Carr Slough

Habitat Restoration Feasibility Study

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1 INTRODUCTION

1.1 BACKGROUND

As part of its Habitat Restoration Technical Assistance Program, the Lower Columbia River Estuary Partnership (Estuary Partnership), through its contract with the Bonneville Power Administration (BPA), provides feasibility-level funding to restoration partners for the purpose of scoping, design, or planning larger, more complex estuary restoration projects. This includes gathering baseline data and conducting preliminary feasibility analyses on restoration projects intended to meet Reasonable and Prudent Alternatives (RPA) included in the 2008 Biological Opinion of Federal Columbia River Power System Operations (BiOp). The BiOp includes a variety of actions designed to mitigate for the impacts of the hydropower system on the 13 populations of Columbia and Snake River salmon and steelhead listed as endangered or threatened under the Endangered Species Act (ESA). The BiOp mandates that a certain amount of survival benefits to fish must accrue from improvements in the Columbia River Estuary (CRE).

The Estuary Partnership works with local entities to implement restoration projects in the CRE. The restoration project site identified in this study, the Carr Slough Habitat Restoration Feasibility Study, was chosen for its potential to restore quality rearing and feeding habitat for juvenile salmonids and for its location in the CRE.

1.2 STUDY AREA

The project area covered by this study includes a large low lying floodplain area formed on the inside of a former sandbar on the mainstem Columbia River located in Columbia County, Oregon, at approximately River Mile 71.5 (Figure 1). The study area comprises 103-acres of tidal freshwater wetland. The site and surrounding environs have been significantly altered by past and on-going land-use activities including railroad building, road crossings/culverts, industrial activity, ditch and levee building, agricultural use (ditching, land/vegetation clearing, draining), residential development, dredging, and channel maintenance. These activities have altered the landscape and impaired habitat conditions for ESA-listed salmonids. Despite these changes and the constraints that do exist, the site offers opportunities to restore habitat elements that will benefit lower and upper Columbia River and Snake River fish populations.

Figure 1. Site locator and overview map.

1.3 Project Objectives and Potential Constraints

The primary goal of this feasibility study is to gather baseline information and identify conceptual restoration alternatives that will meet BiOp requirements and enhance habitat for ESA-listed Columbia River fish species as well as listed wildlife. Habitat enhancements should focus on actions that enhance the survival, productivity, abundance, distribution, and life history diversity of these species. In support of this goal, this study identifies and analyzes a suite of habitat restoration alternatives with respect to their biological benefit, feasibility, and risk. A baseline analysis of site conditions was conducted to provide a technical foundation upon which to base these analyses.

1.3.1 Project Objectives

Increase tidal channel habitat availability, diversity, and function

Increase off-channel wetland habitat availability, diversity, and function

Improve and enhance connectivity of existing habitats and hydrologic/geomorphic processes

Improve the quality, diversity, and function of riparian and wetland habitats

1.3.2 Potential Project Constraints

Potential project constraints and other considerations were identified in order to provide guidance for the development and evaluation of restoration alternatives. These were developed based on site observations, data collection and analysis, and discussions with project stakeholders. At this stage, considerations and potential constraints are included as part of project evaluations and are not necessarily viewed as impediments to project implementation.

1.4 Development of Alternatives

A total of 5 restoration alternatives were identified and evaluated as part of this feasibility assessment. Although these 5 restoration opportunities are framed as alternatives, they are not necessarily mutually exclusive, and combinations of the alternatives could be conducted at the site. Alternatives were developed based on site investigations and analysis conducted as part of this effort, discussions with project stakeholders, and with reference to previous studies with restoration recommendations for the CRE (i.e. Roni et al. 2002, Johnson et al. 2003, Bottom et al. 2005, NOAA 2007).

The development and evaluation of alternatives is intended to inform the future direction of habitat restoration work at the site. Once a preferred alternative, or combination of multiple alternatives, is selected, additional survey, analysis, and design work will be necessary to determine the technical details required and the specific type and location of habitat restoration activities to be implemented.

The following is a list of the alternatives that have been identified as part of this effort. Section 4 describes and evaluates these alternatives:

Alternative A: Reconnect Slough and Enhance Existing Habitat

Alternative B: Reconnect Slough, Block Main Ditch, and Enhance Existing Habitat

Alternative C: Reconnect Slough, Fill Ditches, Create New Tidal Channels, and Enhance Habitat

Alternative D: Replace Tidegate to Southern Property

Alternative E: Enlarge Channel Inlet at Railroad Trestle

2 SITE INVESTIGATION METHODS

2.1 EXISTING DATA

LiDAR

Light Distance and Ranging (LiDAR) topographic data are available for the site through the Puget Sound LiDAR Consortium (PSLC; http://pugetsoundlidar.ess.washington.edu). The PSLC LiDAR data were collected in 2005. A comparison of the accuracy of the data set is included in Section 2.5.

Aerial Photography

Historical and recent aerial photography is available for the site. Historical photography dating to 1933 was obtained from the US Army Corps of Engineers (USACE), Portland, OR offices. A decadal time series of aerial photos was obtained from the USACE; the time series includes the years 1933, 1948, 1956, 1961, 1970, 1983, 1996, 2001, and 2009.

Historical Survey Records

General Land Office (GLO) cadastral survey records and maps, dating to 1856, are available for the study area. This map represent early legal boundary surveys (Township, Range, and Section) as well as surveys of significant topography and river locations. Two subsequent GLO surveys are available from 1882 and 1898, but the latter two mapping efforts do not record any ground topography.Though precise geo-rectification is difficult, these maps were used in this study to provide estimates of historical conditions at the project site.

Hydrologic Data

Two river stage and flow gages provide information on hydrologic conditions at the site; these include the Longview tidal gage (NOAA #9440422) on the Columbia River and the Beaver Army depot gage near Quincy, OR (USGS #14246900) on the Columbia River. The Longview gage is located approximately five miles downstream of the site and provides the best record for water surface elevation for the project site. The Beaver depot gage is located about 15 miles downstream of the site with several substantial tributary streams joining the Columbia between the site and the gage. Thus the gage provides a means of checking stream discharge patterns against tidal patterns at Longview, but does not provide an accurate discharge record at the site.

Fish Sampling Data

Fish sampling data have been collected by a number of different organizations at several sites that are located near the study area. These data help to characterize the existing and potential future use of the site by salmon, steelhead, and other Columbia River fish species. These data are presented in Section 3.2.

2.2 Site Reconnaissance

Site reconnaissance was performed in August 2011 to identify relevant site features and to characterize site geomorphology, vegetation, and stream habitat at the site. These data are discussed in their relevant sections in this report. Photographs were also taken throughout the study area in order to document existing features and locations for potential restoration activities. Photos from the August visit, as well as photos from other site visits, are included in the report in sections with their respective narrative topics.

2.3 Water Level and Temperature Monitoring

A total of three water level and temperature monitoring stations are established throughout the project site. These stations utilize In-Situ Level Troll 300 pressure transducer and temperature data loggers. These loggers collect surface water elevation data. A map of station locations is included in Section 3.4.1. These stations were intended to determine the general hydrologic relationship between the Columbia River, the slough system near its mouth (C1), in the main ditch (C2), and in Carr Slough itself (C3). These stations were installed between May 2011 and July 2011.

2.4 Topographic Survey

Topographic survey data were collected to establish elevations for the water level monitoring stations, to spot check the accuracy of available topographic data (i.e. LiDAR), and to gather key topographic information to support the development of restoration alternatives. This survey included select tidal channel and site-wide cross-sections, and topography of critical limiting features such as soil plugs in Carr Slough. Survey data were collected using survey grade GPS equipment. Survey data were calibrated to NAVD88 vertical datum using Geodetic Survey benchmarks (brass caps) located at Prescott, OR.

2.5 Evaluation of LiDAR Accuracy

Site-surveyed topographic data were used to evaluate the accuracy of existing LiDAR data for the site. LiDAR was available from the Puget Sound LiDAR Consortium (PSLC). This evaluation was conducted in order to understand the quality of the LiDAR data that are used for portions of the analyses described later in this report. The analysis is simply determining the residual error between ground survey data and comparable LiDAR data. The evaluation was performed by selecting LiDAR data points within 1 ft of a survey point which yielded a total sample of 28 points. Following this initial selection, survey points that were collected in wetted channels were removed from the data set because water interferes with the LiDAR return signal and invariably produces incorrect ground elevation values. Removal of these points left a total of 19 sample points with a mean residual error of 1.18 ft, meaning the LiDAR data was over a foot higher than surveyed data on average. Several points in this data set were taken in tidal channels that were dry at the time of the survey. The residual error between these points and the LiDAR data was significantly greater than the residual error for the rest of the data set. This may be due to the presence of water in these channels at the time the LiDAR was collected. Removal of these data points left 14 data points with an average residual error of 0.68 ft, meaning on average the LiDAR was 0.68 ft higher than survey data. Results of the analysis of this final data set are included in Table 1; a plot of the results is included as Figure 2. Although the average residual error was under a foot, the standard deviation and maximum deviation reveal that there is LiDAR data that vary from surveyed elevations on the order of feet. In general, LiDAR data will be expected to be slightly higher than surveyed ground elevations (as observed here with the PSLC data). It should be noted that the points with the greatest residual error between LiDAR and survey data occurred in low areas that could have been inundated at the time of LiDAR collection. Analysis performed with LiDAR data should always be interpreted with caution.

Table 1. Evaluation of LiDAR accuracy for LiDAR obtained from Puget Sound LiDAR Consortium. Values are the difference between LiDAR grid cell values and points surveyed at the site (using a total station and survey-grade GPS).

Metric	Residual Error (LiDAR - Survey) ft.
Mean	0.68
Standard Deviation	0.5
Min	0.19
Max	1.35

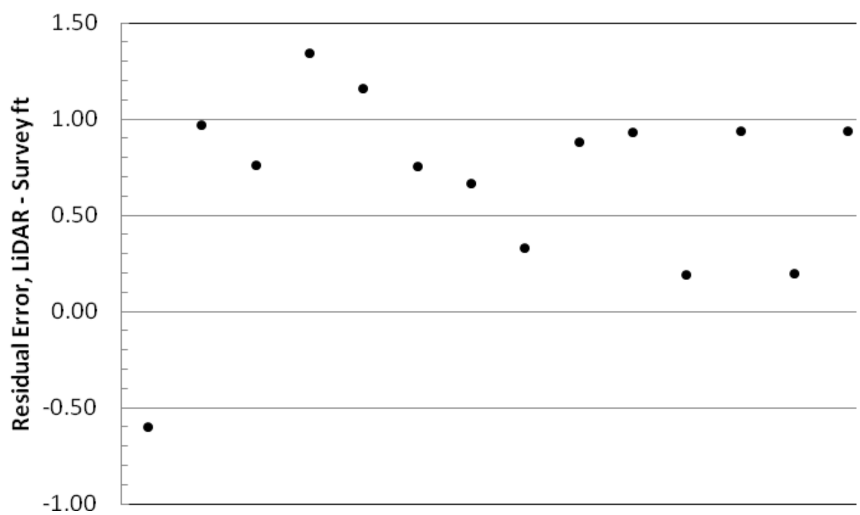

Figure 2. Results of LiDAR accuracy test (LiDAR data minus survey data) for PSLC LiDAR data. Sample size is 14 points.

3 SITE CHARACTERIZATION AND BASELINE ANALYSIS

3.1 SITE CONDITIONS AND LAND-USE HISTORY

Site conditions and history were evaluated based on the August 2011 field survey as well as by using historical surveys and aerial photography.

Pre-disturbance representations of the site lack sufficient detail to re-construct an early history of land-use development. The earliest map of the site is a General Land Office survey map from 1856 (Figure 3). The map depicts a 1.6 mile long floodplain channel just to the west of the current slough alignment. Several hillslope tributaries joined the 1856 channel along its length which extended well beyond that of the modern channel. There is no industrial development of the site, and no rail or other transportation corridor in the floodplain. This 1856 representation is likely a good general example of pre-disturbance conditions. Subsequent surveys by the GLO did not include any topographic or hydrographic details on the site, so any change in the configuration of the channel between 1856 and 1898 is not known. The 1898 map does not show a railroad or any other transportation corridor on the site. However, these later GLO surveys appear to only show property boundaries so it is possible that the railroad was in place and simply not depicted.

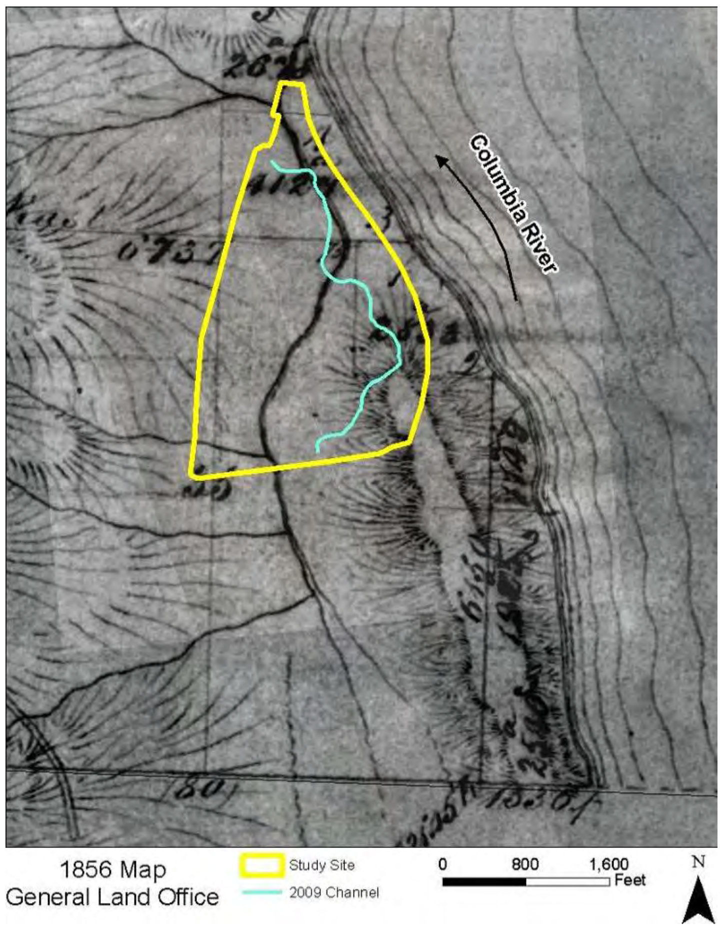

Figure 3. The study area and the extent of Carr Slough as depicted on a General Land Office map from 1856, with an overlay of the modern channel alignment for comparison.

1933 aerial photography shows that substantial development of the site and surrounding area had taken place with direct alteration to the slough system. Sometime between 1856 and 1933 a railroad corridor was established between Carr Slough and the Columbia River, a road was built along the hillslope west of Carr Slough, a mill was built along the Columbia River, and an east/west access road was constructed effectively bisecting Carr Slough (Figure 4). The railroad created a barrier between the slough and the Columbia River for its entire length, with a trestle imposing a hydraulic constriction at the outlet of Carr Slough. The road along the hillslope intercepted all tributaries that were shown in 1856 thus disconnecting upland habitats from the slough. Access roads hydrologically disconnect Carr Slough from a large upstream area. The disconnected channel and floodplain upstream of the road remained physically intact.

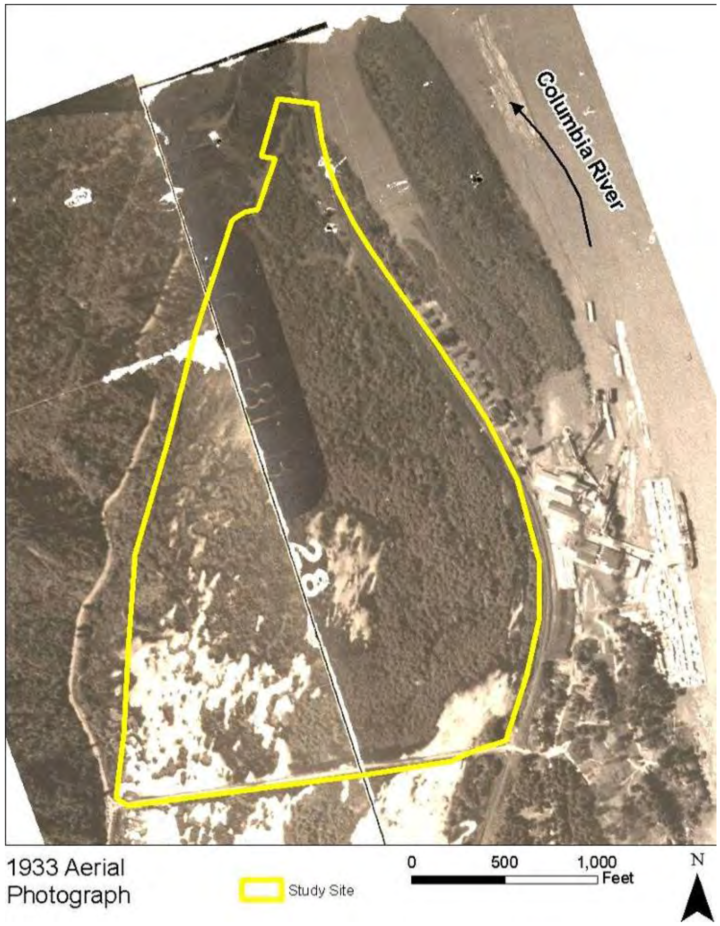

Figure 4. 1933 aerial photograph depicting early land-use in the study area. By this time the outlet of Carr Slough is constricted, the upstream area is disconnected, the Columbia River is disconnected laterally, and hillslope tributaries are disconnected.

Significant changes in land use continued into the next decade. In the 1948 aerial photography, multiple alterations are apparent within the study area and in surrounding locations (Figure 5). In 1948, the majority of the buildings, docks, and piers associated with the mill on the Columbia River were gone. The east/west access road remained intact, and a ditch was excavated along the downstream toe of the road for its entire length across the floodplain. It appears that the ditch had become a part of the slough system at that time. Vegetation across the entire western half of the site appeared to have been removed. There was still dense vegetation on both sides of Carr Slough, but the channel appears wider and more open. The channel is straightened just upstream of the railroad trestle.

Figure 5. 1948 aerial photograph of the study area with notable land-use alteration including the removal of the mill along the Columbia River and the ditch along the southern border of the study area.

By 1956 most of the physical and hydrologic alterations had taken place that currently affect Carr Slough (Figure 6). Highway 30 was placed into its current alignment and the main north/south ditch had been excavated running parallel to the roadway. The up and downstream ends of Carr Slough appear to have been blocked, leaving the ditch as the primary conveyance for tidal fluctuations. In addition to blocking the ends of the slough, vegetation near the channel appears to have been cleared and the channel itself straightened somewhat near its up and downstream extents. At the downstream end of the slough, there was a large area of bare ground that could have been dredge spoils or excavated material from the ditch or slough channel. Upstream of the study area, the land had been drained and put into agricultural use.

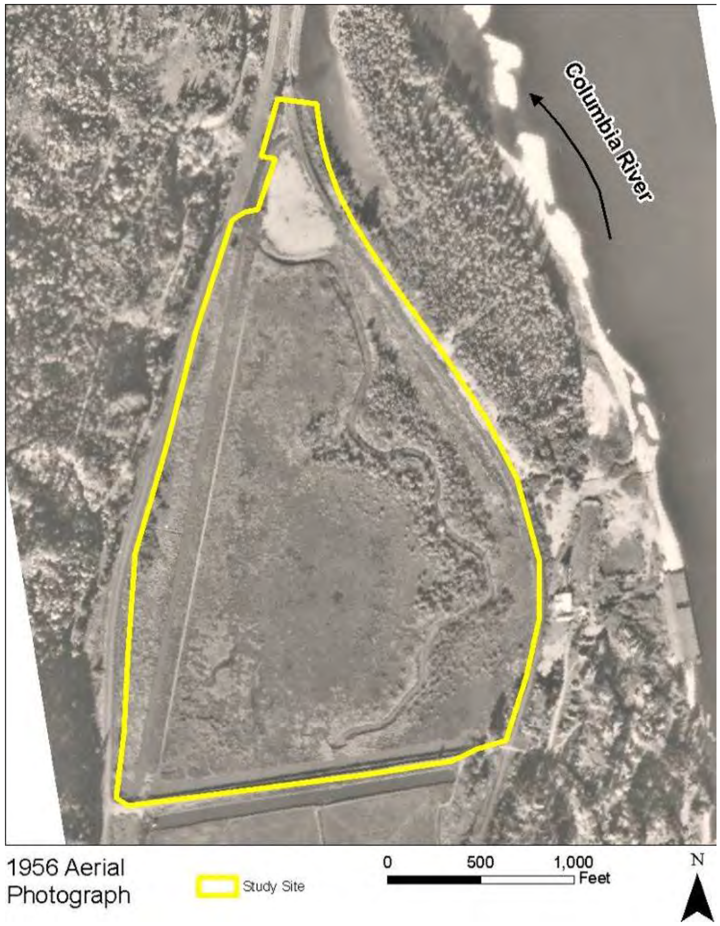

Figure 6. 1956 aerial photograph of the study area with notable land-use activities being the re-alignment of Highway 30 and construction of the main north/south ditch. Carr Slough itself is altered near its up and downstream ends.

In 1961 aerial photography, it appears that no significant changes had occurred within or near the site since 1956 (Figure 7). Ditch and slough channel configurations remained the same as did land use. Vegetation near the slough channel appeared to have recovered to some degree. The slough remained blocked at both ends. Very little alteration took place within the study area boundaries between 1961 and 1970 (Figure 8). Vegetation cover continued to increase near the slough channel. The soil plug at the downstream end of the slough remained intact and had been colonized by vegetation, but the blockage at the upstream end of the slough appears to have deteriorated. Outside the study area boundary, substantial changes in land-use were taking place. Upstream, land-use transitioned from agriculture to apparent abandonment and flooding, which is potentially related to land subsidence that occurred during the period of agricultural use and associated diking and draining. To the west, residential development was taking place on adjacent hillslopes. Along the Columbia River to the east, large areas of bare ground were visible either from clearing or placement of dredged material. These trends continued through 1983, with increased vegetation cover along the slough channel and complete deterioration of the blockage at the upstream end of the slough (Figure 9). Outside the study area boundary, residential development continued to the east and west, placement of dredge material continued along the Columbia, and former agricultural areas upstream of the study area remained flooded and out of use.

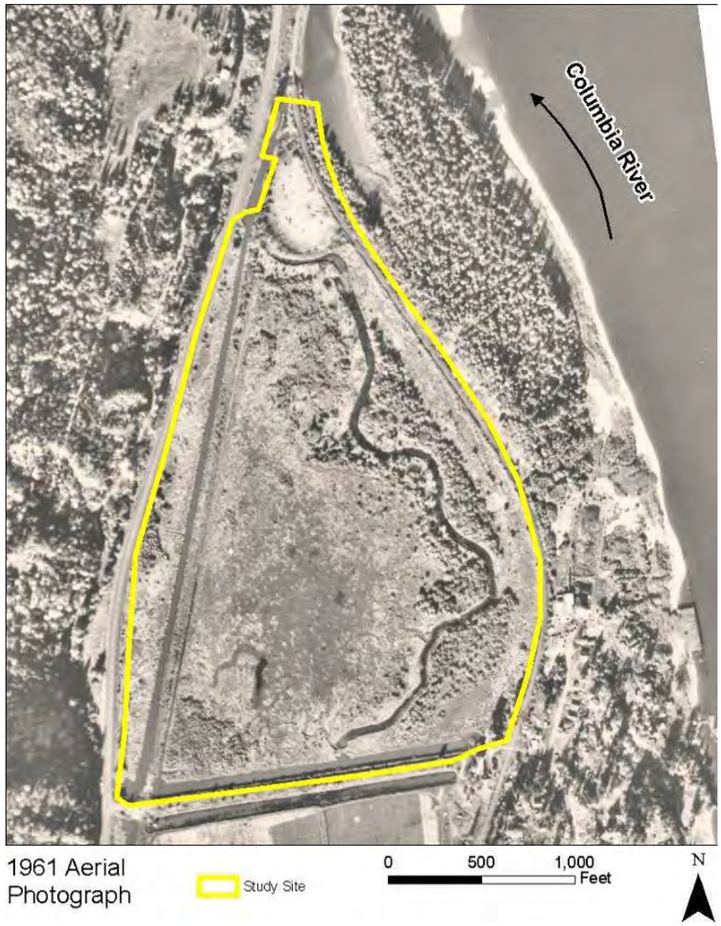

Figure 7. 1961 aerial photograph of the study area showing no major land-use changes since 1956.

Figure 8. 1970 aerial photograph of the study site showing vegetative stabilization of the blockage near the downstream end of Carr Slough and degeneration of the blockage at the upstream end.

Figure 9. 1983 aerial photograph of the study area illustrating land-use trends continued from 1970.

In more recent aerial photography from 1996 and 2001, there was no significant change to land-use in the study area (Figure 10, Figure 11). Vegetation continued to recover along the channel of Carr Slough and widened to the west. By 2001, it appears that shrub vegetation had colonized a large portion of the cleared area in the western half of the study area. There is evidence of continued deterioration of the structure of the ditches that were put in place in the first half of the 20th century. The plug at the upstream end of Carr Slough is severely compromised in 1996 and fully breached by 2001. Also apparent in 1996, and increasing through the turn of the century, are lateral breaches in the levee along the eastern border of the main north/south ditch. These breaches appear to let water flow into a narrow ditch that runs parallel to the main ditch. The breaches also may have eventually contributed to increased inundation of the central portion of the study area, although tide elevation at the time of photography affects the apparent extent of inundation. A county park (Prescott Beach Park) had been established along the Columbia by 1996.

Figure 10. 1996 aerial photograph of the study site showing no change in terms of land-use since 1983.

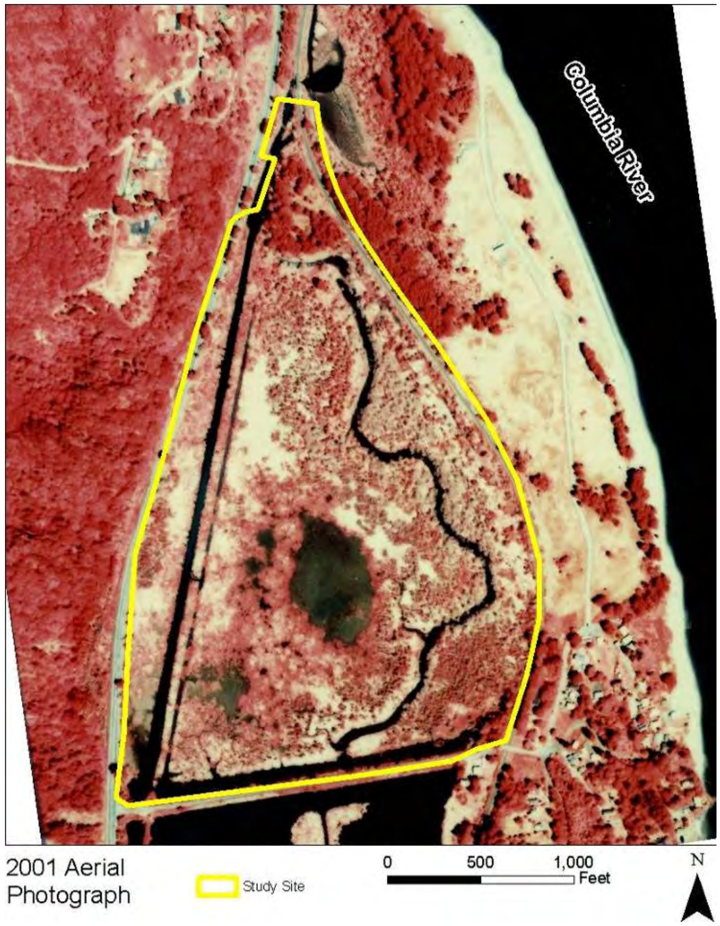

Figure 11. 2001 aerial photograph of the study area. The image highlights locations of levee breaching and the complete deterioration of the plug at the upstream end of Carr Slough.

3.2 Fish and Wildlife Ecology

The Carr Slough property holds a diverse array of habitat types supporting a variety of fish and wildlife species within the lower Columbia River system. As a part of our investigation, a search was conducted of all existing literature and data to develop a better understanding of the various populations and habitat conditions occurring within the area. A key focus was placed on salmonids due to the site's good connectivity and close proximity to the Columbia River. Enhancement and restoration of this property's habitat could play a key role in providing critical refugia to at-risk migrating salmonids.

3.2.1 Landscape Ecology and Habitat Conditions

The Lower Columbia River Estuary (LCRE) is broken down into eight distinct hydrogeomorphic reaches from the mouth to Bonneville Dam. The reaches are classified using the Environmental Protection Agency's (EPA) Level IV Ecoregions structure with its boundaries modified by incorporating additional parameters including salinity intrusion, maximum tide level, upstream extent of current reversal, geology, and major contributing tributaries to further refine each reach's individual classification (Simenstad et al. 2011). This classification yields eight distinct reaches (A through G) describing the LCRE landscape and the geologic and hydrologic interactions that formed it (Sagar et al. 2011).

The Carr Slough property is located in the Western Cascades Tributary Confluences Hydrogeomorphic Reach (Reach D). The reach starts just downstream of Longview, WA at approximately river kilometer (RKm) 98 and extends upriver to RKm 118 past the Columbia's confluence with the Cowlitz and Kalama rivers. The reach is characterized by a confined valley along the Columbia River mainstem resulting in a steep profile that causes the vast majority of sediment inputs to be transported out of the reach. Furthermore, the reach experiences continuous sediment inputs from the Cowlitz and Kalama Rivers due to volcanogenic sediments from the Mount St. Helens eruptions and lahars. These continuous inputs have constructed a complex bottomlands area at the mouths of the Cowlitz and Kalama Rivers by the city of Longview (Simenstad et al. 2011).

Land use within the reach is heavily urbanized and few habitats can be found that are not impacted by anthropogenic activities (Sobocinski et al. 2006). Activities that degrade habitat include the construction of pile dikes and levees, grazing of wetlands and the riparian floodplain, introduction of contaminants from industrial activities, and continual dredging of sediments delivered by Mount St. Helens. These impacts, combined with the steep physiography within the reach, has left little off-channel and emergent habitat available at the reach scale.

3.2.2 Fish Populations and Assemblages

Although no fisheries data exists for the site, Carr Slough has direct connectivity with the Columbia River via an approximately 12 foot wide channel beneath the railroad trestle. Inspections of the connection indicate that the channel is passable under a variety of flows for a wide diversity of salmonid species and life history forms. Given Carr Slough's high connectivity with the Columbia River, it is expected that multiple salmonid species utilize the site for rearing and refugia. Species listed by Oregon Department of Fish and Wildlife as occurring within the mainstem of the river that may use the site include coho, Chinook, steelhead, chum, Pacific Lamprey, western brook lamprey, and coastal cutthroat trout (ODFW 2010, Table 2).

Table 2. Salmonid ESUs within the Columbia River in Reach D and their use (Streamnet 2011, NMFS 2008)

Species	ESU	Strata	Habitat Utilization
Chinook	Lower Columbia River	Fall and Spring	Migration, Rearing and Spawning
	Middle Columbia River	Spring	Migration
	Upper Willamette River	Spring	Migration and Rearing
	Upper Columbia River	Spring, Summer and Fall	Migration
	Snake River	Fall, Spring and Summer	Migration
Chum	Columbia River	Fall	Migration, Rearing and Spawning

Coho	Lower Columbia River	Fall	Migration and Rearing
Steelhead	Lower Columbia River	Winter and Summer	Migration and Rearing
	Upper Willamette River	Winter	Migration
	Middle Columbia River	Summer	Migration
	Upper Columbia River	Summer	Migration
	Snake River	Summer	Migration

3.2.3 Juvenile Salmonid Use of Tidal Freshwater Habitats

In 2005, the Bonneville Power Administration (BPA), the U.S. Army Corps of Engineers, Portland District (USACE), and the U.S. Bureau of Reclamation commenced a study to investigate juvenile salmonid use of shallow (<5 m) tidal freshwater habitats in the LCRE. Sampling was conducted in Reach D and E from RKm 110 to 141 in 2009 (Figure 12). Six different habitat types within the sampling reach were sampled; these habitat types consisted of wetland channel, off-channel, main channel, confluence, main-channel island, and off-channel island. Habitat types were broken into 500-m units with one to five sites per strata randomly selected for sampling within the reach (Johnson et al. 2011).

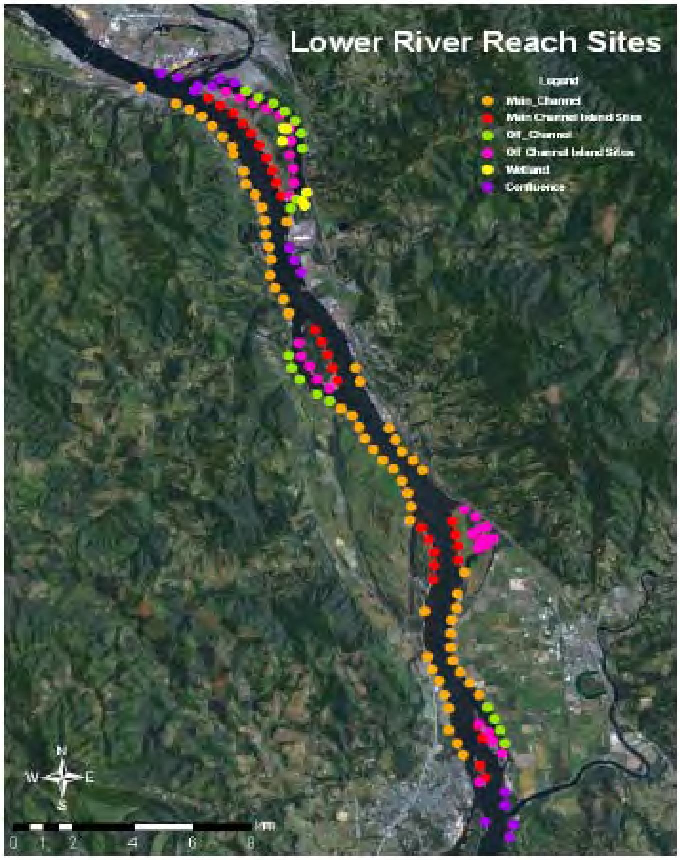

Figure 12. Sampling locations along the reach (RKm 110–141) with the six different habitat strata (taken from Johnson et al 2011).

Sampling occurred during a 2.2 week period in January, February, May, August, and November using beach seines and/or set techniques. Whenever possible, the beach seine was conducted by boat with two replicate, non-overlapping hauls at least 30 minutes apart (Johnson et al. 2011).

Sampling efforts showed that salmonids were feeding and rearing across all habitats during the sampling period with no significant difference between the habitat units. Threespine stickleback was the most prominent species caught, making up 62.2% of the catch across the entire sampling period. Banded killifish and pike minnow were the second and third most abundant, making up 18.7% and 4.61% of the catch, respectively. Unmarked Chinook salmon were the fourth most prominent fish caught at 4.46% of the total catch (Johnson et al. 2011, Table 3).

Table 3. Salmonids caught as a percentage of total catch.

Common Name	Species	Percent of Total Catch
Chinook salmon	Oncorhynchus tshawytscha	4.46
Marked Chinook	Oncorhynchus tshawytscha	0.653
Chum salmon	Oncorhynchus keta	0.125

Coho salmon	Oncorhynchus kisutch	0.196
Marked coho	Oncorhynchus kisutch	0.467
Marked steelhead	Oncorhynchus mykiss	0.023
Steelhead	Oncorhynchus mykiss	0.005

Juvenile salmonids were utilizing the entire reach throughout the year with the greatest density occurring in spring. Broken down across seasons, the average length of Chinook was smallest in the spring with a more bi-modal length distribution in winter. Unmarked Chinook salmon were caught in greater numbers in wetland habitats, indicating their preference for shallow tidal freshwater habitat to a greater extent than marked fish (Johnson et al 2011).

Genetic analysis of 362 sampled Chinook indicated that the West Cascade Tributary Fall stock group constituted 75% of the unmarked salmon caught in January and February. Other prevalent stocks included the Spring Creek Group Tule Fall (12%), West Cascade Tributary Spring (5%) and Willamette River Spring (4%) stocks with no other stock groups contributing more than 1%. Across the entire sampling period, the West Cascade Tributary Fall stock group contributed the majority of fish, followed by the Spring Creek Group (Johnson et al. 2011).

3.2.4 Lord Island Fish Sampling

Lord Island is located at RKm 101, which is downstream of Longview, WA in Reach D. Fish sampling was conducted on Lord Island in 2006, 2007, and 2008 to evaluate the performance of juvenile Chinook salmon and the existing habitat conditions within the estuary (Bottom et al. 2008). The island is ringed by shallow marsh with its interior made up of a mix of mudflat and emergent wetlands dominated by reed canary grass (*Phalaris arundinacea*) (Sagar et al. 2011).

Sampling was conducted across a variety of habitats on Lord Island by conducting beach seines along the island edge and setting net traps within tidal channels. Net traps consisted of two wings across the tidal channel to a centrally located tunnel leading to a live box, which was installed at low tide. Beach seining was conducted across three seasons, including winter (November – February), spring (March – June), and summer (July – October). Wetland channel sampling occurred once a month March through July to evaluate temporal patterns of salmonid use (Bottom et al. 2008).

Chinook salmon abundance at Lord Island steadily increased after March to a peak in April or May, except in 2008, which continued to increase throughout the summer. Threespine stickleback was the most abundant fish, making up 49.12% of the total catch. Chinook salmon were the second most abundant at 27.5% (Table 4). Chum and coho were also captured during the sampling period with chum occurring predominantly during the spring peak (Bottom et al 2008).

The mean fork lengths of juvenile Chinook salmon at all wetland sites progressively increased throughout the sampling period with fry (< 40 mm FL) starting to appear in March. Fry continued to use the wetland side channels on Lord Island through June, making up 60% of all the Chinook caught during the study. Size classes of fish were greatest near the mainstem, decreased toward the protected back shores, and were smallest within the shallow wetland channels that extended into each island’s interior (Bottom et al. 2008).

Table 4. Total species caught on Lord Island (Adapted from Bottom et al. 2008). Asterisks indicate non-native species.

Species (Common Name)	2006	2007	2008	N	%
Threespine stickleback	1,176	1,178	56	2,410	49.12
Chinook salmon	372	445	532	1,349	27.50
Banded killifish*	562	341	61	964	19.65
Coho salmon	2	65	2	69	1.41
Chum salmon	5	22	9	36	0.73
Unidentified sculpin	6	19	3	28	0.57
Prickly sculpin	10	9	6	25	0.51
Unidentified crappie*	11			11	0.22
Common carp*	6			6	0.12
Peamouth	2			2	0.04
Unidentified fish		1	1	2	0.04
Black crappie*		1		1	0.02
Cutthroat trout		1		1	0.02
Largescale sucker			1	1	0.02
Unidentified centrarchid*		1		1	0.02
Northern pikeminnow					
Total	**2,152**	**2,083**	**671**	**4,906**	

Marked Chinook made up a low percentage of the total catch, with 2.5% in 2006, 1.7% in 2007, and 7.3% in 2008. The mean fork length of hatchery fish caught was larger than that of unmarked salmon with their numbers decreasing from the mainstem shore to the interior wetland channel. This supports the concept that smaller, unmarked wild fish prefer shallow protected habitats (Bottom et al 2008).

Habitat on Lord Island was also evaluated for its degree of availability to salmonids based upon a minimum depth of 0.5 m and maximum temperature of 19° C at each sampling site. Using these criteria, habitat was defined as available, not available, or marginal. During 2007, habitat availability for salmon declined from ~75% of the time in March to <30% of the time in August. This was attributed to low flows in the Columbia causing shallow depths on the island. The higher river flows in 2008, however, retained water at a sufficient depth for salmon to access the wetland channels >90% of the time from March - August. Habitat conditions were considered marginal due to high temperatures exceeding 19° C in June, July, and August each year (Bottom et al. 2008).

Feeding preferences were also sampled during the study period to determine preferred Chinook prey. Dipteran insects made up the dominant prey for juvenile Chinook with a specific preference for emerging chironomids. The number of chironomid prey consumed decreased over time with increasing fish size, however, with a proportional increase in the consumption of amphipods and polychaete annelids. Juvenile Chinook feeding preference for detritivorous chironomids demonstrates the importance of shallow water wetland habitats, which produce the necessary macrophytes that support chironomids (Bottom et al. 2008).

3.2.5 Crims Island

Crims Island is an island in Reach C downstream of Longview, WA that extends from RKm 87.1 to 91.7. In August 2004 to September 2005, the USACE restored Crims Island by excavating backwater channels to create habitat for juvenile salmonids. When completed, a total of 34.4 hectares of tidal emergent marsh and 3.7 hectares of intertidal channels were created on the island. As a part of the project, USGS collected pre- and post monitoring data to determine the effectiveness of the project at restoring juvenile salmonid habitat.

Sampling was conducted in 2004 pre project and in 2006, 2007, and 2008 post project at multiple reference and restoration sites. Site sampling was conducted along the mainstem Columbia off Gull Island, in a natural intertidal marsh on Gull Island, and in the newly created tidal channels on Crims Island (See Figure 13). Beach sampling was conducted with a 20.7 m beach seine pulled parallel to shore for 50 m and with two fyke nets (one facing upstream and one facing downstream) were used to sample the backwater channels.

Figure 13. Aerial photo of Monitoring Site (taken from Haskell and Tiffan 2011).

During the entire study, 25 species of fish were captured made up primarily of threespine stickleback (*Gasterosteus aculeatus*, 58.4 percent), banded killifish (*Fundulus diaphanus*, 16.9 percent), peamouth chub (*Mylocheilus caurinus*, 13.4 percent), and subyearling Chinook (9.1 percent). Subyearling Chinook were the most prominent salmonids captured with 12,833 subyearlings, 221 chum salmon juveniles, 84 yearling Chinook salmon, and 5 coho salmon juveniles (Table 5). Extrapolating from these numbers, USGS estimates that the peak yearly number of subyearlings caught during beach seines ranged from 13,962 in 2006 to 11,613 in 2008 (Haskell and Tiffan 2011).

Table 5. Summary of fish caught as a percentage of total listed by species between 2004 and 2008.

Species	Common Name	Percentage of the total numbers of fishes caught			
		2004	**2006**	**2007**	**2008**
Oncorhynchus clarki	Cutthroat trout	<0.01	–	–	–
Oncorhynchus keta	Chum salmon	0.21	0.06	0.23	0.23
Oncorhynchus kisutch	Coho salmon	0.13	<0.01	<0.01	–
Oncorhynchus mykiss	Steelhead	<0.01	<0.01	–	<0.01
Oncorhynchus tshawytscha	Yearling Chinook salmon	0.11	0.02	0.01	0.06
Oncorhynchus tshawytscha	Subyearling Chinook	22.46	8.39	5.64	4.18

During the study, subyearling density was greatest from the months of mid-March to late May with their numbers beginning to decline around mid-June. This decline coincides with water temperatures beginning to exceed 20 °C as subyearlings leave intertidal habitats for the mainstem and subtidal channels in the summer. Based upon this information, USGS predicts the majority of subyearlings captured during the sampling period were wild fish reproduced in the mainstem or tributary habitats downstream of Bonneville Dam. Upriver subyearlings often migrate in June–August when water temperatures are too warm in backwaters habitats to be utilized by fish (Haskell and Tiffan 2011). Salmonid genetic testing conducted across five sites in Reach C by the Estuary Partnership in 2009 also supports this hypothesis. During the Estuary Partnership's study, the majority of fish caught were from Lower Columbia River ESUs with the West Cascade Spring stock dominating the number of fish caught (Sagar et al. 2010).

In addition to studying salmonid utilization of the restoration and reference sites, subyearling feeding preferences were monitored. Small subyearlings consistently fed on dipterans in backwater habitats before increasing in size and migrating to nearshore habitats where they consumed primarily *Daphnia* and *Corophium*. The primary prey of subyearlings probably relates to the types of food sources available during their growth, but subyearlings consistently fed most intensively upon chironomids. This underscores the importance of intertidal channels, which produce higher populations of chironomids and provide better opportunities for forage than in the mainstem. In addition, use of these shallow-water habitats offers lower predation risk and warmer temperatures optimizing salmonids growth (Haskell and Tiffan 2011).

3.3 Vegetation

3.3.1 Overview of Vegetation Conditions

Carr Slough is primarily composed of four wetland habitat types, including Palustrine Forest, Palustrine Shrub Scrub, Palustrine Emergent Marsh, and Riverine Aquatic Bed. Broken down into their different vegetation communities, the site consists of 9 associations (Figure 14). Many of these vegetation communities reflect their Euroamerican presettlement condition structurally, but they are heavily degraded, as is common within the Columbia River Floodplain.

While Native Oregon ash (*Fraxinus latifolia*) and Pacific willow (*Salix lucinda spp. laciandra*) still dominate the site's canopy at higher elevations, the community has become significantly reduced due to historical clearing. In addition, management of the Columbia for hydropower and flood abatement has reduced the magnitude and frequency of flood events, which historically would have inundated the site. This, combined with the construction of the railroad trestle and the disconnection of the backwater meandering channel, has significantly altered the site's hydrology. The tidal prism is now muted, allowing reed canarygrass (*Phalaris arundinacea*) to become ubiquitous and suppress much of the herbaceous layer's diversity. In addition, the loss of flushing flows through the backwater meandering slough has allowed the channel to become choked with Canadian waterweed (*Elodea Canadensis*), floating-leaved pondweed (*Potamogeton natans*), and coontail (*Ceratophyllym demersum*).

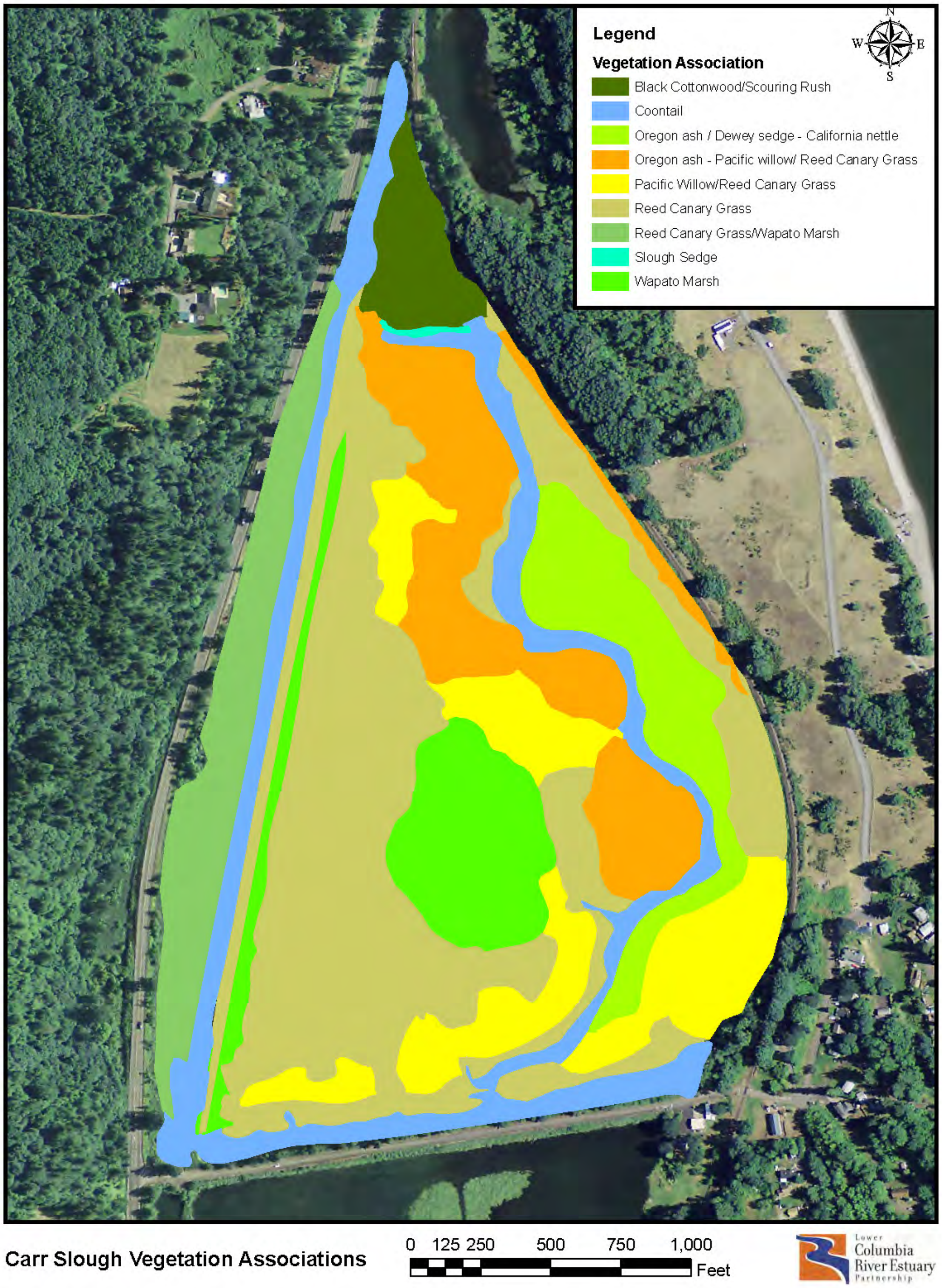

Figure 14. Carr Slough vegetation associations.

3.3.2 Sampling Methodology and Classification System

The Estuary Partnership conducted vegetation surveys across the site identifying and delineating all existing vegetation communities. Classification methodology followed the *Standards for associations and alliances of the U.S. National Vegetation Classification* (Jennings et al. 2009). Vegetation communities and their boundaries were initially identified using a combination of LIDAR, orthophotographs, and color infrared imagery. Once all potential communities were identified in ArcGIS, the property was ground-truthed with each individual community boundary defined based upon the characteristic or dominant species occurring. Sampling was then conducted within each individual community treated as a large single plot by identifying all plants to the species level and giving them a percent cover (Jennings et al. 2009). Communities were then classified based upon their distinct floristic composition and abiotic conditions into Vegetation Associations according to the National Vegetation Classification System (NVCS) (Christy 2004). Where no existing NVCS association fit due to anthropogenic disturbance, one was modified or created to represent the community. A list of all species identified, their average cover class, and association is provided in Table 6.

Table 6. Average percent cover of sampling plot within each association.

		Average Percent Cover of Plant Species per Association								
	Species	Black Cottonwood/Scouring Rush	Coontail	Oregon ash / Dewey sedge - California nettle	Oregon Ash - Pacific Willow/Reed Canary Grass	Pacific Willow/Reed Canary Grass	Reed Canary Grass	Reed Canary Grass - Wapato Marsh	Slough Sedge	Wapato Marsh
Trees	*Fraxinus latifolia*	10%	---	50%	40%	---	---	---	1%	---
Trees	*Populus balsamifera ssp. trichocarpa*	55%	---	---	---	---	---	---	---	---
Trees	*Quercus garryana*	1%	---	---	---	---	---	---	---	---
Trees	*Salix lucida ssp. lasiandra*	1%	---	5%	30%	50%	2%	---	---	---
Small Trees & Shrubs	*Cornus sericea*	10%	---	1%	5%	---	---	---	---	---
Small Trees & Shrubs	*Crataegus douglasii*	2%	---	---	---	---	---	---	---	---
Small Trees & Shrubs	*Cytisus scoparius*	10%	---	---	---	---	---	---	---	---
Small Trees & Shrubs	*Rosa nutkana*	5%	---	---	1%	---	---	---	---	---
Small Trees & Shrubs	*Rubus discolor*	35%	---	---	---	---	---	---	1%	---
Small Trees & Shrubs	*Spiraea douglasii*	---	---	---	1%	2%	1%	---	---	---
Small Trees & Shrubs	*Symphoricarpos albus*	5%	---	---	---	---	---	---	---	---
Herbaceous	*Alisma plantago-aquatica*	---	---	---	---	---	---	1%	---	1%
Herbaceous	*Bidens cernua*	---	---	---	---	---	---	1%	---	---
Herbaceous	*Carex obnupta*	---	---	---	---	---	---	---	70%	---
Herbaceous	*Eleocharis palustris*	---	---	---	---	---	---	5%	---	5%
Herbaceous	*Equisetum hyemale*	25%	---	---	---	---	---	---	---	---
Herbaceous	*Iris pseudacorus*	---	---	---	---	---	1%	5%	---	---
Herbaceous	*Ludwigia palustris*	---	1%	---	---	1%	---	2%	1%	---
Herbaceous	*Lysimachia nummularia*	---	---	1%	---	1%	1%	---	---	---
Herbaceous	*Lemna minor*	---	10%	---	---	2%	2%	5%	10%	10%
Herbaceous	*Nuphar luteum ssp. polysepalum*	---	---	---	---	2%	10%	25%	---	---
Herbaceous	*Phalaris arundinacea*	10%	---	50%	55%	40%	65%	40%	15%	25%
Herbaceous	*Polygonum amphibian*	---	---	---	---	5%	1%	---	---	---
Herbaceous	*Polygonum persicaria*	---	1%	---	---	1%	1%	2%	1%	1%
Herbaceous	*Sagatarria latifolia*	---	---	---	---	5%	10%	30%	---	60%
Herbaceous	*Sparganium emersum*	---	5%	---	---	---	---	5%	5%	5%
Herbaceous	*Typha angustifolia*	---	---	---	---	---	---	2%	---	---
SAV	*Ceratophyllum demersum*	---	50%	---	---	---	---	---	---	---
SAV	*Elodea Canadensis*	---	25%	---	---	---	---	---	---	---
SAV	*Potamogeton natans*	---	10%	---	---	---	---	---	---	---

3.3.3 Vegetation Community Descriptions

Oregon ash / Dewey sedge - California nettle

The Oregon ash / Dewey sedge – California nettle (*Fraxinus latifolia / Carex deweyana - Urtica dioica ssp. gracilis*) Association occurs frequently in forested depressions and bottomlands subject to prolonged flooding by the Columbia River. Oregon ash is often the only tree present in this type of association with a poorly developed shrub and herbaceous layer (Christy 2004), as was the case at Carr Slough. During the time of sampling (early August), the area had been flooded for an extended period of time into mid-July, which probably suppressed much of the herbaceous layer. In addition, the understory is heavily dominated by reed canarygrass, which makes up 50% of the herbaceous cover. The invasion of reed canarygrass into this community has become a common occurrence due to an increase in grazing and reduced inundation of the floodplain by hydromanagment (Christy 2004). The community dominantly occurs along the natural meandering slough at elevations above 10.5 ft NAVD88 at the site.

Oregon ash - Pacific willow/ Reed Canarygrass Association

The Oregon ash – Pacific Willow/Reed Canarygrass (*Fraxinus latifolia-Salix lucida ssp. lasiandra/ Phalaris arundinacea)* Association is a common community type that occurs along sloughs and streams within the Columbia and Willamette floodplains (Titus 1996). In this association, the Oregon ash and Pacific willow are growing intermixed throughout the community. In general, Oregon ash occupies the higher elevations of this association along the natural meandering channel with the Pacific willow occurring in the lower more saturated soils. Several other woody species were also found within this association in low numbers including creek dogwood (*Cornus sericea*), Nootka Rose (*Rosa nutkana)*, and spiraea (*Spiraea douglasii*).

The herbaceous understory is depauperate with reed canarygrass, which comprises over 50% of the cover. The combination of high reed canarygrass cover and prolonged flooding this past year has probably suppressed much of the native herbaceous diversity that would typically occur within this association during the time of sampling. In addition, there appears to be poor regeneration of ash within this community due to the heavy thatch formed by the reed canarygrass.

Figure 15. Pacific Willow/Reed Canarygrass Association (August 2011)

Pacific willow/ Reed Canarygrass Association

The Pacific willow/Reed Canarygrass (*Salix lucida ssp. lasiandra/ Phalaris arundinacea*) Association is common within the Columbia and Willamette River floodplains (Titus 1996). At one time, this community was probably a Pacific Willow/California Nettle (S*alix lucida* ssp. *lasiandra / Urtica dioica* ssp. *gracilis*) Association, which today is considered

Globally and State Imperiled (Kagan et al. 2004). Christy describes this native shrub swamp as occurring along low gradient channels or ponds with Oregon ash forest surrounding it on higher less saturated soils. Beavers help maintain these shrub swamps; and some beaver activity was evident during the survey. Current site conditions fit the Pacific Willow/California Nettle Association description except for the invasion of reed canarygrass, which is noted as occurring frequently in disturbed Pacific willow shrublands (Christy 2004). The invasion of reed canarygrass, grazing and hydropower management of the Columbia has converted this native shrub swamp to the association it is today.

Figure 16. Reed Canary Grass Association (August 2011)

Reed Canarygrass Association

The Reed Canarygrass *(Phalaris arundinacea)* Association was created by the author because no association like it existed in the NVCS. The association occurs throughout the majority of site where a native emergent marsh or wet meadow once existed. Reed canarygrass is 60% or more of the canopy cover in this association with other herbaceous species being largely suppressed. Wapato (*Sagatarria latifolia*) and spatterdock (Nuphar luteum ssp. polysepalum) do occur sporadically throughout this association making up 10% of the cover respectively.

Canarygrass has become a common community type within the Columbia River floodplain due to anthropogenic disturbances. Hydropower management, the installation of flood control structures, and the conversion of land for grazing purposes have significantly reduced what was once a diverse native emergent plant community.

Figure 17. Black Cottonwood/Scouring Rush Association (August 2011)

Black Cottonwood / Scouring Rush Association

The black cottonwood/Scouring rush (*Populus balsamifera* ssp. *trichocarpa/Equisetum hyemale*) Association is one that occurs sporadically throughout Oregon (Kagan 2004). Historically, the association did not occur on the site, but was formed when sand dredge spoils were placed in the 1950s. This dredge spoil placement converted what was once a forest/shrub swamp into upland with well-drained soils. Test holes were dug within the community revealing soils made up of at least 70%

sand. Creation of this habitat feature promoted the establishment of cottonwoods, which prefers well drained moist, sandy soils (Cooke 2007).

Cottonwood dominates the canopy with some Oregon ash and Oregon white oak (*Quercus garryana*) occurring in the mid-canopy layer. The understory is more diverse with a mix of snowberry (*Symphoricarpos albus*) and creek dogwood (*Cornus sericea*) occupying the shrub layer. Himalayan blackberry has also invaded the site making up approximately 35% of the shrub layer stratum. The herbaceous layer is undeveloped with scouring rush (*Equisetum hyemale*) characterizing this stratum.

Wapato Marsh Association

The Wapato Marsh (*Sagittaria latifolia*) Association is an emergent marsh community that occurs in seasonal ponds, sloughs, and in freshwater tidal mudflats (Kagan et al. 2004). The community is often inundated in the spring with it potentially drying out in the late summer unless it remains irrigated by tides from the Columbia River (Christy 2004). Historically, the association was widespread throughout the Columbia River floodplain, but has significantly diminished over time with introduction of flood control and reed canary grass. Currently, the association is listed as State imperiled and at risk of extinction (Kagan et al. 2004).

Figure 18. Wapato Marsh Association (August 2011)

The community occurs on the Carr Slough property within a seasonal pond that is on average below 9.5 ft NAVD 88. This has allowed the community to remain too wet for reed canarygrass invasion, which makes it the most diverse native herbaceous association occurring within the project site. Other characteristic species commonly occurring in the herbaceous stratum include common spikerush (*Eleocharis palustris*), spatterdock (*Nupahar luteum*), and water knotweed (*Polygonum amphibian*).

Slough Sedge Association

The Slough Sedge (*Carex obnupta*) Association is a small community that occurs along Carr Slough itself near the plug that was installed. This association frequently occurs within isolated depressions and shrub swamps. The community type is highly variable ranging from one with rich diversity to monotypic stands (Christy 2004). The stand occurring in Carr Slough is representative of a depauperate community made up almost entirely of slough sedge.

Reed Canary Grass - Wapato Marsh Association

The author created the Reed Canary Grass/Broadleaf Arrowhead (Phalaris arundinacea/Sagittaria latifolia) Association because no current NVCS classification accurately describes this community, which is present at Carr Slough. The association is a mix of reed canary grass, broadleaf arrowhead, spatterdock, and other emergent wetland species. The association occurs along the west side of the property between Hwy 30 and the ditch dug out to drain the project site.

The association has intense competition between the three characteristic species for space. The community also consists of a large diversity of native and non-native species being scattered throughout the community including yellow flag iris (*Iris pseudacorus*), spikerush (*Eleocharis palustris*), water knotweed (Polygonum amphibian), lady thumb (*Polygonum persicaria*), and bur-reed (*Sparganium emersum*). Topography through the association is extremely hummocky with pockets of mud flat and pooling. Elevations range between 9 ft and 10.5 ft NAVD88.

Coontail Association

The Coontail (*Ceratophyllum demersum*) Association occurs throughout Carr Slough and the many waterways running through the property. This association is common in low gradient, eutrophic streams and sloughs in western Oregon (Christy 2004). Anthropogenic activities have probably promoted its distribution and dominance throughout the site due to a loss in flushing flows that once maintained more open water habitats. Other characteristic species found during sampling included Canadian waterweed (*Elodea Canadensis*), duckweed (*Lemna minor*), Floating-leaved pondweed (*Potamogeton natans*), and bur-reed (*Sparganium emersum*).

3.4 HYDROLOGY

Overview

Surface water flows and elevations in ditches, tidal channels, and wetlands on the site are governed by water surface elevations (stage) in the Columbia River. The Columbia River sets a baseline stage controlled by discharge, and tidal fluctuation is imprinted on top of stage. The oldest photos available show a downstream connection between Carr Slough and the Columbia River near the northwest corner of the site. In these photos, the geometry of the inflow was already altered by the railroad trestle, and a roadway to the mill site had already disconnected the Carr Slough system from upstream channels and wetlands with only a tide gate connecting the large upstream area. Prior to road construction, there was a much larger channel network.

The results of preliminary water level monitoring in the study area indicate that stage in the ditch and slough is significantly different than stage at the Longview tidal gage on the Columbia River, which is located several miles downstream (north) of the study site. The Longview Gage therefore cannot be used as a record of stage for the site. However, comparable records from depth sensors at the site with tide gage records at Longview are useful for characterizing hydrologic relationships between the site and the mainstem Columbia River.

Columbia River and Tidal Influence

The stage of the Columbia River governs water surface elevation for the ditch and slough system within the study site. Stage on the Columbia is subject to diurnal tidal fluctuations as well as seasonal variation. The tide cycle ranges from 9.56 ft (MHHW) to 4.98 ft (MLLW), with a mean tide level of 7.2 ft (Table 7). This is a mean tidal range of 3.74 ft and a great diurnal range of 4.58 ft. High water can occasionally reach near 16 ft and regularly (multiple times per year) exceeds 12 ft. Extreme low water often drops to nearly 3 ft (Figure 19). The effect of increased river flow on stage and the magnitude of tidal fluctuation can be seen as the difference between higher high and lower low tides in Figure 19. The greatest diurnal fluctuation occurs in mid-to late summer when river flow is the lowest. As flows come up in the winter and spring, the lower low tides are muted by the steadily higher stage of the Columbia, and the higher high tides are at their highest elevations.

Table 7. Tidal Datum Epoch statistics for the Longview Gage (NOAA #9440422).

Daily Tide Stages	Stage Elevation (NAVD88 ft)
Mean Higher-High Water	9.56
Mean High Water	9.07
Mean Tide Level	7.2
Mean Low Water	5.33
Mean Lower-Low Water	4.98
Great Diurnal Range	4.58
Mean Range of Tide	3.74

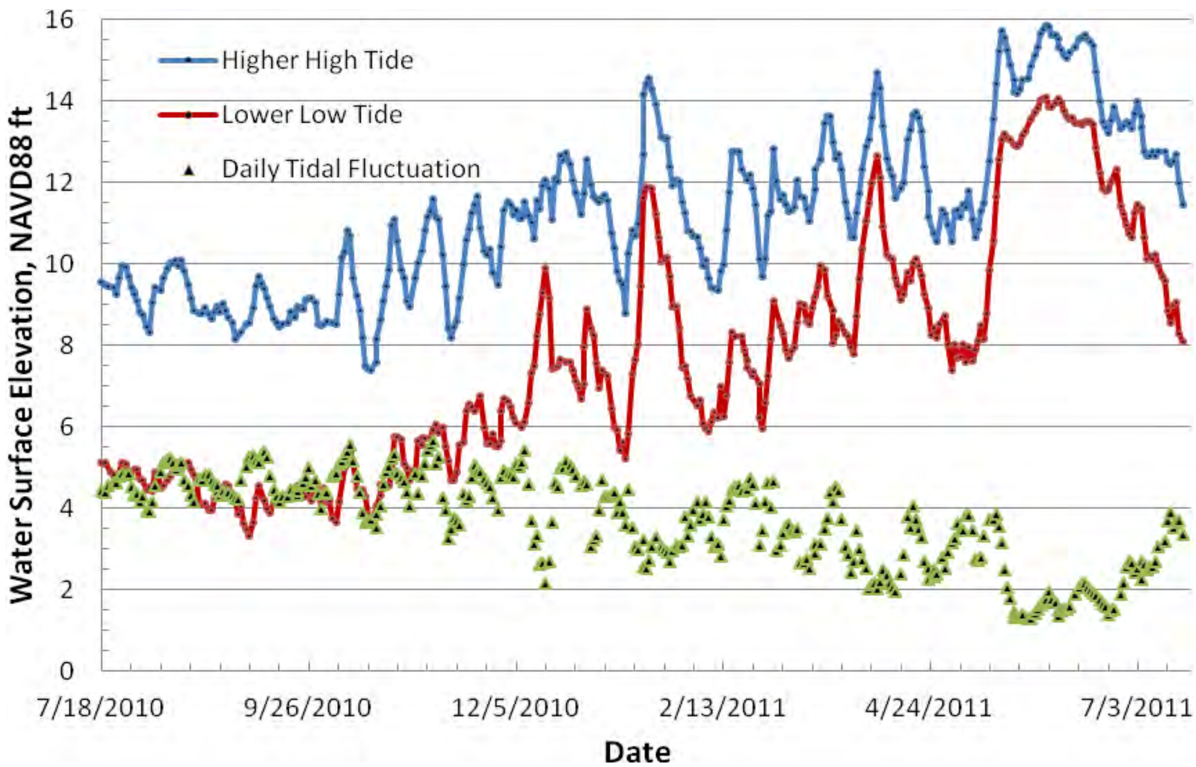

Figure 19. Daily higher high and lower low Columbia River stage for the last year of verified data at the Longview Gage (NOAA #9440422). The difference between the higher high and lower low tides is also shown, illustrating the effect of Columbia River flows and seasonal variation in tidal fluctuation.

Water Level Monitoring

Water level monitoring has been ongoing at three locations at the study area (Figure 20, Table 8). During the comparable observation period (July 25, 2011 - August 15, 2011), tidal fluctuations within the project site differ substantially from those observed on the Columbia River at the Longview Gage (Figure 21). Therefore, the Longview record cannot be used reliably as a direct proxy for water surface elevations within the project area. Nevertheless, the Longview record remains valuable for characterizing seasonal flow patterns, flood history, and for helping to understand flow dynamics between the study site and the Columbia River.

Figure 20. Water monitoring locations within and just downstream of the study site. C1 is located nearest to the Columbia River (downstream of the railroad trestle), C2 is in the main ditch channel, and C3 is in Carr Slough (2009 aerial imagery).

Table 8. Water surface elevations observed at the three monitoring stations in the study area. The observation period is July 25 to August 15, 2011. All elevations are relative to NAVD88.

	C1 (ft)	C2 (ft)	C3 (ft)
Mean of Daily Maximum Water Level	10.02	9.46	9.13
Mean of Daily Minimum Water Level	8.09	8.86	8.83
Mean of Daily Water Level	8.63	9.07	8.97
Daily Tidal Fluctuation	1.93	0.6	0.3

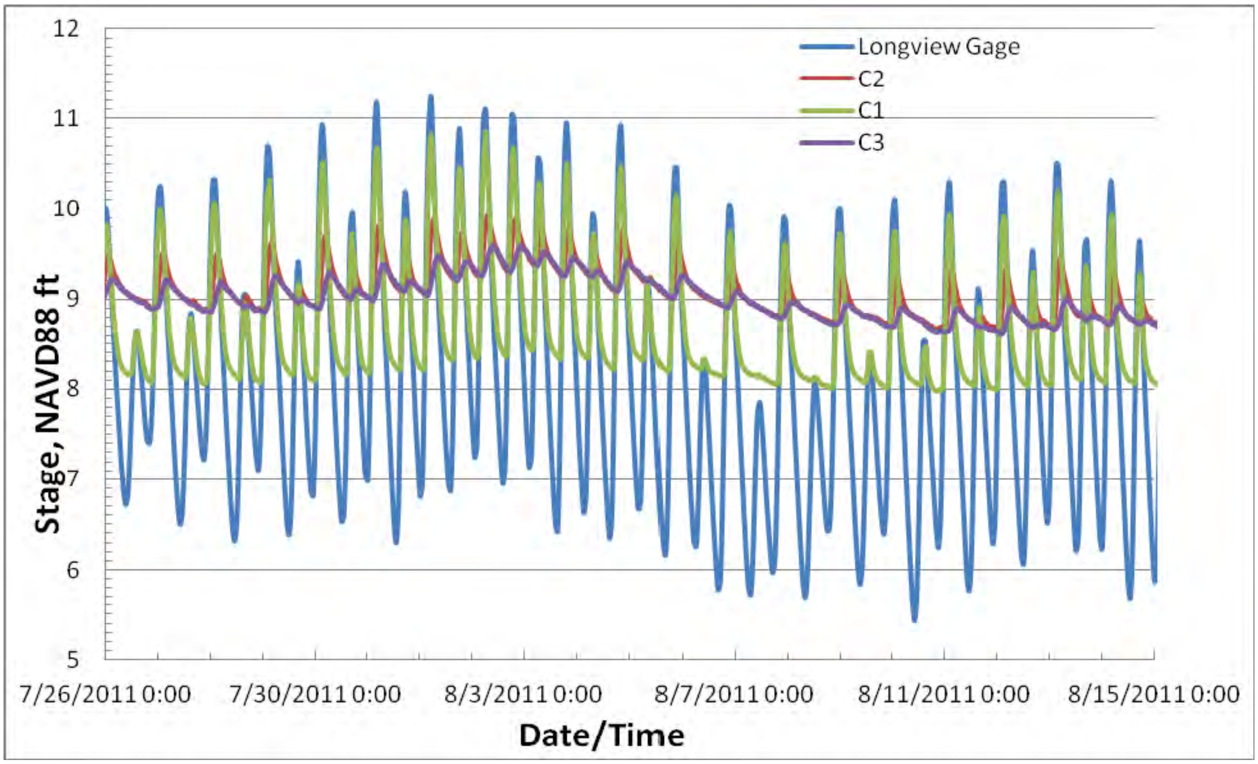

Figure 21. Water surface elevation record for three stations in the study area and the Longview Gage on the Columbia River. Chart illustrates differences in peak tide elevations, low tide elevations, and diurnal fluctuation.

The monitoring location at C1 is downstream of the railroad trestle and closest to the Columbia River. Stage at C1 appears to be reasonably well connected to tidal fluctuations on the Columbia. Peak timing and magnitude are similar given the distance between station locations (about 6 miles). However, minimum tidal elevations outside the railroad trestle do not go below 8 ft, whereas low tides on the Columbia can drop below 6 ft during the same time period. This suggests that the sandbar near the mouth of the outlet channel controls minimum water surface elevation between the trestle and the Columbia River.

Upstream of the railroad trestle at monitoring station C2, the tidal signal is substantially different than the Longview gage and C1. The magnitude of diurnal variation is reduced (lower peaks and higher low tides). The low tides at C2 are higher in elevation than at C1, suggesting a second hydraulic control on minimum water surface elevation. Initial survey data and site observations suggest that this hydraulic control is located just upstream of the railroad trestle. Rip-rap is located along the bed at this location and may have been placed during construction of the trestle or may be the result of bank rip-rap collapsing into the channel. This hydraulic control reduces the amount of water that is drained from the ditch during the ebb tide. Survey data also suggests that there has been channel constriction at the trestle, which may affect tidal exchange between the site and the mainstem Columbia River.

Compared to historical conditions, the soil plugs at the downstream end of Carr Slough reverse the direction of tidal flows. In contrast to historical conditions, the flood tide now flows in the northerly direction and the ebb tide flows in the southerly direction. At monitoring station C3, which is located midway up Carr Slough, the average daily fluctuation from high to low tide is under 0.5 ft. There is a longer rise to peak at high tide, a lag in the timing of the peak, and a slower decline to low tide. The lowest water surface elevation observed at C3 leaves over three feet of water in the channel at that location, never completely draining it. There were no surveyed channel invert locations in Carr Slough that would completely drain at observed low water level.

Flooding and Site Inundation

Inundation potential was determined using LiDAR obtained from the Puget Sound LiDAR Consortium (PSLC). Using the water level record from C2, LiDAR data was used to map the approximate inundation extents of several high water levels. This analysis provides an estimate of inundation. Sources of error include elevation inaccuracies in the LiDAR, which tend to increase in heavily vegetated areas, and variations in water surface elevations across the site, such as can be seen between monitoring locations C2 and C3 (Figure 21).

Monitoring at C2 began in May, two months before C1 and C3 were installed. In May, Columbia River flows were elevated from snowmelt runoff, providing a good example of a flood inundation period. The maximum water surface elevation of 16.6 ft occurred at C2 on June 2, 2011. This water level completely inundates the site except for a small portion of high ground at the north end of the study area boundary (Figure 22). This magnitude of inundation is corroborated by field observation at the site near this time period (Bennett, pers. comm. 2011).

The comparable record between the three monitoring locations is limited to water surface elevations captured during mid-summer, which is a time of low flows on the Columbia (Figure 21). The mean high water elevation observed during this period (9.46 ft) inundates the ditch and slough channels, a portion of the low lying area in the center of the study area, and low lying areas along the eastern edge of the study area (Figure 23). The highest water level observed during this time period (9.93 ft) inundates much of the site (Figure 24).

Figure 22. Approximate inundation at a water surface elevation of 16.6 ft, the highest water level observed at the C2 station during the monitoring period (2009 aerial photograph).

Figure 23. Approximate inundation at 9.46 ft, the mean daily high tide at the C2 station during the comparable monitoring period for all three stations (2009 aerial photograph).

Figure 24. Approximate inundation at 9.93 ft, the highest water level observed at the C2 station for the comparable monitoring period for the three stations (2009 aerial photograph).

3.5 Water Temperature

Water temperature was recorded at each of the three water level monitoring stations from July 25 through August 22, 2011. Although this is a short dataset, the data helps to document temperature patterns across the site and can be used to help evaluate habitat benefits of restoration alternatives. Additional, longer term sampling is on-going and will continue to inform restoration planning.

A summary of temperature data is presented in Table 9. Summary metrics include the average of the daily maximum and minimum, the daily average, and the average daily diurnal range. Site C1, located outside the railroad trestle and in direct hydrologic connection to the Columbia River, showed the highest average daily temperature and the greatest diurnal variation in temperature. Station C3, located in Carr Slough and the farthest removed monitoring station from the Columbia, experienced the lowest average daily temperature and the lowest diurnal variation in temperature. Site C2, located in the main ditch, showed intermediate values. All three sites show higher average daily maximum temperature and greater diurnal variation than the Columbia River at Longview; although site C3 showed a lower average daily temperature than the Longview average.

Table 9. Summary of water temperature measurements at Carr Slough.

Water Temperatures July 25 – August 22, 2011	C1	C2	C3	Longview
Average Daily Maximum	22.7	21.6	20.6	20.5
Average Daily Minimum	18.6	18.4	17.9	18.0
Daily Average	20.2	19.9	18.9	19.5
Average Diurnal Variation	4.1	3.2	2.7	2.5

All stations displayed a typical diurnal cycle of cooling at night and warming during the day (Figure 25, Figure 26, and Figure 27). Solar radiation appears to have a dominant effect on water temperature, with tidal cycles playing a minor role during the monitoring period. This is evidenced by a pattern of high water temperatures following immediately after high air temperatures, and low water temperatures following immediately after low air temperatures. Greater shade from riparian vegetation, and possibly from aquatic vegetation, at C3 appears to mitigate the effects of direct solar radiation by decreasing maximum daily temperatures and reducing the overall daily temperature range. This emphasizes the importance of shading and the potential for Carr Slough to provide more suitable rearing temperatures for salmonids compared to the main ditch.

All three sites remained below the upper lethal limit (~26° C) of water temperatures but were above the optimum for rearing of juvenile salmonids. This is supported by monitoring of tidal channels at Crims Island, where use of backwater tidal channels by subyearling Chinook salmon decreased as temperatures exceeded 20° C (Haskell and Tiffan 2011). However, small numbers of subyearlings did continue to occupy backwater areas at Crims Island even during periods of high temperature.

Because the available dataset for the Carr Slough site is so short, we are unable to describe temperature patterns throughout the year. However, it is likely that temperatures are more suitable for juvenile salmonid rearing during the remainder of the year. Based on the Crims Island study, it is likely that temperatures in the spring would be optimal for growth compared to the cooler temperatures in the mainstem, and would therefore receive greater use by outmigrating juvenile salmonids during that period.

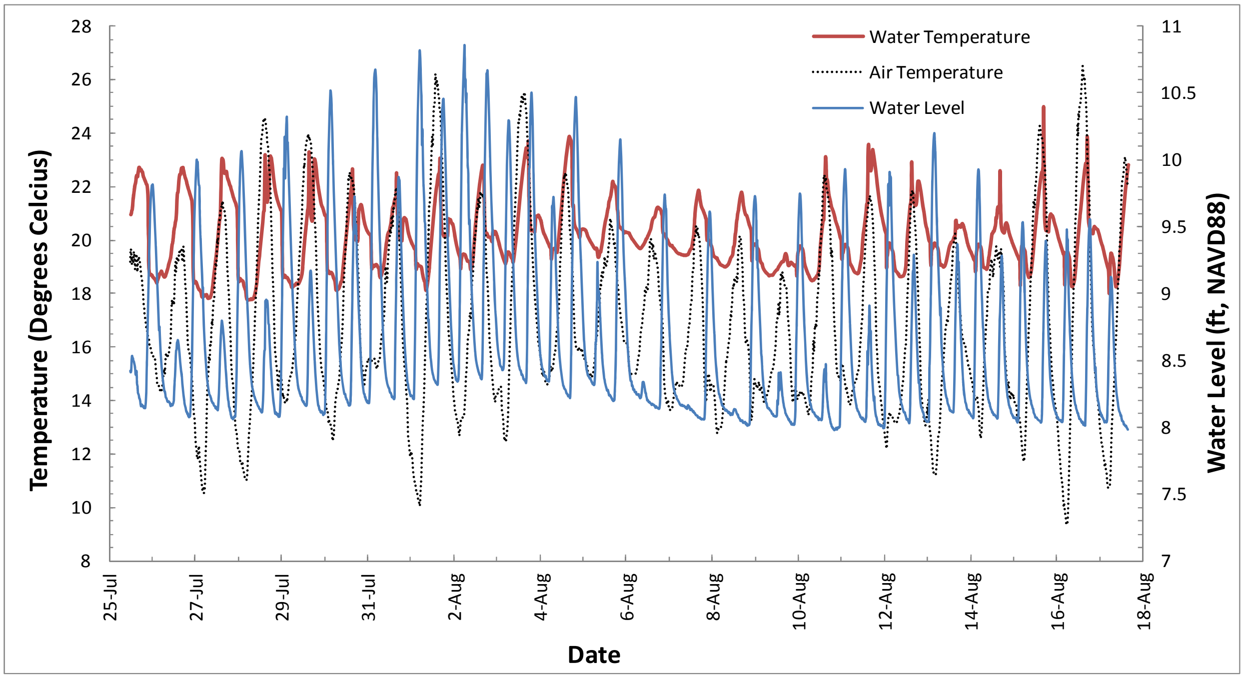

Figure 25. Water temperature, air temperature, and water level patterns at site C1 from July 25 to August 22.

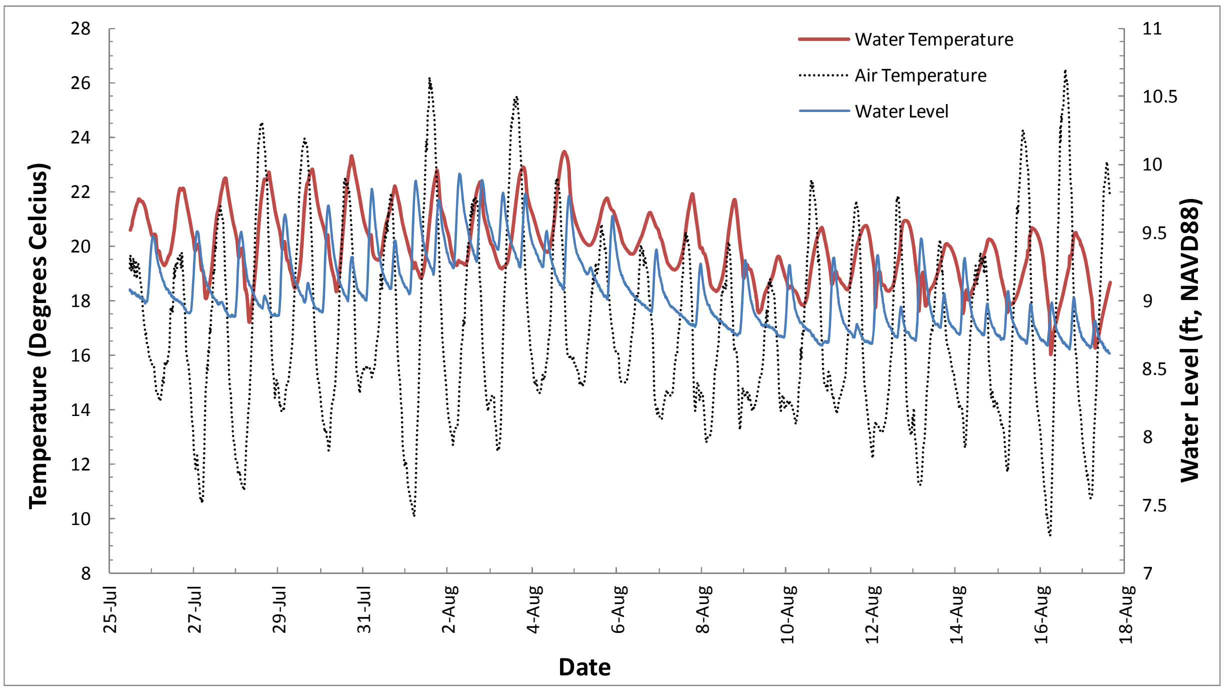

Figure 26. Water temperature, air temperature, and water level patterns at site C2 from July 25 to August 22.

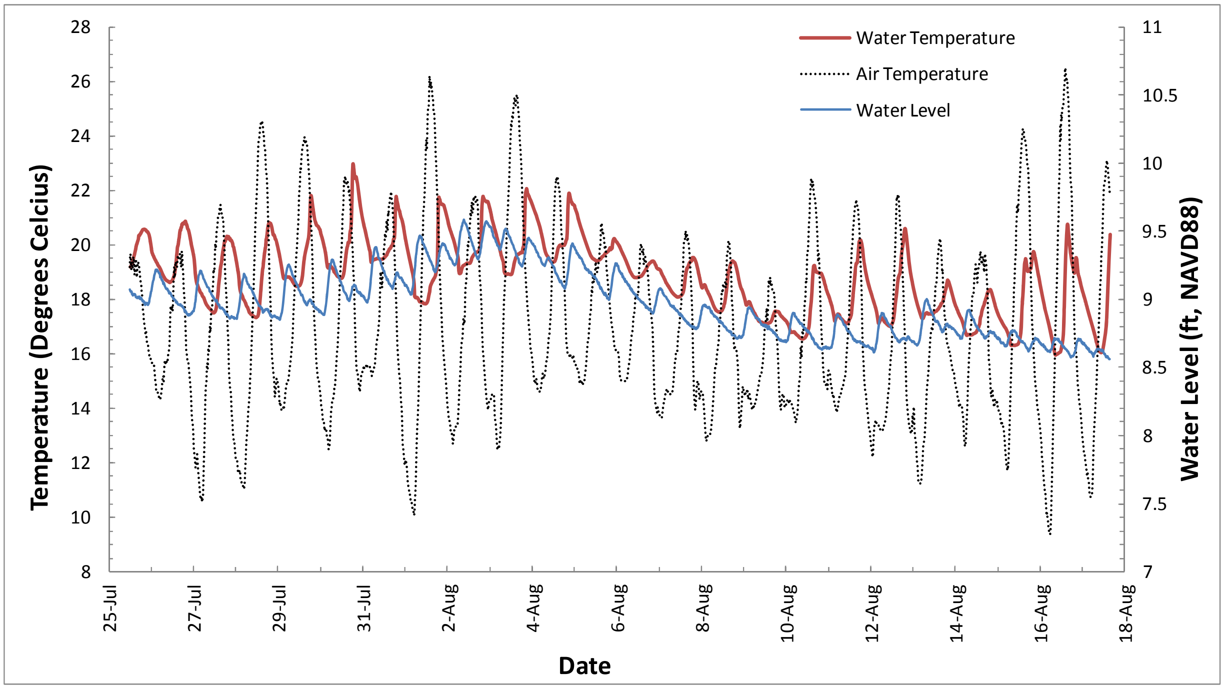

Figure 27. Water temperature, air temperature, and water level patterns at site C3 from July 25 to August 22.

3.6 Geomorphology

Overview

The site is a low elevation surface within the floodplain of the Columbia River and was created by fine sediment deposition and organic matter accumulation in a floodplain/estuary environment. The site is within the "fluvial region" of the Columbia River Estuary (Simenstad et al. 1984) and is upstream of any significant salinity intrusion. This region of the estuary is dominated by fluvial sedimentary processes, although tidal processes are also significant. Sediment at the site is contributed primarily from the Columbia River or the drainage basins contributing to the Carr Slough system. These include directly adjacent hillslope drainages and upstream floodplain environments. Fluvial processes, as well as tidal dynamics, affect sediment transport and deposition. Portions of the site not significantly affected by dredge sand placement are subject to daily tidal fluctuation and inundation by Columbia River floods on an annual basis. Fluvial and tidal processes have created mudflats, marshes, sloughs, wetlands, and tidal channels whose characteristics are dependent on the elevation, frequency, and duration of inundation as well as vegetation patterns.

The site historically supported tidally connected wetlands (forest, shrub, and marsh) throughout the site, as well as networks of connected tidal channels. The natural geomorphology has been altered by various land-use activities over the past century. The most significant impact has been the blockage of Carr Slough, construction of levees and roads, and the creation of a ditch system that now conveys the diurnal tidal prism, upstream drainage, and hillslope tributary flow. As a result, fine sediment has accumulated in Carr Slough, which has aggraded and narrowed. Dredge sand placement, which is a major impact at some Columbia River estuary sites nearby, has been limited to areas east of the railroad and at the northern extent of the Carr Slough site. As a result, topography west of the railroad and northeast of the main ditch system remain essentially intact. The most significant topographic alteration to Carr Slough itself was the placement of soil plugs near the downstream end of the channel that effectively block tidal inflow and outflow. Due to this blockage, flows must travel the length of the ditch system to enter (flood tides) and exit (ebb tides) Carr Slough at its upstream extent, thus reversing the natural tidal flow direction in the slough.

Other significant land-use impacts on the site include a lumber mill along the Columbia prior to 1948, residential development at Prescott Beach, agricultural development at the adjacent site to the south, and vegetation clearing associated with road and ditch development.

Site Topography

Cross-sections were surveyed across the site roughly perpendicular to the main ditch system and Carr Slough (Figure 28 to Figure 31). These cross-sections characterize ground surface elevations bounded by Highway 30 to the west and the railroad to the east. Cross-sections were also obtained to characterize the typical geometry of the main ditch system and Carr Slough.

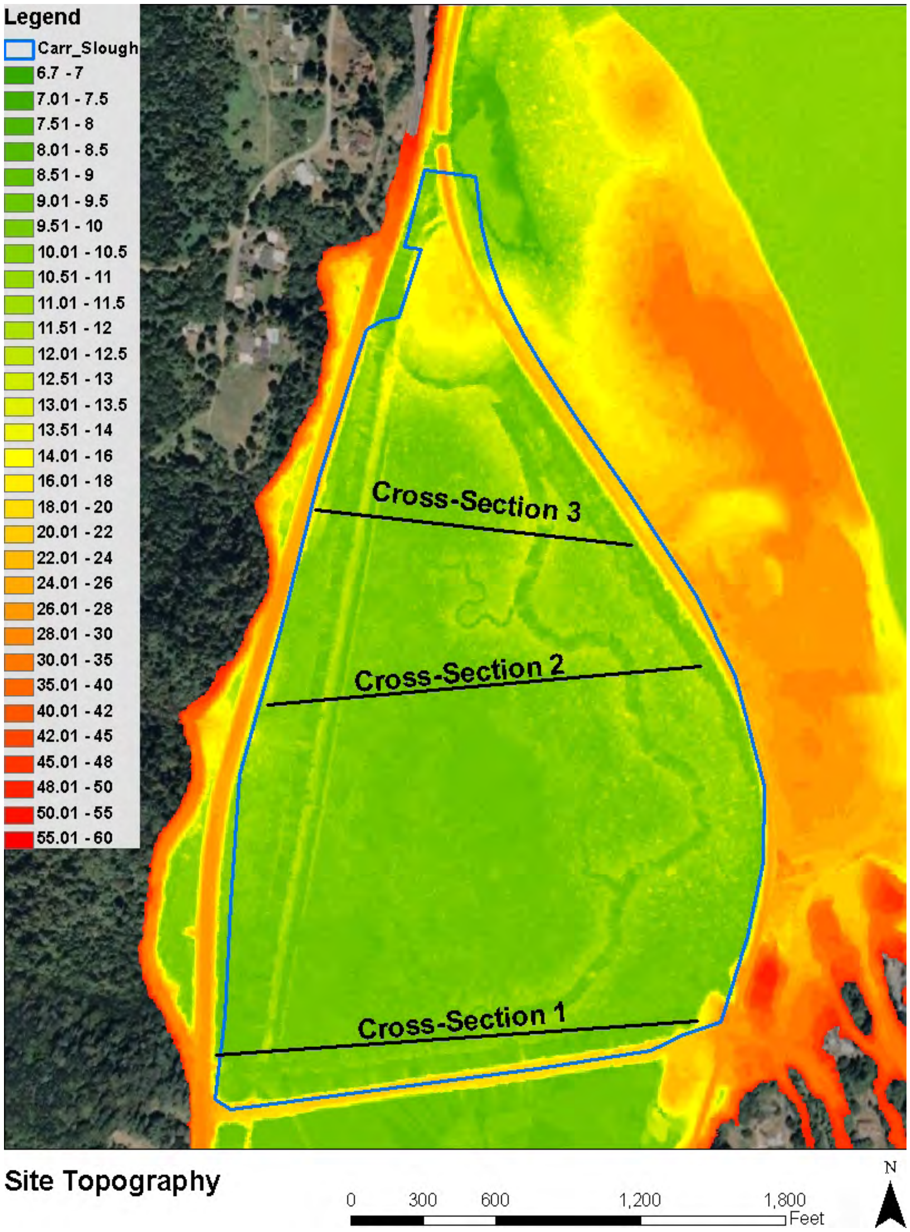

Figure 28. Overview of cross-section locations shown on LiDAR. Low elevations are depicted in green; higher elevations are depicted in red. LiDAR courtesy of Puget Sound LiDAR Consortium.

Major topographic alterations at Carr Slough include the ditch system, roads and associated fill, the railroad grade, and the soil plugs at the downstream end of the slough. The average top width of the main ditch system is 66 ft, and the average max depth is 4.5 ft. These measurements, especially depth, may not capture the true range of channel dimensions at the site. This is due to site conditions that limited the ability of surveyors to access certain portions of the channel network. There does not appear to have been significant placement of dredge sands within the project area. The majority of this material appears to have been placed east of the study area along the margin of the mainstem Columbia. The railroad grade is approximately 15 ft higher than the land surface within the site. Most of the land east of the railroad grade is higher than within the site (west of the railroad). It is unknown how much of this topography is naturally higher than the slough and how much is artificially elevated from railroad construction and from placement of dredge material from the Columbia River.

Carr Slough itself appears to be topographically unaltered, aside from sediment accumulation caused by reduced tidal connectivity. The historical planform and cross-section geometry is essentially intact along its length except for the large soil plugs at the downstream end and its upstream truncation by the east/west ditch system and road. The interior of the tidal area maintains a network of connected tidal channels and a large depression that is wetted on an annual or semi-annual frequency.

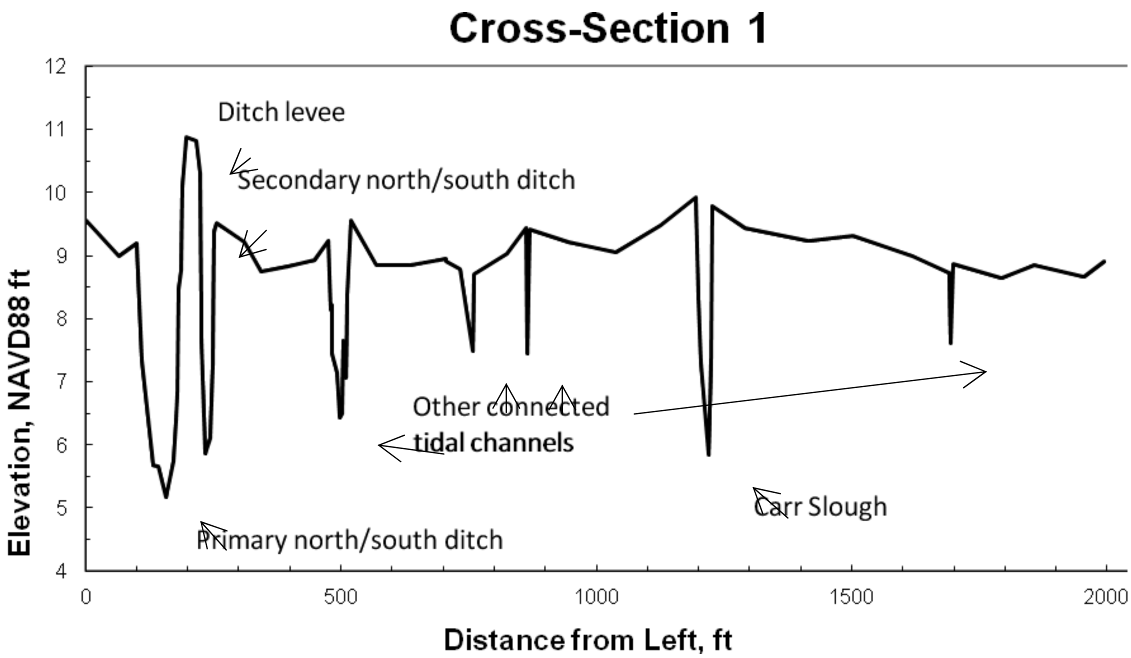

Figure 29. Cross-section 1 surveyed near the sourthern boundary of the study area. The cross-section depicts the main ditch channel on the left, a secondary ditch, several smaller tidal channels, and Carr Slough.

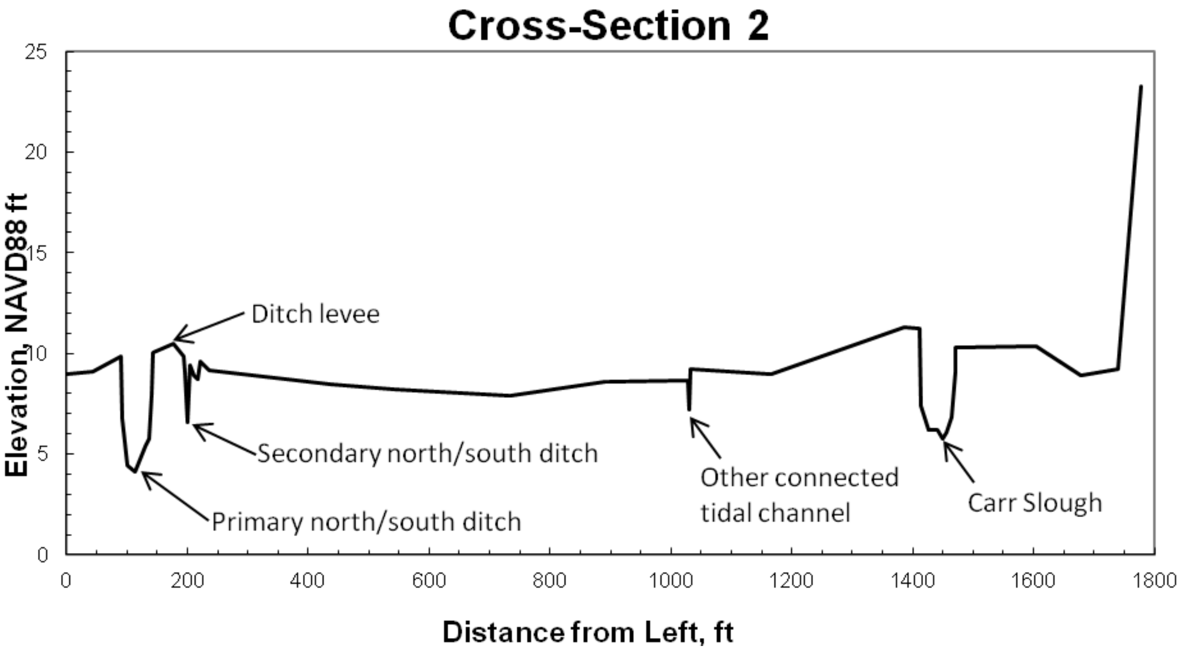

Figure 30. Cross-section 2 surveyed near the middle of the study area. The cross-section depicts the main ditch channel on the left, a secondary ditch, several smaller tidal channels, and Carr Slough.

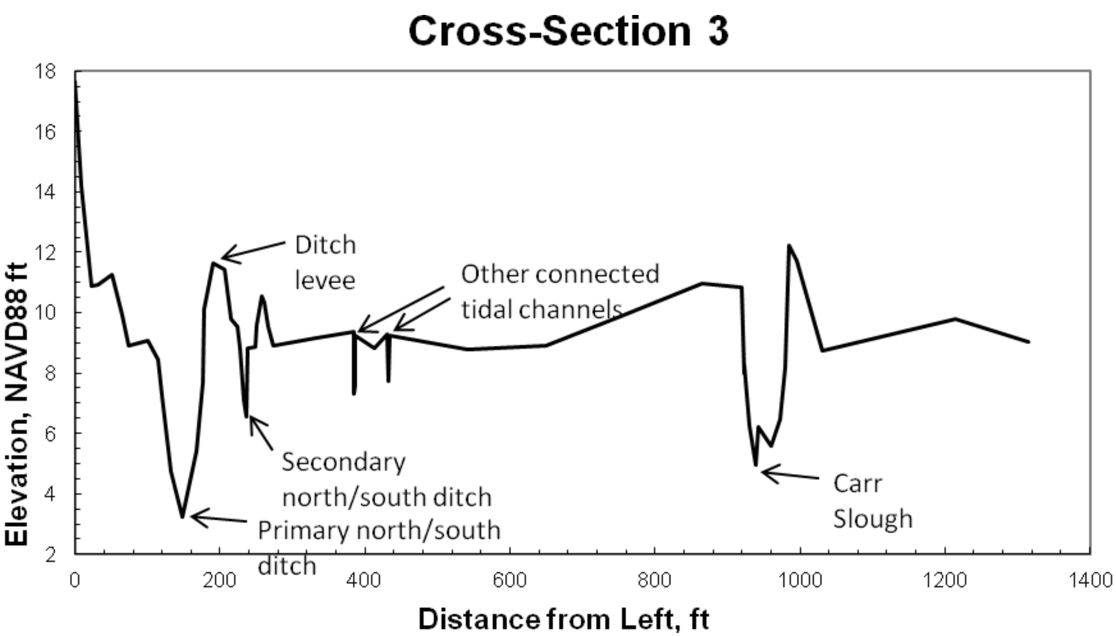

Figure 31. Cross-section 3 surveyed near the northern boundary of the study area. The cross-section depicts the main ditch channel on the left, a secondary ditch, several smaller tidal channels, and Carr Slough.

Tidal Channel Geomorphology

Several channel cross-sections were surveyed in order to characterize typical cross-section geometry of Carr Slough (Figure 32 to Figure 35). Planform geometry was analyzed using aerial photography in a GIS. The planform and cross-sectional geometry of Carr Slough does not appear to have undergone significant alteration during the aerial photo period. The most significant changes to channel geomorphology are the soil plugs near the downstream end, the change in tidal connectivity, which appears to have caused aggradation of fine sediment, and the upstream truncation of the channel system by the ditch and road. Carr Slough has a sinuosity of 1.44, an average top width of 57.5 ft, and an average maximum measured depth of 4.25 ft. It should be noted that the depth of fine sediment in the channel made measurements of channel topography difficult. Depth of refusal was not found at any location, and the thalweg was sometimes unreachable due to difficult access by surveyors. Actual channel invert elevations may therefore be lower than what was measured.

There are several smaller tidal channels that connect to Carr Slough. None of these were investigated in detail. However, field observations indicate that they range from very small channels to larger channels with depths of several feet and widths of tens of feet. Several of these channels connect to the large wetland depression (Wapato Marsh) in the interior of the study area.

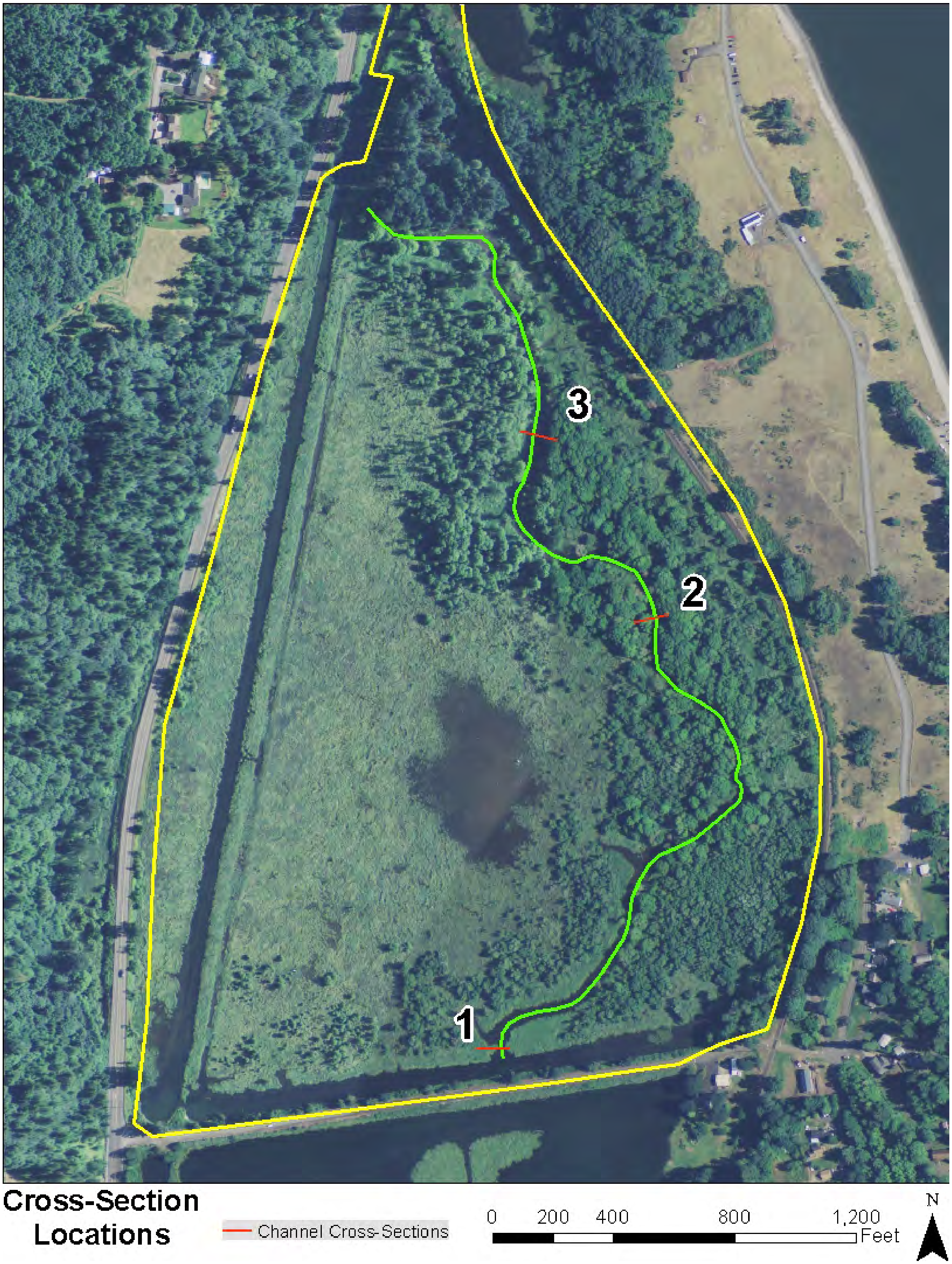

Figure 32. Location of surveyed channel cross-sections on Carr Slough. 2009 aerial imagery.

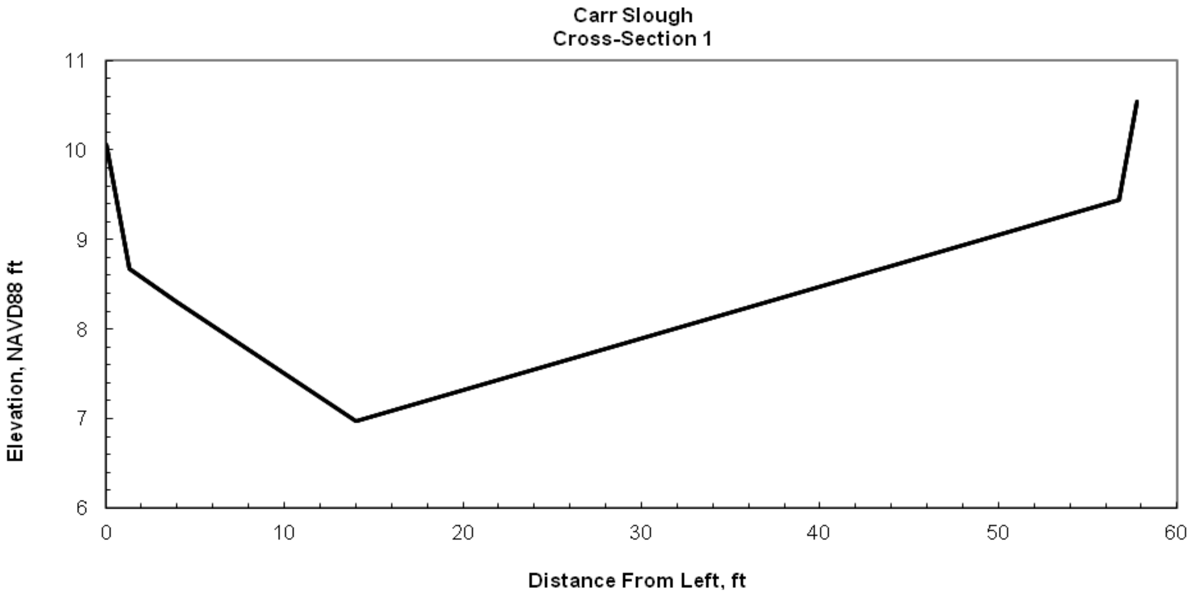

Figure 33. Cross-section 1 surveyed near the upstream end of Carr Slough.

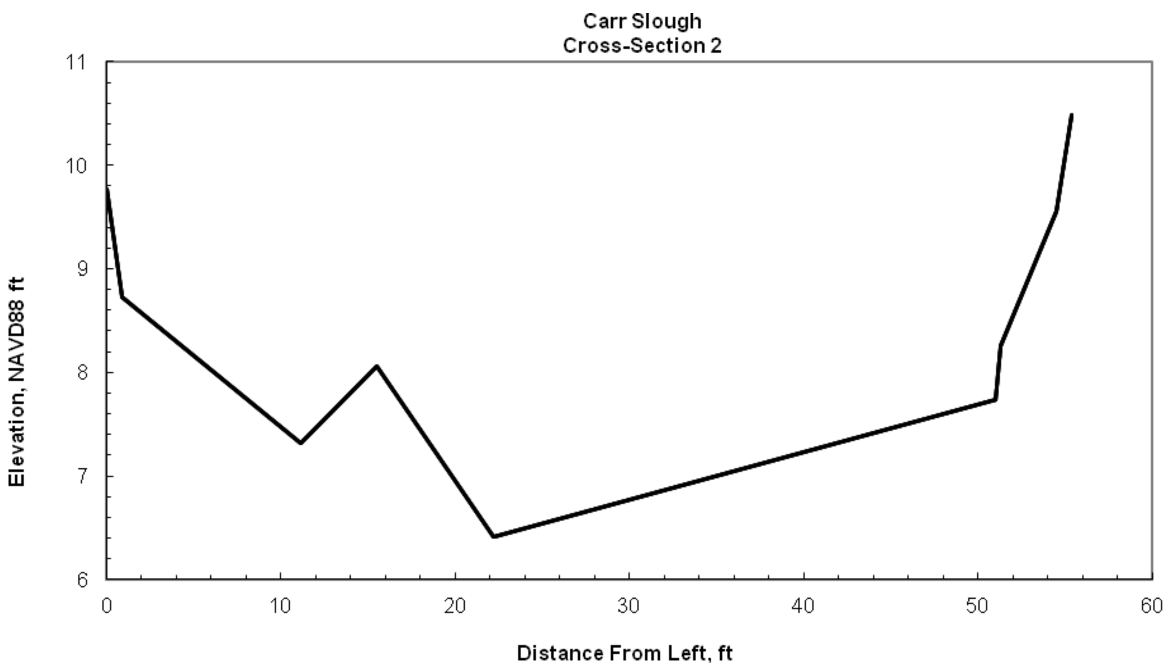

Figure 34. Cross-section 2 surveyed near the middle of Carr Slough.

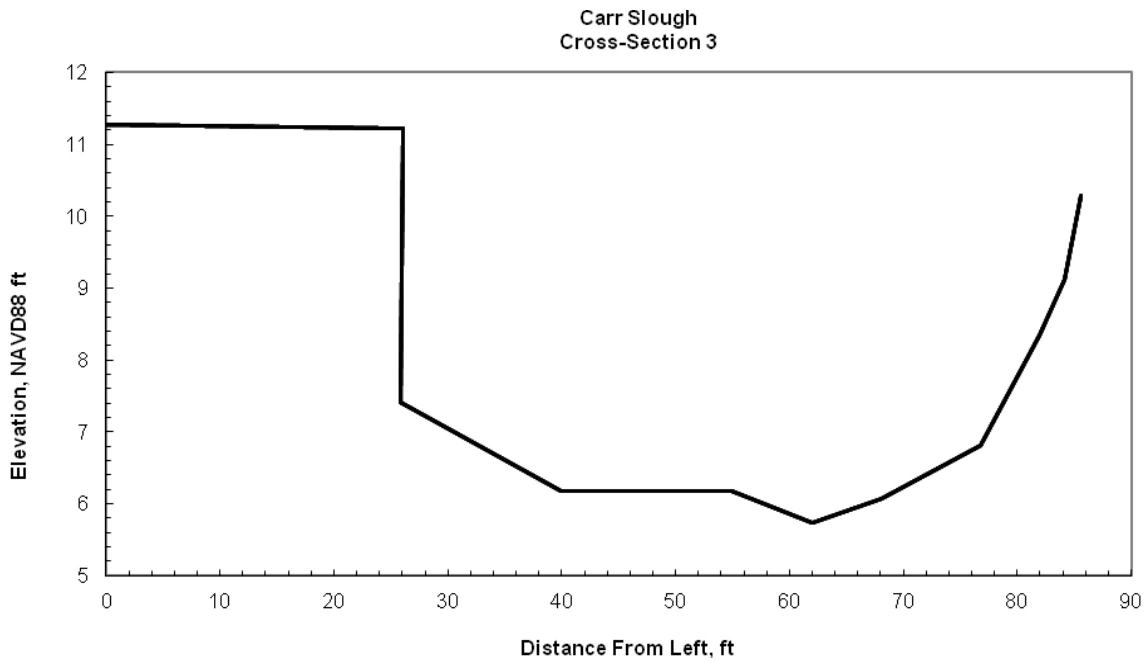

Figure 35. Cross-section 3 surveyed near the downstream end of Carr Slough.

Soils

The Natural Resources Conservation Service (NRCS) maps one soil unit within the study area, the Rafton-Sauvie-Moag complex (MUKEY 43). The NRCS describes the Rafton member as being associated with floodplain landforms, with a parent material of silty alluvium derived from mixed sources. The soil is very poorly drained with a shallow water table, frequent flooding, and frequent ponding. A typical profile includes a shallow surface layer of silt loam, a thick silty clay loam, and silt loam again at depth. The Sauvie unit differs only in the soil profile, which describes a thick silty clay loam on the surface. The Moag unit is again described as the other two units with a soil profile that includes a silty clay at depth.

The characteristics of this unit are consistent with field observations and expectations of a river floodplain and estuarine environment; very poorly drained, frequently saturated silt loam grading to silty clay with depth. Observed soil conditions were consistent with the mapped soil unit description. Soil observations were made in exposed channel bed and banks throughout the site. Observed soils were in areas subject to daily tidal fluctuation and almost constant inundation. These materials tend to represent the more clay-rich components of the soil type found on the site with river floodplain deposits overlain by alluvial deposition resulting from recent tidal activity and decaying organic material deposited in channels.

4 ALTERNATIVES EVALUATION

The alternatives presented in this section are not necessarily mutually exclusive and could be implemented in combination as part of a comprehensive restoration strategy for the site, which may also allow for phased project implementation. Each alternative is assigned a cost category according to the following: Low <$100,000; Moderate $100,000 – $500,000; High $500,000 – $1 million; Very High >$1 million. However, there is considerable uncertainty regarding costs at this level of conceptual design.

4.1 Alternative A: Reconnect Slough and Enhance Existing Habitat

4.1.1 Description

This alternative includes removing the soil plugs at the downstream end of Carr Slough to restore hydrologic connectivity. Large wood would be placed throughout Carr Slough and the existing ditch network in order to enhance aquatic habitat. Revegetation of native vegetation communities and invasive species management would occur throughout the site.

Removing the soil plugs would restore hydrologic connectivity to the north end of Carr Slough, which was historically connected at this location. This reconnection would restore southern flow during the flood tide and northern flow during the ebb tide, patterns that were reversed when the soil plugs were placed in the 1950s. Reconnection would also increase the range of tidal stage of the slough through a reduction in tidal muting that occurs now. The volume of tidal exchange in the slough would also increase, thereby increasing sediment competency and, over time, reducing the amount of accumulated sediment and fine organic material that now fills the channel. However, accumulation of fines would continue to remain above historical levels because the main ditch would continue to convey a portion of the tidal flows that enter the site.

4.1.2 Benefits

Removing the soil plugs would enhance access to Carr Slough by rearing juvenile salmonids. Rearing capacity in the slough would also be increased due to the expected export of accumulated fine sediment and organic material due to increased tidal exchange. Increased tidal exchange would also be expected to reduce the presence of dense mats of aquatic plants that currently exist in much of the Carr Slough channel. Habitat conditions in the restored Carr Slough channel would be expected to be more suitable than the existing main ditch due to lower temperatures and more woody riparian vegetation.

Addition of large wood material to the existing slough and ditch network would enhance aquatic habitat complexity. Restoration of native vegetation and controlling invasive species in select locations would have long-term benefits for aquatic and terrestrial organisms.

Preliminary sampling data suggests that water temperatures may be lower in Carr Slough compared to the main ditch during the summer, and therefore Carr Slough may provide more suitable juvenile salmonid rearing habitat. However, water temperatures may be affected by restoring the hydrologic connectivity of the slough. Additional water temperature monitoring will help to better understand temperature dynamics and the potential effects of restoration alternatives on water temperatures patterns.

4.1.3 Potential Limitations

Reconnecting Carr Slough would decrease the tidal prism conveyed by the main ditch, thereby reducing sediment transport capacity and eventually increasing fine sediment accumulation in the existing ditch network. However, the specific effects of reconnection on sediment transport and channel morphology-controlled tidal prism dynamics warrants further investigation. The effect on water exchange with the adjacent PGE site to the south also warrants further analysis.

Although reconnection of Carr Slough is expected to enhance access to and availability of rearing habitat for juvenile salmonids, there will also likely be effects on habitat suitability for exotic/predatory species. The specific influence on exotic species, and potential biological interactions with native fish, is unknown and warrants further investigation.

If excavation spoils are disposed of on-site, the potential impacts to existing habitat at the spoils disposal area will need to be evaluated.

4.1.4 Level of Effort/Cost

This alternative has relatively low level of effort and cost. The primary costs include: 1) excavation and hauling of soil plugs, 2) placement of LWD for habitat enhancement, and 3) riparian planting and invasive species control. Using a nearby spoils disposal area would help reduce costs.

Access to the site for the removal of the soil plugs would likely occur from the western or southern portions of the site to avoid crossing the railroad tracks. Access would require a temporary bridge or placement of fill across the existing ditch and would require construction of a temporary access road. Use of swamp mats and temporary fill may be necessary to cross wet areas. Any wood placements would need to be ballasted in order to prevent potential transport out of the site or damage to the railroad trestle.

Cost Category = Moderate ($100,000 – $500,000)

4.2 Alternative B: Reconnect Slough, Block Main Ditch, and Enhance Existing Habitat

4.2.1 Description

This alternative includes removing the soil plugs at the downstream end of Carr Slough to restore hydrologic connectivity and placing a new soil plug in the main ditch just upstream of the slough junction. This action would shift the tidal inflow and outflow from the main ditch to Carr Slough, as was the historical condition. Large wood would be placed throughout Carr Slough, and potentially within the existing ditch network as well, in order to enhance aquatic habitat. Revegetation of native vegetation communities and invasive species management would occur throughout the site.

The reconnection of Carr Slough would restore southern flow during the flood tide and northern flow during the ebb tide, patterns that were reversed when the soil plugs were placed in the 1950s. Reconnection of Carr Slough would also increase the range of tidal stage of the slough through a reduction in tidal muting that occurs now. The volume of tidal exchange in the slough would also increase, thereby increasing sediment competency and, over time, reducing the amount of accumulated sediment and fine organic material that now fills the channel. Compared to Alternative A, this alternative would be expected to more efficiently remove accumulated sediment from the Carr Slough channel because all of the flow would now enter and exit through Carr Slough only.

4.2.2 Benefits

Access to Carr Slough by rearing juvenile salmonids would be enhanced. Rearing capacity in the slough would also be increased due to the expected export of accumulated fine sediment and organic material due to increased tidal exchange. It is anticipated that the full width of the historical Carr Slough channel would be maintained via tidal flow. Increased tidal exchange would also be expected to reduce the presence of dense mats of aquatic plants that currently exist in much of the Carr Slough channel. Habitat conditions in the restored Carr Slough channel would be expected to be more suitable than the existing main ditch due to lower temperatures and more woody riparian vegetation.

Addition of large wood material to the existing slough and ditch network would enhance aquatic habitat complexity. Restoration of native vegetation and controlling invasive species in select locations would have long-term benefits for aquatic and terrestrial organisms.

Preliminary sampling data suggests that water temperatures may be lower in Carr Slough compared to the main ditch during the summer, and therefore Carr Slough may provide more suitable juvenile salmonid rearing habitat. However, water temperatures may be affected by restoring the hydrologic connectivity of the slough. Additional water temperature monitoring will help to better understand temperature dynamics and the potential effects of restoration alternatives on water temperatures patterns.

4.2.3 Potential Limitations

Access to the main ditch by salmonids would be reduced and shifted to the south end via Carr Slough. Accumulation of fine material in the main ditch would increase over time due to less tidal flow. The range of tidal stage would also decrease in the main ditch due to increased tidal muting (i.e. due to further travel distance from the mainstem). Sediment transport and channel morphology would not be expected to change significantly in the lateral ditch. The specific effects of slough reconnection and ditch blocking on sediment transport and channel morphology warrants further investigation. The effect on water exchange with the adjacent PGE site to the south also warrants further analysis.

Although reconnection of Carr Slough is expected to enhance access to and availability of rearing habitat for juvenile salmonids, there will also likely be effects on habitat suitability for exotic/predatory species. The specific influence on exotic species, and potential biological interactions with native fish, is unknown and warrants further investigation.

If excavation spoils are disposed of on-site, the potential impacts to existing habitat at the spoils disposal area will need to be evaluated.

4.2.4 Level of Effort/Cost

This alternative has relatively low level of effort and cost. The primary costs include: 1) excavation and hauling of soil plugs, 2) placement of new soil plug in main ditch, 3) placement of LWD for habitat enhancement, and 3) riparian planting and invasive species control. Using the excavated material from Carr Slough to block the main ditch would eliminate the need for significant hauling of material and would therefore reduce costs.

Access to the site for the removal of the soil plugs and blocking of the main ditch would likely occur from the western or southern portions of the site to avoid crossing the railroad tracks. Access would require a temporary bridge or placement of fill across the existing ditch and would require construction of a temporary access road. Use of swamp mats and temporary fill may be necessary to cross wet areas. Any wood placements would need to be ballasted in order to prevent potential transport out of the site or damage to the railroad trestle.

Cost Category = Moderate ($100,000 – $500,000)

4.3 Alternative C: Reconnect Slough, Fill Ditches, Create New Tidal Channels, and Enhance Habitat

4.3.1 Description

This alternative includes: 1) removing the soil plugs at the downstream end of Carr Slough to restore hydrologic connectivity, 2) filling the main ditch and lateral ditch with soil, and 3) creating a new network of tidal channels. This alternative would shift the tidal inflow and outflow from the main ditch to Carr Slough, which is more in-line with historical conditions. A complex tidal channel network that mimics natural conditions would be created in the main ditch alignment. Large wood could be placed throughout Carr Slough and the newly created channel network in order to enhance aquatic habitat. Re-vegetation of native vegetation communities and invasive species management would occur throughout the site.

The reconnection of Carr Slough would restore southern flow during the flood tide and northern flow during the ebb tide, patterns that were reversed when the soil plugs were placed in the 1950s. Reconnection of Carr Slough would also increase the range of tidal stage of the slough through a reduction in tidal muting that occurs now. The volume of tidal exchange in the slough would also increase, thereby increasing sediment competency and, over time, reducing the amount of accumulated sediment and fine organic material that now fills the channel. Excavation of fine material in the channel could be conducted to accelerate channel evolution and improve habitat in the near-term. Creation of a new tidal channel network would be conducted with reference to existing site topographic features and the location of historical tidal channels. New channels would mimic the planform, cross-sectional shape, and complexity of natural/historical channels.

4.3.2 Benefits

Access to Carr Slough by rearing juvenile salmonids would be enhanced. Rearing capacity in the slough would also be increased due to the expected export of accumulated fine sediment and organic material due to increased tidal exchange. It is anticipated that the full width of the historical Carr Slough channel would be maintained via tidal flow. Increased tidal exchange would also be expected to reduce the presence of dense mats of aquatic plants that currently exist in much of the Carr Slough channel. Habitat conditions in the restored Carr Slough channel would be expected to be more suitable than the existing main ditch due to lower temperatures and more woody riparian vegetation. The new tidal channel network would enhance habitat suitability for salmonids while keeping approximately the same overall rearing capacity that exists currently.

Addition of large wood material to the existing slough and the newly created tidal channel network could be used to enhance aquatic habitat complexity. Restoration of native vegetation and controlling invasive species in select locations would have long-term benefits for aquatic and terrestrial organisms.

Preliminary sampling data suggests that water temperatures may be lower in Carr Slough compared to the main ditch during the summer, and therefore Carr Slough may provide more suitable rearing habitat. However, water temperatures may be affected by restoring the hydrologic connectivity of the slough. Additional water temperature monitoring will help to better understand temperature dynamics and the potential effect of restoration alternatives on water temperatures patterns.

4.3.3 Potential Limitations

The specific effects of slough reconnection, ditch filling, and creation of new tidal channels on sediment transport and channel morphology warrants further investigation. The effect on water exchange with the adjacent PGE site to the south also warrants further analysis.

Although reconnection of Carr Slough is expected to enhance access to and availability of rearing habitat for juvenile salmonids, there will also likely be effects on habitat suitability for exotic/predatory species. The specific influence on exotic species, and potential biological interactions with native fish, is unknown and warrants further investigation.

If excavation spoils are disposed of on-site, the potential impacts to existing habitat at the spoils disposal area will need to be evaluated.

4.3.4 Level of Effort/Cost

This alternative has relatively high level of effort and cost. The primary costs include the filling of ditches and the creation of new tidal channels. Other, secondary, costs include removing the soil plugs in Carr Slough, placement of LWD, and riparian planting and invasive species control. Configuring the design to minimize hauling of material (either removing excavated material or importing new material) would help reduce costs.

Access to the site for this alternative would likely occur from the western or southern portions of the site to avoid crossing the railroad tracks. Access would require a temporary bridge or placement of fill across the existing ditch and would require construction of temporary access roads. Use of swamp mats and temporary fill may be necessary to cross wet areas. Any wood placements would need to be ballasted in order to prevent potential transport out of the site or damage to the railroad trestle.

Cost Category = Very High (>$1 million)

4.4 Alternative D: Replace Tidegate to Southern Property

4.4.1 Description

This alternative includes replacing the existing tidegate at Graham Road in order to improve hydrologic connectivity between the Carr Slough site and the PGE site to the south. The tidegate could be replaced with a new tidegate, a free-flowing culvert, or a bridge. This alternative could occur in conjunction with other alternatives.

4.4.2 Benefits

Benefits of this alternative include: 1) an increase in tidal exchange between the two sites, and 2) improved passage of fish and other aquatic organisms. An increase in tidal exchange between the sites would likely enhance tidal flow within the Carr Slough site due to effectively increasing the tidal prism. Over time, this would be expected to reduce the amount of accumulated fine material in the slough and ditch network and would restore hydrologic and geomorphic processes closer to the pre-disturbance (historical) conditions. Improving aquatic organism passage would potentially enhance fish access to a substantial amount of habitat located in the properties to the south.

4.4.3 Potential Limitations

Prior to conducting this action, the specific existing fish passage conditions should be evaluated at the tidegate to ensure that adequate fish passage benefits will be provided. The specific effects of tidegate replacement on tidal flow, and thus sediment transport and channel morphology, within the Carr Slough and PGE site warrants further investigation.

Water and sediment quality in the PGE site should be evaluated prior to enhancing hydrologic connectivity between the sites. The specific influence on exotic species, and potential biological interactions with native fish, should also be evaluated.

4.4.4 Level of Effort/Cost

This alternative has a moderate-to-high cost and level of effort. Costs depend on whether the tidegate is replaced with a new tidegate, a culvert, or a bridge.

Cost Category = High ($500,000 – $1 million). Assumes replacement of existing culvert and tidegate (no bridge).

4.5 Alternative E: Enlarge Channel Inlet at Railroad Trestle

4.5.1 Description

This alternative includes enlarging the channel cross-section where the slough exits the site under the railroad trestle. Surveys indicate that the channel at this location was likely constricted when the railroad trestle was constructed. It now has a smaller cross-section shape than the historical channel outlet. The trestle structure and associated rip-rap constrict the width of the channel at this location. The channel invert also appears to have been elevated within and just upstream of the trestle via placement of rip-rap (or collapse of bank rip-rap) on the channel bed. This constriction may alter the amount and rate of tidal inflow and outflow, which affects tidal flow, and thus sediment transport and channel morphology within the site. This alternative could occur in conjunction with the other alternatives.

4.5.2 Benefits

Additional investigation will be necessary to determine specific need and benefits of this alternative. However, based on initial observations and data collection, enlarging the outlet channel may decrease a flow bottleneck that is potentially created by the constriction. This bottleneck limits the amount and rate of inflow that can enter the site during the flood tide and the amount and rate of outflow during the ebb tide (reducing the effective tidal prism). Enlarging the channel to more closely mimic the historical channel (and existing channels within the site) would be expected to eliminate the constriction, thereby increasing tidal exchange within the site. This may help to reduce fine sediment accumulation in the channels and may increase the range of tidal stage within the site. In particular, the elevated channel invert at the trestle holds water levels within the site artificially high during the ebb tide. Lowering the channel invert would increase the magnitude of the diurnal tidal fluctuation, which could help to transport fine sediment out of the slough network.

4.5.3 Potential Limitations

Coordination with and cooperation from the railroad would be needed to implement this alternative. Costs, disruption of train traffic, and access will be major considerations. The specific effects of the constriction on tidal exchange, sediment transport, and channel morphology warrants further investigation prior to implementing this alternative.

4.5.4 Level of Effort/Cost

This alternative has a moderate to high level of effort and cost. A large determinant of cost would be whether the existing trestle would need to be replaced or if channel enlargement could occur without replacement (e.g., via manipulation of rip-rap banks, or addition of culverts under the railroad prism). Obtaining access to the site may also be expensive. Dewatering may also incur significant costs.

Cost Category = High ($500,000 – $1 million). Assumes modifications can be made to the channel without significant alterations to, or replacement of, the existing trestle.


Railroad Trestle
Remove Soil Plugs
Columbia River
Prescott Beach
County Park
Hwy 30
Main Ditch
Carr Slough
Enhance Existing Slough
and Ditch Network
Using LWD Additions
Existing Tide Gate
Lateral Ditch
Graham Rd
Alternative 1
Existing Channel Network
Excavation Areas
Wood Placements
N
W
E
S
0
500
1,000 Feet


Railroad Trestle
Place Fill to Block Ditch
Remove Soil Plugs
Columbia River
Prescott Beach
County Park
Hwy 30
Main Ditch
Carr Slough
Enhance Existing Slough
and Ditch Network
Using LWD Additions
Existing Tide Gate
Lateral Ditch
Graham Rd
Alternative 2
Ditch Block
Excavation Areas
Existing Channel Network
Wood Placements
N
W
E
S
0
500
1,000 Feet


Railroad Trestle
Remove Soil Plugs
Columbia River
Fill Existing Ditch Network
Remove Existing Levee
Prescott Beach
County Park
Hwy 30
Recontour Ditches and
Create New Tidal Channels
Enhance New and Existing
Slough Network
Using LWD Additions
Carr Slough
Existing Tide Gate
Graham Rd
Alternative 3
New Alignment
Ditch Fill
Existing Channel Network
Excavation Areas
Wood Placements
N
W
E
S
0
500
1,000 Feet


Railroad Trestle
Prescott Beach
County Park
Columbia River
Hwy 30
Main Ditch
Carr Slough
Replace Existing
Tidegate
Lateral Ditch
Graham Rd
PGE Site
Alternative 4
Existing Channel Network
N
W
E
S
0
500
1,000
2,000
3,000 Feet


Columbia River
Enlarge Channel
at Railroad Trestle
Alternative 5
Existing Channel Network
N
W
E
S
0
500
1,000 Feet

5 LITERATURE CITED

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