shade the channel. The trapezoidal slough channel will have a bottom width of 1.5 feet and 1.5H:1Vside slopes.

The profile for the West Fork Tributary was designed to maximize the depth of the slough channel to minimize reed canary grass encroachment into the channel. The entire reach of slough channel is located below the elevation of the of the dry-season water level. The design bottom slope is 0.8% and the elevation at the confluence matches that of the new Strawberry Creek slough channel. At the edge of the wetland, the channel slope transitions to 4.5% slope as it enters the new culvert outlet (Appendix A).

Wetland Side Channels

Within the wetland, a 255-foot long through-flow side-channel will parallel the main slough channel of Strawberry Creek, diverging from Strawberry Creek near the upstream area of the wetland and connecting reconnecting with Strawberry Creek near the new West Fork Tributary channel. Several dead-ended wetland side channels, totaling approximately 245 feet in length, will connect to the through-flow side channel and to Strawberry Creek and the West Fork Tributary channels. The wetland side channels were located in the southern portion of the wetland area to maximize the use of a north-east facing hillslope and adjacent planting mounds for shading. The wetland side channels will have nearly vertical banks 3 feet in height and a 5-foot bottom width. They will be inundated year-round.

A wetland side channel will also be excavated to connect flows from the existing culvert to the north of the West Fork Tributary. This culvert drains floodplain flows for the West Fork Tributary.

4.1.3. Wetland Planting Mounds, Crib Walls and Nurse Logs

Mound Locations and Composition

Wetland planting mounds will extend fairly continuously along both sides of the Strawberry Creek and West Fork Tributary slough channels. The extents of the mounds shown in the plans fully utilize all of the available RNP planting stock and are the minimum area of planting mound necessary to fully shade Strawberry Creek and the West Fork Tributary stream channels. Additional mounds could be constructed in the future, but would require additional importing of fill material and also propagation of additional plant material that meets NPS planting requirements.

A mix of excavated channel material and imported material will be used to construct the planting mounds. The imported material, consisting of river-run gravel, could come from the nearby Redwood Creek dredging project, making fill importation cost effective. The river-run gravel will be used to make the core of the mound, and the excavated channel material will be used to create a planting surface on the mound top and sides. RNP is also investigating other borrow sources to find a material that is suitable and cost effective.

A planting mound will be used to block off a portion of the existing Strawberry Creek channel and divert flows into the new channel. The abandoned Strawberry Creek channel will remain as a backwater channel within the main wetland complex. The portions of the mound constructed within the existing Strawberry Creek channel will be constructed of adequately compacted suitable material salvaged from the channel excavation.

Mound Elevations

The planting mounds were designed to simulate the hummocks between slough channels in the historical wetland (MLA, 2008). Several remnants of hummocks exist at Strawberry Creek, as well as occasional new growth of spruce and alder on low hummocks in the existing wetland area. During the project survey, the elevation of the base of the tree trunk on each hummock and the ground elevation within the wetland adjacent to the hummock were measured. Table 4-1 presents the results of these surveys.

Based on limited monitoring, the typical water surface elevation within the wetland complex during the wet season is approximately 20.25 feet NAVD88 (Section 3.2.2). To be conservative, the winter wet-season water levels in the wetland was assumed to be approximately 21 feet. The results of the tree survey indicate that the healthiest trees grow at elevations between 22 to 24 feet, feet, approximately 1 to 3 feet above the highest seasonal water level. The planting mounds were designed to create hummocks with a broad planting surface at or near an elevation of 24 feet, where the desired species are currently growing. Two-year old Sitka spruce will be planted at 2-foot spacing on the tops of the planting mounds. Willow cuttings and 2-year old red alder will be planted at 2-foot spacing down the side slopes of the mound (See planting details, Appendix A and Riparian Planting Plan, Appendix E).

It is expected that implementation of Phase 1 downstream of the RNP property will eventually lower seasonally high water levels one to two feet once the riparian canopy becomes mature. Because this may take a number of years and the exact impact on water levels is uncertain, the planting mounds are designed based on current-day hydrology and field measurements of healthy trees. If water levels drop, it is expected that the riparian area will still receive sufficient water.

Mound Orientation

The locations and orientations of the planting mounds were based on the stream channel alignments and the predominant spring and summer sun orientation to the wetland, with the objective of fully shading the slough channel reaches of Strawberry Creek and the West Fork Tributary with riparian vegetation. To maximize the amount of shade to the slough channels and adjacent wetland areas, channel alignments were oriented roughly east-west where feasible so that direct sunlight does not shine along the axis of the channel. Mounds constructed on both sides of the channels will fully shade the channels laterally. This will create a barrier of high ground and riparian vegetation to separate the restored wetland from the remaining wetland area, where invasive grasses are pervasive. A large hillslope to the south and west shades the project area from late afternoon sun, therefore mounds are not necessary along the north side of the hillslope.

Table 4-1. Surveyed tree elevations within the Strawberry Creek wetland.

Tree Surveyed	Elevation at Base of Trunk on Hummock (feet NAVD88)	Elevation of Adjacent Ground in Wetland (feet NAVD88)[1]
>24" Spruce on hummock	22 to 23 feet	21.4 feet
18" Spruce on hummock	24.0 feet	21.2 feet
<1" Alder (Unhealthy)	21.1 feet	20.11 feet

[1] *Seasonal high water level approximately 20-21 feet.*

Nurse Logs

Nurse logs will be placed within the wetland area adjacent to wetland side channels where mounds are not presents. The intent of the proposed nurse logs is to mimic natural nurse logs as observed in nature, providing a growing media above the wet-season wetland water level where upland vegetation can establish. These are viewed as an experimental planting approach.

The nurse logs will consist of old-growth redwood trunks and portions of root wads with numerous tubelings-size Sitka spruce seedlings installed in openings drilled into the nurse log. The holes will be filled with a soil mix suitable for spruce growth. A mound of soil will be placed adjacent to the planting areas to allow root expansion in the event that the log does not decay and provide a rooting media.

Rainfall and wicking of water through the nurse log in the dry season will provide a water source for the tubelings. Because of the high mortality rate expected, approximate 5 to 10 tubelings will be installed in each nurse log with the intent of achieving survivability of one to two trees.

The nurse logs will be partially buried into the wetland surface, but the bulk of the wood will be located above the seasonal high water level. Keeping the majority of the wood above the high water level will prevent the nurse log from becoming buoyant.

Crib Walls

The planting mounds will be discontinuous in several locations to allow inflow of the East and West Tributaries, promote circulation, and connect the main slough channel to the wetland side channels. The openings between each mound will be constructed using log cribwalls to minimize the width of each opening and prevent sunlight from reaching the open water. Log crib walls planted with willow staking will be constructed on both sides of the gaps between mounds (Appendix A).

The log cribwalls will be a minimum of 5-feet tall and extend the full width of the planting mound. The cribwalls will be constructed with 2-foot diameter logs, stacked in a "log-cabin" framework and anchored together using CDFG-approved wood anchoring methods. Cross logs extending at an angle into the planting mounds will act as dead-men to prevent both overturning and flotation of the structure. The two crib logs will be separated vertically by a cut portion of the deadman logs to create a one foot high opening. This opening will be backfilled with soil at a 2H:1V slope and planted with live willow cuttings. The face of the cribwall will form an approximate 0.6H:1H slope. If available, root wads can be incorporated into the crib walls at the channel elevation to provide additional channel complexity and cover.

Large Wood Habitat Structures

Cover structures constructed of large wood, including rootwads, will be installed in a minimum of 8 locations within the wetland slough channels. These structures will follow CDFG approved design and anchoring guidelines and will provide cover habitat for salmonids and other aquatic organisms.

4.2. Strawberry Creek Channel Design Upstream of the Wetland

Approximately 220 feet of Strawberry Creek, upstream of the wetland and slough channel complex, will be restored. This restored reach ends at the outlet of the existing Strawberry Creek culvert. The Strawberry Creek culvert will not be replaced at this time due to a lack of upstream habitat and associated cost (Section 1.3). The restored channel will be a log step-pool channel that is geomorphically similar to the wood-forced step-pool channel observed in the reference reach, but will have a more gentle slope. The downstream reaches of the step-pool channel will be submerged by the wet-season water level in the wetland, but will function as step-pools during the dry season when the wetland water level is lower.

4.2.1. Channel Alignment

The alignment of Strawberry Creek will be moved away from the toe of the west hillslope to follow the slope of the alluvial fan, create a slightly more sinuous channel and allow riparian planting on both sides of the channel. The channel alignment was constrained by the orientation of the existing culvert, a buried power line, and the location of the slough channel alignment within the wetland.

4.2.2. Channel Profile Design

The proposed channel profile is shown in Appendix A. The channel profile was designed to fit within the geomorphic context of the alluvial fan, to create a sediment depositional reach upstream of the wetland area, and to allow for installation of an adequately sized culvert in the future without the need to reconstruct any log structures.

The upstream limit of the Strawberry Creek restoration is located at the existing Strawberry Creek culvert outlet. At the culvert outlet, the new channel will be constructed with a thalweg elevation one foot lower than the culvert outlet elevation. The channel will continue downstream for 40 feet at a 5.2% slope. This reach of channel will not contain any grade control structures and will be constructed as a "transition channel" to capture flow out of the culvert that is currently sheet-flowing down the fan. Over time, it is expected that the transition channel may incise, potentially creating up to a 2.5-foot drop out of the culvert. When the culvert is ultimately replaced, this reach of channel can be constructed to a slope that is passable for fish and compatible with the channel profile through the new culvert.

Between the transition channel and slough channel reaches, 180 feet of channel will be constructed at a 2.2% slope and will be formed with log step-pool separated by gravel riffles. The log steps will control the channel bed elevation and the downstream scour pools will dissipate the flows energy (Section 4.4). The gravel riffle will function as the tailwater control for the pool and maintain the channel profile between log structures. The water surface drop between the log steps and the downstream riffle will not exceed 0.5 feet.

4.2.3. Channel Cross Section Design

Typical cross sections for the new riffle, pool, and culvert outlet transition channel reaches are shown in Appendix A. New channel cross sections were designed to simulate reference conditions and provide adequate flow conveyance for the bankfull flow. Within the step-pool channel reach, the bankfull channel dimensions will be controlled by log structures placed at specific locations along the stream channel. Channel hydraulics were calculated using the cross section controlled by the log structure. Hydraulic conditions were estimated using a combination of weir flow and uniform flow calculations, depending on the degree of submergence from the downstream pool at each log structure.

The step-pool portion of the Strawberry Creek channel was designed to convey the bankfull flows and to facilitate frequent overbank flow and deposition. The bankfull channel at each log structure and riffle will be 1.5-feet deep and 8 feet wide. The bankfull width will widen to a width of 11 feet in the pools. Flows larger than the bankfull event will inundate 3.5 to 5-foot wide floodplains and existing low areas on either side of the channel, providing a depositional surface.

The transition channel immediately downstream of the existing culvert will consist of a trapezoidal channel with a 3-foot bottom width and 1.5H:1V side slopes.

4.3. West Fork Tributary Channel Design Upstream of the SOC Access Road

A portion of the West Fork Tributary of Strawberry Creek will be realigned and restored upstream of the replaced West Fork Tributary culvert (Appendix A). The upstream limit of the channel restoration is located about 140 feet upstream of the culvert crossing at the confluence of the two smaller channels that form the West Fork Tributary. To avoid impacting two large spruce trees, the realigned channel was kept within an open area to the south of the present channel. The channel crosses under the SOC Access Road at a right angle to the road.

The proposed channel profile for the restored reach of the West Fork Tributary is shown in Appendix A. The channel profile was designed to restore the channel upstream of the culvert to its historical elevation, move the depositional reach downstream of the culvert crossing, and place the channel elevation sufficiently low to pass under the SOC Access Road with minimal adjustment to the road profile. The new profile transitions the stream from a 5% sloped wood-forced step-pool morphology to a 4.5% slope channel that flows through the new culvert. Downstream of the culvert, the channel continues at a 4.5% slope for 35 feet, where it transitions into the slough channel in the wetland complex.

The step-pool channel reach of the West Fork Tributary will be formed with log-steps and log-weirs, separated by scour pools, glides and riffles. The log-steps and log-weirs will control the channel bed elevation. The scour pools will dissipate the flows energy (Section

4.4). The gravel glides and riffle will function as the tailwater control for the pool, maintaining the channel profile between log structures and maintaining the residual pool depth. The water surface drop over the log-steps and log-weirs will be 0.5 feet.

The bankfull channel at each log-step, log-weir and riffle will be 1.0 feet deep and 5 feet wide. The bankfull width will widen to a width of 7.5 feet in the pools. Grading will transition to existing ground at a 3H:1V slope. It is expected that the excavated soils in this reach will be saturated, making detailed channel bank grading, such as floodplains, impractical.

4.4. Channel Bed morphology for the Step-Pool Reaches of Strawberry Creek and the West Fork Tributary

Two different types of log structures were developed for the restored channel reaches outside of the wetland complex, each based on observations of wood features within the upstream reference reach and in other small streams with large wood features controlling the profile. The two structures are termed *log steps* and *log weirs (*Appendix A). The log steps and log weirs will control the channel bed elevation and create scour pools that dissipate the flow's energy. Pools, glides, and riffles will be constructed between the log structures. Plan views and cross sections of these structure are shown in Figure 4-1, Figure 4-2, Figure 4-3, and Figure 4-4.

Though the profile-control functions of these two structure types are similar, the log configurations are different between structure types. These differences will create variability in channel cross section, flow patterns, drop heights, scour pool depth and location, and overall visual appearance.

Both log steps and log weir structures will be constructed within the West Tributary. Log weirs will be located between every two log steps. Only log step pools will be constructed in Strawberry Creek due to its gentler slope.

4.4.1. Log Steps

Each log step will consist of a 2 to 3-foot diameter *step log* spanning the channel at a 60° angle to the direction of flow, with the orientation alternating from step to step. The step log will be pitched across the channel, with the high side of the log placed at bankfull elevation and the low side of the log placed 1 to 1.5-foot lower to form the step invert (Figure 4-2). The high side of the log will create a sill across the floodplain surface and will be keyed deep into the existing ground to prevent floodplain degradation and end-around erosion. A *footer log* will be installed to a minimum depth of four feet below the crest of the log step, placing the bottom of the footer log well below the estimated scour depth (CDFG, 2009). A 1.5 to 2-foot diameter *training log* will be installed along the streambank on the low side of the *step log*. The training log will guide the approaching flow away from the stream bank; provide bank protection and focus the plunging flow over the step towards the center of the channel.

4.4.2. Log Weirs

Each log weir will consist of a 2 to 3-foot diameter *weir log* spanning the channel at an angle nearly perpendicular to flow. The weir crest will be pitched at a 12H:1V slope, with the lower side forming the channel invert. A 2 to 3-foot diameter *footer log* will be installed to a minimum depth of four feet below the crest of the weir log, well below the estimated scour depth (CDFG, 2009). Training logs, 2-feet in diameter, will be installed along both streambanks to guide flows towards the center of the channel and provide bank protection.

Log weirs were designed to provide an additional safeguard against potential undermining and cascade failures of log structures in steeper stream reaches, in the event that a downstream log structure fails. The flatter pitch of the log weir results in the footer log being keyed into the streambed deeper across the width of the cross section, arresting any potential headcut migration from downstream.

4.4.3. Log Structure Anchoring

The primary forces that may cause wood to move are buoyancy, lift, and drag (NRCS, 2007). These forces were calculated for the log structures using predicted water velocities and depths at the 100-year flow. Buoyant forces were computed assuming the entire logs structure was submerged and conservatively using the dry density of old growth redwood. Lift and drag forces were computed assuming that the average velocity was acting perpendicularly to the exposed area of the log. The analyses also included the resistance forces (passive earth pressure) of the adjacent soil. Saturated soil conditions were assumed for all soil lying below the elevation of the 100-year water surface in the channel.

To achieve stability, all logs in a log structure will be bolted together using threaded rebar in accordance with CDFG (1998). Soil placed on top of structure ends is not adequate to resist buoyancy forces. Therefore, two log piles, minimum 1.5-foot diameter, will be driven into the banks and serve as anchors for each log structure. They will resist both buoyancy forces as well as drag forces imposed by the flowing water.

The length and diameter of the log piles was computed using standard skin friction equations for driven piles. Soil properties for the soil were obtained from the geotechnical properties of the clayey sandy silts encountered in soil borings obtained at the County Transfer Station, downstream of Highway 101 (Galli Group, 2011). The shallow materials encountered in the borings were similar to the materials encountered by PWA in their soil samples on the West Tributary and higher elevation sample on Strawberry Creek (PWA, 2011). The internal angle of friction of the soil is 20 degrees; the cohesion is 100 pounds per square foot and the unit weight of soil was 110 pounds per cubic foot. Computations were performed assuming fully saturated conditions. A lateral earth pressure coefficient of 1.5 for a low-density wood pile and external angle of friction of 2/3 the internal angle of the soil for the wood pile.

A 1.5-foot diameter log pile installed 6 feet below the limits of trenching will provide a safety factor of 1.7. RNP has indicated that a safety factor less than 2 is acceptable. Therefore, the log piles are specified to extend a minimum of 6 feet below the limits of excavation. If feasible, the piles will be driven deeper than the minimum depth. The post-hole for the piles may be augured to facilitate installation, but the augured hole should be a minimum of 8 inches smaller than the diameter of the pile to ensure sufficient skin-friction on the pile.

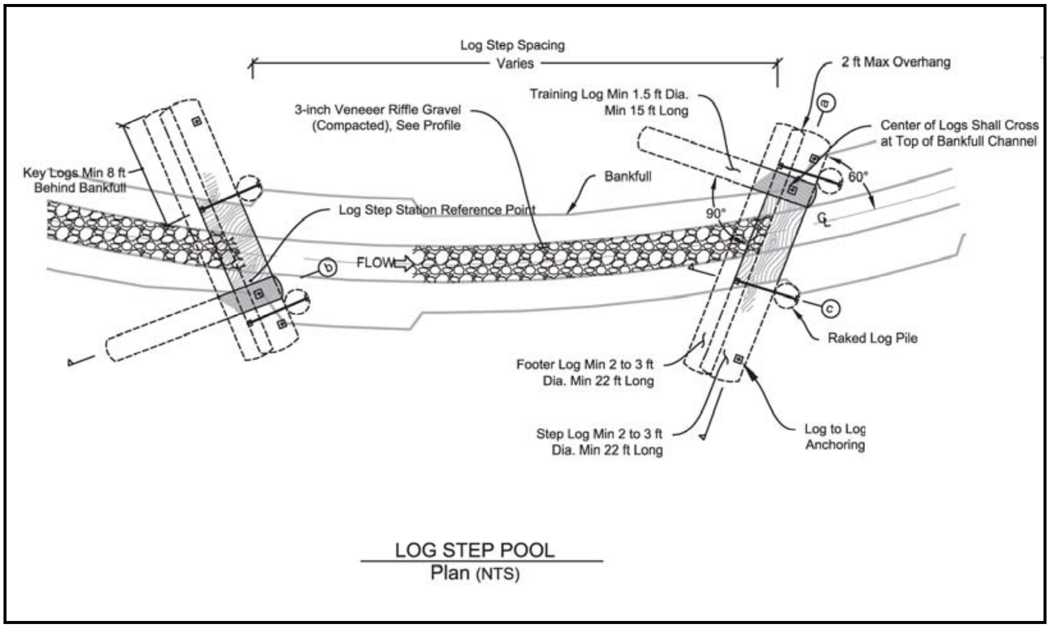


Figure 4-1. Plan view detail of log steps and pools.

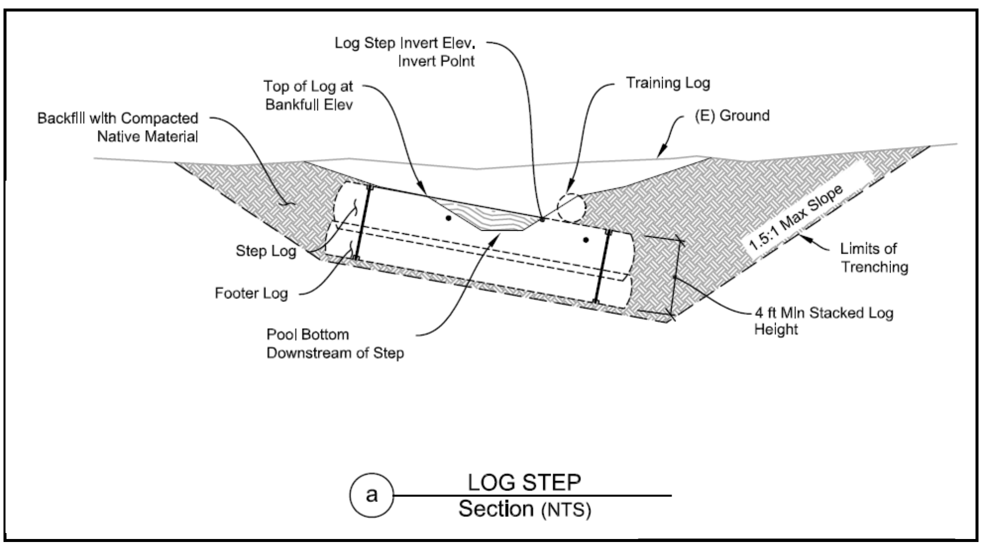


Figure 4-2. Cross Section view of Log Step.

4.4.4. Pools, Glides and Riffles

A pool will be located between each log step or log weir to dissipate energy created by the plunging flow over the 0.5-foot drop. The pools will be constructed with a residual depth of 0.5-feet at the base of the step, similar to reference reach pool depths. However, the design will accommodate the self-adjustment of the pool width and depth. Pool scour and depth is expected to be variable through time, depending in part on streamflows and sediment supply.

The downstream end of each pool will transition through a glide to a riffle crest that is located at approximately one-half of the log structure spacing. The riffle crests are set 0.5 feet lower than the invert of each log structure to facilitate upstream passage of juvenile salmonids. The riffle will continue downstream to the next log structure at the overall slope of the channel.

The surface of the glide and riffle will be constructed with compacted river-run gravel 3-inches thick, obtained from the Redwood Creek flood control project dredging spoils. The gravel will form a surface resistant to initial surface erosion, as well as provide habitat for invertebrates. A sieved bulk sample from the stockpile of the dredged material indicates that the Redwood Creek material used in the project will have a D_{50} of 12 mm and a D_{84} of 36 mm. These materials are slightly larger than the gradation of the channel bed material found in the Strawberry Creek reference reach. This larger material will be less mobile than the native bed material, which is a desirable attribute immediately after construction as the channel becomes "seasoned". Over time, the top layer of the installed Redwood Creek material will be transported downstream and replaced with native material.

4.5. Riparian Restoration Design

Planting plans, notes and details for the riparian restoration of the project area are shown in Appendix A.

The riparian area restoration will include planting over 15,600 2-year old trees and approximately 5,000 willow stakes to create a riparian buffer along the entire 1,600-foot length of restored stream and slough channels. In the stream channel reaches, upslope from the wetland complex, 25-foot riparian buffer of densely planted 2-year old Sitka spruce and red alder will be planted above bankfull elevation. Willow stakes and salvaged *Carex* will be installed along the bankfull elevation of the channel to provide bank stability.

Within the wetland restoration area, riparian areas will be planted on the constructed planting mounds and will consist of willow staking and salvaged *Carex* near the waterline, and densely planted 2-year old Sitka spruce and red alder on the sides and top of the planting mounds.

An electrified Elk Fence will be installed around the perimeter of the project area to control grazing.

RNP was responsible for developing the riparian restoration plan. A summary of the plan is presented in Appendix E.

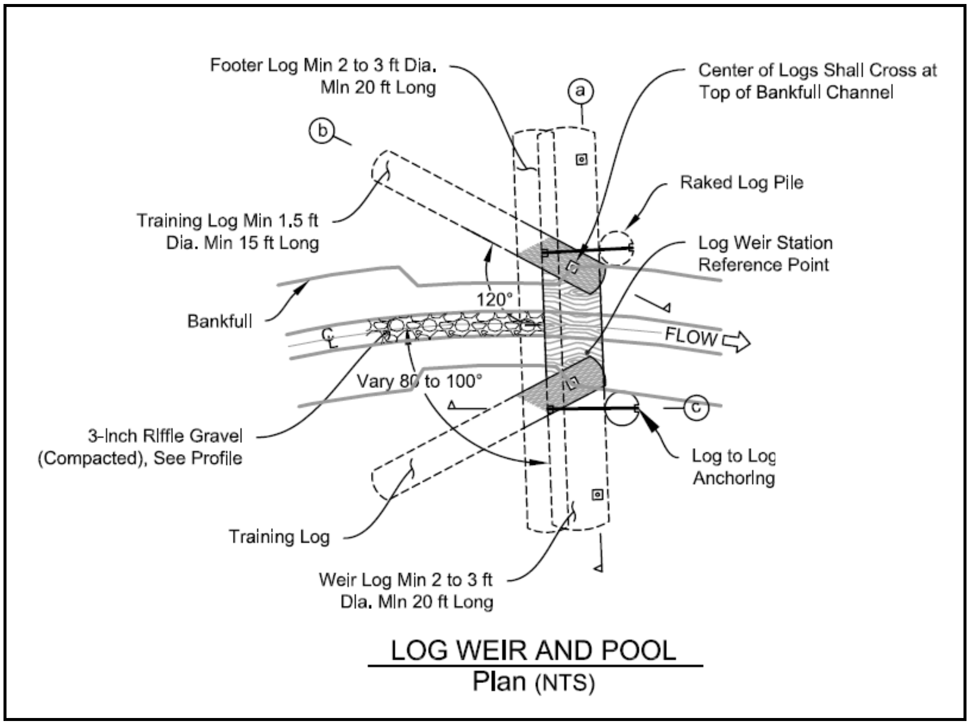


Figure 4-3. Plan view detail of log weir.

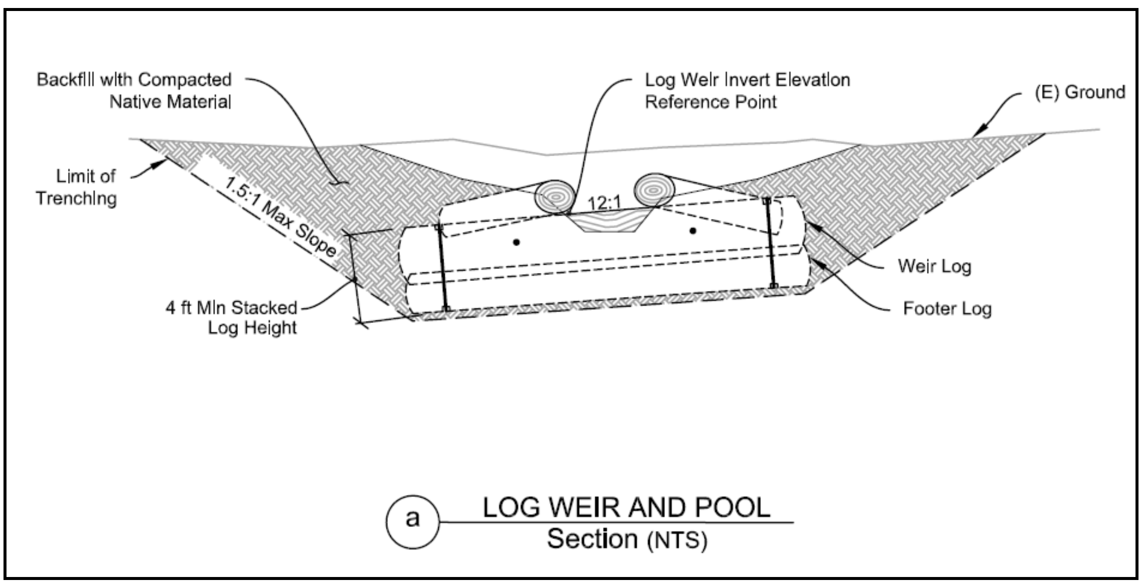


Figure 4-4. Cross Section view of Log Weir.

4.6. West Fork Culvert Replacement

4.6.1. Design Approach

The culvert replacement was designed using the Stream Simulation Approach (CDFG, 2009 and 2003; NMFS, 2001; and USFS, 2008) and the Federal Highway Administration's culvert hydraulic model HY-8 (FHWA, 2005). The premise of steam simulation is that a channel that mimics the morphology of the adjacent channel will prove to be no more of an impediment to movement of aquatic organisms than the natural channel. Based on this, the new culvert will be embedded below finished channel grade and contain a channel bed constructed with a similar slope and morphology as the adjacent stream channel.

To avoid pressurized flow that can compromise bed stability for a stream simulation channel, the culvert was designed to convey the 100-year peak flow without submerging the culvert inlet. The freeboard will minimize backwater effects, facilitate sediment transport, and reduce the potential for blockages by debris.

4.6.2. Alternatives Analysis

At the February 7, 2011 meeting, Mr. Mark Smelser, CDFG geologist, requested that an alternatives analysis be prepared to identify if construction costs could be reduced for the replacement of the West Fork Tributary culvert. The primary elements associated with the culvert crossing that influence construction cost are (1) the culvert depth and slope, (2) size and material of the culvert, and (3) culvert length.

<u>Consideration of a No-Slope Culvert</u>

Rather than a sloping stream simulation culvert, as previously proposed, Mr. Smelser requested that the design consider using a bare culvert at a flat grade, placed below the water level within the wetland. This alternative falls into the hydraulic design approach, where water velocities and depths are designed to meet passage criteria for adult and juvenile salmonids. Although this alternative allows use of a culvert with a smaller end-area because no bed material is installed within it, it also has influence on the constructed channel profile upstream of the culvert.

Approximately 140 feet upstream of the road crossing the West Fork Tributary branches into two channels. One of the project constraints is to avoid extending the channel restoration beyond this point. Given this design constraint, the no-slope culvert alternative places the channel at the culvert inlet at a lower elevation and results in a much steeper (>6%) upstream channel profile in comparison to the stream simulation culvert alternative previously proposed. In considering this alternative, the resulting upstream channel slope was viewed as increasing the risk of upstream channel instability to an unacceptable level. Additionally, the use of the bare culvert was considered undesirable, given that NMFS (2001) lists it as the lowest preference for replacement culverts that require fish passage.

<u>Culvert Material</u>

A number of available culvert materials were considered. Estimates were obtained from manufactures for both corrugated steel culverts and precast concrete box culverts. The concrete culverts were found to be more than double the cost of a metal culvert of equal length.

Culvert Shape

A corrugated metal pipe-arch (squash pipe) culvert was found to be preferable when compared to a circular culvert. The pipe-arch shape provides the cross sectional geometry needed for the stream simulation channel while meeting road cover requirements and conveying the 100-year peak flow. To accomplish the same objectives with a circular shape requires a larger and more costly culvert.

Culvert Size

The previous design submittal recommended a 117" x 79" pipe-arch culvert embedded 2-feet below stream grade. The headwater at the 100-year design flow was 21 inches below the soffit of the culvert. The 21 inches of freeboard was provided to reduce the risk of debris clogging at the inlet. The additional headroom provided by the culvert would also help facilitate installation of the stream simulation bed material.

Reducing the pipe-arch culvert by two sizes, to 103" x 71" produces a headwater depth at the 100-year design flow that is 12 inches below the culvert soffit. Inquiries with culvert manufactures found that reducing the proposed culvert to this smaller size would substantially reduce delivery cost. Unlike transporting the 117" x 79" pipe-arch culvert, this slightly smaller culvert would not be an oversized load requiring a pilot car. Further reductions in the culvert size result only in inconsequential reductions in cost while making construction more difficult and increasing the risk of pressurized flow and debris plugging. Therefore, the proposed culvert size will be a 103" x 71" corrugated metal pipe-arch culvert.

Reduction of Culvert Length

The current roadway width, including the shoulders, is 21 feet. Any reduction in the roadway width reduces the culvert length by the same amount. RNP has agreed that the overall width of the roadway can be reduced to a single lane capable of handling oversized loads, including lowboys and modular housing units. The wheelbase associate with trailers used to haul modular housing units is 14 feet. Therefore, the minimum road width was set at 16 feet, which provides 1 foot of shoulder on each side of the graveled 14-foot wide road. With this shorter road width and using a projecting inlet and outlet (no headwalls or wingwalls), the required culvert length is 45 feet.

Other means of reducing the required culvert length is to use headwalls or wingwalls. They are generally expensive to construct or install and do not save cost. Costs for prefabricated concrete wingwalls were obtained from a manufacture. The cost of the wingwalls, not including installation, was more than the cost of the entire metal culvert. Therefore, wingwalls and headwalls to reduce culvert length were not used in the design.

4.6.3. Selected Alternative design

A design profile for the new West Fork Tributary culvert is shown in Appendix A. The West Fork Tributary culvert will consist of a 103-inch by 71-inch (8.6 ft x 5.9 ft) corrugated metal pipe arch (CMPA) that is 45 feet long and embedded 2-feet below the finished grade of the stream channel. The culvert slope would be 4.5%, which matches the design slope of the upstream and downstream channel.

The new channel within the culvert will consist of a trapezoidal channel constructed using stream simulation bed material, boulders steps, and rock banklines that will simulate the natural channel shape and roughness. The channel cross section will have a bankfull width of 5 feet and a depth of 1-foot, the same bankfull dimensions at the riffle and log structure cross sections in the upstream restored channel. The boulder steps will simulate the log features in the upstream restored channel. Pools below each boulder step will be allowed to self-form. Use of logs as steps inside the culvert was viewed as impracticable because of difficulty with installation and anchoring.

The boulder steps in the culvert are spaced at approximately 11-foot intervals, limiting the drop between boulder steps to 0.5 feet. The small drop heights are intended to facilitate fish passage and limit the scour depth in the receiving pools so that the culvert invert is not exposed. Boulder weirs will be installed at the upstream and downstream ends of the culvert to maintain the channel grade within the culvert.

Sizing of the boulder steps and rock banklines within the West Fork Tributary culvert were based on CDFG guidelines (CDFG, 2009) to remain stable under 100-year return period flows. The D_{84} (84% material smaller than) of the bed material will be 1.3 feet, and the maximum particle size will be 2.0 feet. For additional stability, a 1.5-foot tall steel bed retention sill will be welded to the culvert bottom in the middle of the culvert and used to buttress one of the boulder steps. The stream simulation bed material within the culvert between boulder steps will consist of salvaged river run gravel from Redwood Creek mixed with a small proportion of larger angular material to provide some bed stability.

Capacity of the embedded pipe-arch culvert with projecting inlet was analyzed using HY-8. It was found to be inlet controlled at the 100-year design flow of 78 cfs and have a headwater depth 12 inches below the culvert soffit.

5. FINAL DESIGN AND CONSTRUCTION ISSUES

5.1. Earthwork

Table 5-1 summarizes total excavation volumes for the project which includes grubbing of invasive grasses under the planting mounds, planting areas and along the alignment of the stream channels. MLA computed grubbing volumes assuming that 2 feet of material will be grubbed from under the mounds and wetland slough channels, and 1-foot of material will be grubbed under the 25-foot riparian corridors and along the stream channels, resulting in a grubbing volume of 7,269 cubic yards of materials.

The proposed project will result in a total volume of 1,891 CY of material suitable for reuse, with material originating from the slough channels, West Fork Tributary culvert replacement, upstream channels of Strawberry Creek and the West Fork Tributary, and crossing decommissioning within the watershed. A total of 11,353 cy of material is needed to construct the wetland planting mounds, which is 9,462 cy more than supplied by the channel excavation. Therefore, it will be necessary to import 9,462 cy of material for construction of the planting mounds. It is expected that the imported material, consisting of river-run gravel, will come from the nearby Redwood Creek dredging project, making fill importation cost effective because of the short haul distance. Additionally, the placed river run gravel used for the core of the planting mounds will serve as a suitable access ramp for heavy equipment.

Table 5-1. Summary of excavation and fill volumes for the Strawberry Creek and West Fork Tributary stream channels, West Fork Tributary culvert replacement, wetland slough and side channels, and wetland planting mounds.

Location	Excavation Volume*	Grubbing Volume	Fill Volume
Strawberry Creek Channel	373 CY	1,831 CY	-
West Fork Tributary Slough Channel	50 CY	207 CY	-
Wetland Side Channels	-	278 CY	-
West Fork Tributary Culvert Replacement and Upstream channel	631 CY	-	-
Stream Crossing Decommissioning	1,000 cy	-	-
Wetland Planting Mounds	-	4,444 CY	11,353 CY
Riparian Planting Areas	-	509 CY	-
Total	**2,054 CY**	**7,270 CY**	**11,353 CY**
Imported Fill Volume Needed			**9,462 CY (13,247 Tons)**

**Reusable material, excluding grubbing volume*

5.2. Water Management

Phase 2 of the Strawberry Creek Restoration Project will be constructed during the dry season in summer and fall, when stream and wetland water levels are at their lowest. Strawberry Creek and the West Fork Tributary are both perennial streams, necessitating removal and exclusion of any listed aquatic organisms from the construction area and a clear-water bypass during construction. Salmonids are the only listed species near the project area, and to date none have been found within the project area (David Anderson, Personal communication). During construction, the project area will be fully isolated so that no listed species enter during construction.

5.2.1. Stream Channels Upstream of the Wetland

In both Strawberry Creek and the West Fork Tributary channel reaches outside the limit of the wetland, a passive diversion pipe can be set up to divert streamflow around the project area. If necessary, the diverted water can also be pumped. To excavate the channel and install the wood structures, dewatering of the construction area using pumps will be necessary. Sediment laden water can be treated by pumping it to a flat upland area where it can percolate into the ground.

5.2.2. Construction in the Wetland

It is expected that water management during construction will be a challenge within the limit of the wetland, and water management costs were estimated accordingly. The ground elevation of the wetland within the construction area ranges between approximately 19 to 21 feet. The existing gravel berm elevation bordering a portion of the wetland area is at an elevation of approximately 20 feet, except at two locations where it has been breached to allow water exchange to the east. Water-level monitoring within the wetland in 2010 indicates that, after a wet spring, wetland water levels were slightly below 20 feet in elevation (Appendix D). Field visits during summer months of previous years indicated that the water level within the wetland is below the ground level, except within the existing ditches. Depending on seasonal rainfall, it may be necessary to pump water out of the wetland project area to allow construction access into the wetland.

During construction, it will be necessary to install clear water diversions on both Strawberry Creek and the West Tributary to route streamflow around the wetland area. Because of the width and depth of the existing Strawberry Creek channel adjacent to the wetland area, installation of temporary cofferdams and gravel-bag berms will be necessary to form a barrier for the clear water diversion and to block inflow into the project area from the downstream channel and adjacent wetland. Temporary cofferdams can be constructed using "super sandbags", consisting of approximately 4-feet square bags filled with sands and gravels, or driven sheet pile driven approximately 6 feet below the limit of excavation.

Dewatering using pumps will be necessary for construction of the slough and wetland side channels. Groundwater inflow may necessitate high-volume pumping. Because of the limited area of flat ground near the wetland, a gravity bag filter is specified to filter the sediment-laden water before it returns to Strawberry Creek downstream of the work area.

The selected construction contractor will be required to provide a detailed water management and sediment erosion control plan, to be approved by the project engineer, prior to commencement of work.

5.3. Construction Access

Construction access to the project area will be along Antonioli Road/SOC Access Road, which continues from the County-owned Hiltons Road to the SOC area through a gated entrance. The existing gravel road is approximately 14-feet wide and is used daily by maintenance vehicles and dump trucks using the SOC area stockpiles.

Construction access to Strawberry Creek upstream of the wetland will be from the SOC Access road into open grass areas. Access to the upstream of the culvert replacement on the west tributary will be through an existing clearing between alders.

Construction access into the wetland will be from two places off the SOC Access Road. The first location will be adjacent to the new West Fork Tributary, where the wetland mounds will be constructed to meet the roadway embankment. A second construction entrance will be located further to the south, where a cleared area extends down the hillslope to the existing gravel berm that borders the east side of the wetland area.

Construction access through the wetland area will be along the existing gravel berm and across the wetland planting mounds. The imported river run gravel used to form the core of the planting mounds can be installed first and serve as access routes for heavy equipment. Excavated materials from the slough channel can be placed on top of the gravel and final grading of the mound can occur from downstream to upstream.

5.4. Utility Relocations

A 6-inch diameter municipal waterline and a telephone line currently run under the SOC Access Road and will need to be temporarily relocated during the West Fork Tributary culvert replacement.

The culvert replacement will also necessitate permanent relocation of the existing water line that is currently running under the culvert. California building code requires that water lines carrying potable water be located over top non-potable conveyances, such as a storm drain pipe. Additionally, the water line should be buried a minimum of 18 inches below finished grade and maintain a minimum one foot of separation between the top of the culvert and the waterline. Specifications are provided on the design plans for materials and installation of the water line relocation.

The contractor should contact Utilities Service Alliance (USA) prior any earthwork, and should coordinate with the utility authorities prior to construction.

5.5. Environmental Documentation and Permitting

RNP and PCFWWRA are coordinating all environmental documentation and permitting for the project. A wetland delineation has been performed by RNP. RNP will be submitting the wetland delineation to the Army Corps of Engineers (ACOE) for a Jurisdictional Determination and to discuss associated wetland impacts of the project. Wetland mitigation for other similar projects involving placement of material in wetlands was not required by ACOE as long as the final material elevation is within the elevation limits of adjacent wetlands.

RNP is presently preparing the NEPA documents for the project.

5.6. Implementation Cost Estimate

An estimate of probable construction cost is presented in Appendix F. The cost estimate includes line items with quantities, unit costs and total costs for each activity that is anticipated during construction. The implementation cost for the project was based on quantities measured from the construction drawings and from material and installation costs from bid tabulations of other recent and similar projects. Prices were adjusted based on anticipated level of difficulty of construction. The construction cost estimate for dewatering includes the use of high volume pumps that may be necessary for construction in the wetland areas of the project.

Large wood from the project will consist of a mix of old growth redwood obtained from Park stockpile areas. It will be necessary to purchase additional wood for the project. Green Diamond Resources has indicated that they have sufficient cull-grade Douglas-fir of these dimensions to supply the project, and they provided costs for the logs, including delivery.

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Appendix A

Final Construction Plans

Appendix B
Fish Habitat Assessment

Appendix C

Strawberry Creek Channel Alignment Alternatives Analysis and Meeting Minutes

Appendix D
Plot of Wetland Water Levels (Provided by Redwood National Park)

Appendix E

Riparian Planting Plan (Prepared by Redwood National Park)

Appendix F

Implementation Cost Estimate