8 APPENDIX A: BASELINE ASSESSMENT TECHNICAL MEMORANDUM

Horsetail Creek Site

Baseline Assessment Technical Memorandum

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Inter-Fluve, Inc. and the Lower Columbia River Estuary Partnership

FINAL – December 31, 2010

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1 INTRODUCTION AND BACKGROUND

1.1 INTRODUCTION

The Lower Columbia River Estuary Partnership (Estuary Partnership) is evaluating habitat restoration options on lower Horsetail and Oneonta Creeks in the Columbia River Gorge. These two streams are located on property owned primarily by the U.S. Forest Service (USFS); however, approximately 40 acres of this 190-acre site are located within the Interstate Highway 84 Right-of-Way. The general goals for the potential habitat enhancement work include improving off-channel rearing, winter refugia and spawning habitat conditions for Columbia River salmon and steelhead listed under the Endangered Species Act (ESA-listed).

Currently, the Estuary Partnership is completing a habitat enhancement feasibility study for the site. The study includes three components:

1. Baseline Site Investigations – Collection and analysis of baseline data required to inform alternatives analysis and design;
2. Feasibility and Alternatives Analyses – Development and analysis of enhancement alternatives for each subreach;
3. Conceptual designs – Development of conceptual level designs for each subreach's preferred alternative.

The current report summarizes the results of the initial component, Baseline Site Investigations. Bonneville Power Administration provided funding for this study through the Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp) – an ESA mandated plan to mitigate for the adverse effects of the FCRPS on 13 ESA-listed species of salmon and steelhead.

1.2 SCOPE OF WORK

Inter-Fluve and the Estuary Partnership have jointly conducted the preliminary site investigations. The investigations have included the following:

a. Gather and review existing data.
b. Temperature assessments.
c. Evaluation of streambed and streambank materials.
d. Select topographic survey.
e. Hydrologic and hydraulic analyses.
f. Fisheries assessment.

2 SITE CHARACTERISTICS

2.1 SITE OVERVIEW AND HISTORY

The project site is located on 190 acres of historic Columbia River floodplain near river mile 138, eight miles downstream from Bonneville Dam and two miles upstream of Multnomah Falls (Figure 1). This area falls in sub-reach H of the lower Columbia River Estuary (LCRE;

Figure 2). The site presently contains two perennial streams (Horsetail and Oneonta Creeks) and an array of sloughs, ponds and wetlands (Figure 3). The Horsetail Creek and Oneonta Creek watersheds have maximum elevations of approximately 4000 feet, and drain over the bluffs of the Columbia River Gorge to the Columbia River floodplain (approximate elevation 20-25 feet NAVD 88), to their confluence with the Columbia River (elevation 11 feet NAVD 88). The watersheds are predominantly public land, with 93% in federal ownership, and only 4% in private ownership. Collectively, the watersheds contain approximately 93% forested upland and 3% wetland. The majority of the Oneonta and Horsetail Creek watersheds are located within the Columbia River Gorge National Scenic Area (CRGNSA). However, a small portion of each is located within the City of Portland's Bull Run Management Unit. Although the Bull Run Management Unit, which is closed to the public and protected from development, is managed as the City of Portland's water supply, no water is withdrawn from the Horsetail or Oneonta basins. 100% of the Eastern Slough's watershed is located in the CRGNSA.

Prior to settlement, the site was surveyed by the Government Land Office in 1860 and again in 1906 (Christy 2010). The site was noted to be a forested wetland dominated by large willows, ash (up to 20" diameter) and cottonwoods (up to 50" diameter) (Figure 4). Six streams and sloughs were noted to cross the site, all draining to the Columbia River in distinct locations (Figure 5). One of the sloughs was noted to be approximately 150 feet wide at its widest point.

The Oregon Railway and Navigation Company constructed the rail grade along the southern margin of the wetland in 1882, but no other land claims were noted, though a cabin was located at the far eastern extent of the site. The shoreline of the Columbia was noted as sandy beach with shallow water. The construction of the railgrade was the first significant human intervention at the site. The railroad bridges that cross Horsetail Creek and Oneonta Creek fixed the locations at which the creeks enter the floodplain, which has had the effect of limiting the migration of the creek over their alluvial fans over time. For reference, the openings of the railroad bridges over Horsetail and Oneonta Creeks are 30 and 45 feet wide respectively. These dimensions compare to widths of approximately 1000 feet each for the two alluvial fans measured near the railroad corridor. During the initial surveys, much of the watersheds along the Gorge bluffs were described as burned timber (Christy 2010).

The Columbia River Highway was constructed at the southern extent of the site between 1912 and 1914. The first aerial photography of the site dates to the 1930s, which show distinct outlets to the Columbia River for Oneonta Creek, Horsetail Creek, and a slough channel which originates in the eastern portion of the site (Figure 6 - Figure 8). The site is shown as relatively heavily forested in the 1930 and 1935 images, with agricultural development to the immediate east of the site. Much of the site appears to have been deforested by 1939 (Figure 8). Prominent topographic features at the site included alluvial fans formed where Oneonta Creek and Horsetail Creek emerged from the valley slope to the Columbia floodplain, and a natural levee along the margin of the mainstem. These features are apparent in the 1935 photo (Figure 7) and in the lidar data for the site (Figure 9).

The primary disturbance to the site occurred through the 1940s to 1960s. Shown in the 1948 photo, the lower ends of Horsetail Creek and the Eastern Slough were diverted from their former confluences to a new confluence with Oneonta Creek in conjunction with Interstate Highway 84 (I-84) construction (Figure 10). From this location (the original confluence of Oneonta Creek with the Columbia River), the flow from the three systems was conveyed through a culvert under the highway. In addition, the remaining 2-3 smaller historic drainages reported by Christy (2010) had been diverted into the eastern slough. Thus, the aquatic system at the site which historically included six separate outlets to Columbia had been simplified to a single outlet. In this photo, highway embankment fill is ongoing using sand hydraulically dredged from the river. Although of poor quality, the 1956 series shows the highway partially complete (northern lanes), but gravel mining activity had not commenced on the site (Figure 11). Shown in the 1971 and 1978 aerial images (Figure 12 – Figure 13), there is evidence of land clearing and excavation to provide materials for expansion of I-84 (southern lanes) in the late 1950s and early 1960s. Gravel was mined out of the Oneonta Creek channel and alluvial fan all the way east to the lower part of Horsetail Creek. In response to the gravel excavation, an actively rebuilding sediment delta is also evident in the 1978 image, where Oneonta Creek enters the gravel mining area. Further to the east, a view corridor had been cleared to allow motorists to view Horsetail Falls from the I-84. In the eastern portion of the site, a topsoil borrow area and a potential stock pond can be seen.

By 1995 (Figure 14), much of the site had re-colonized with overstory vegetation (primarily ash), and the Oneonta Creek alluvial fan has continued to extend to the north, such that the creek alignment is distinct from the edge of the gravel borrow pond. This trend continued between 1995 and 2005 (Figure 15).

A timeline of the site development is included in Table 1.

Table 1. Historical timeline of human alteration at the site.

Date	Event	Activity
1860	Settlement	Single cabin noted at east margin of site
1882	Railroad	Rail grade constructed at the south margins of the wetland
1912-1914	Historic Highway	Columbia River Highway constructed between the railroad and the valley slopes
1940s-1950s	Landclearing	Much of the site had been cleared
1940s	Creek Diversion	Lower Horsetail Creek and Eastern Slough diverted to new confluence with Oneonta Creek in preparation for interstate highway construction.
1940s-1950s	I-84	Interstate Highway 84 construction along northern margin of site
1950s-1960s	Gravel Mining	Gravel excavated from Oneonta Creek and fan, and Lower Horsetail Creek for highway construction

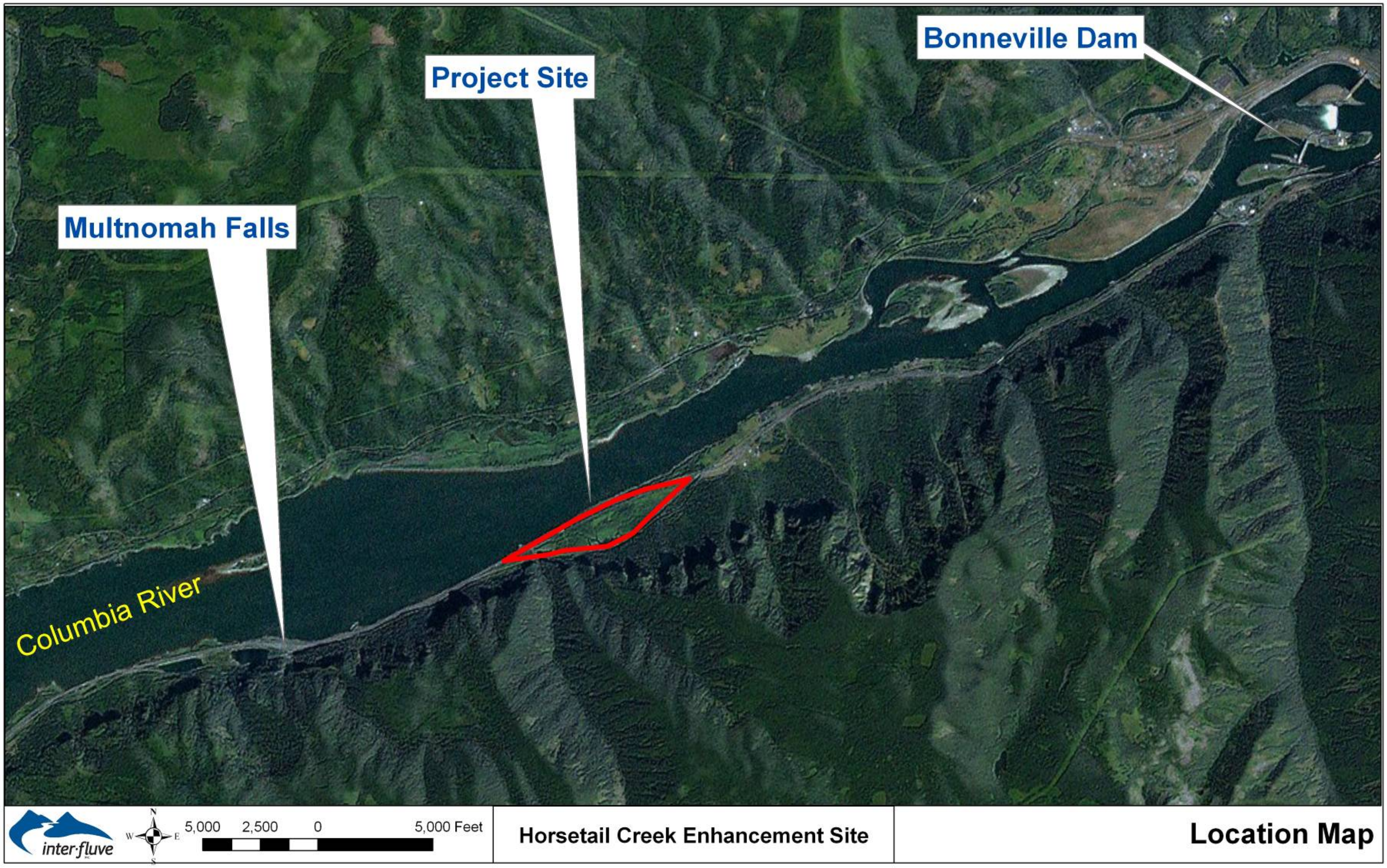


Figure 1. Location Map for the Horsetail Creek site.

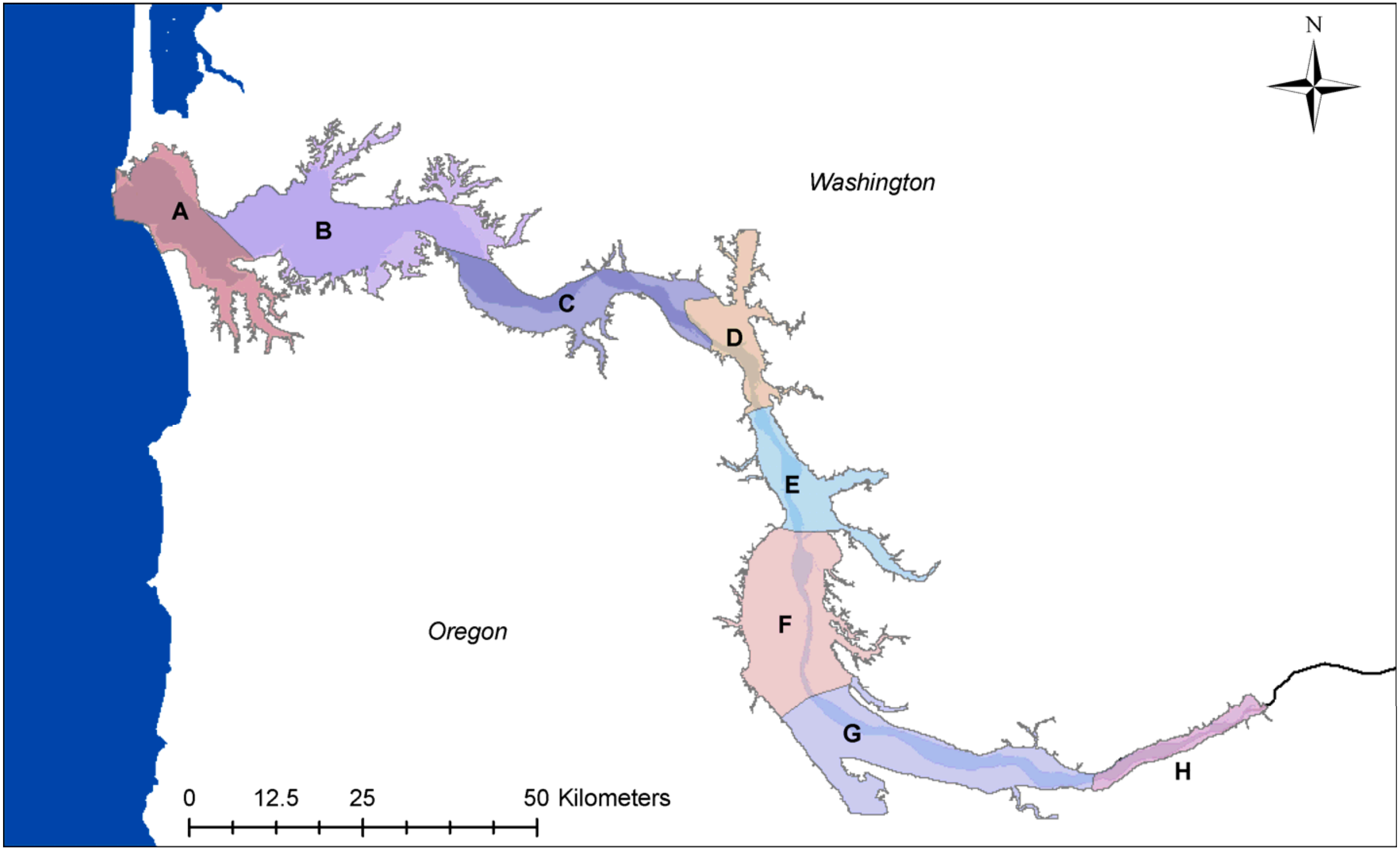


Figure 2. Map of Lower Columbia River Estuary showing Estuary sub-reaches. Horsetail Creek site is located in sub-reach H. *Source: Estuary Partnership*.

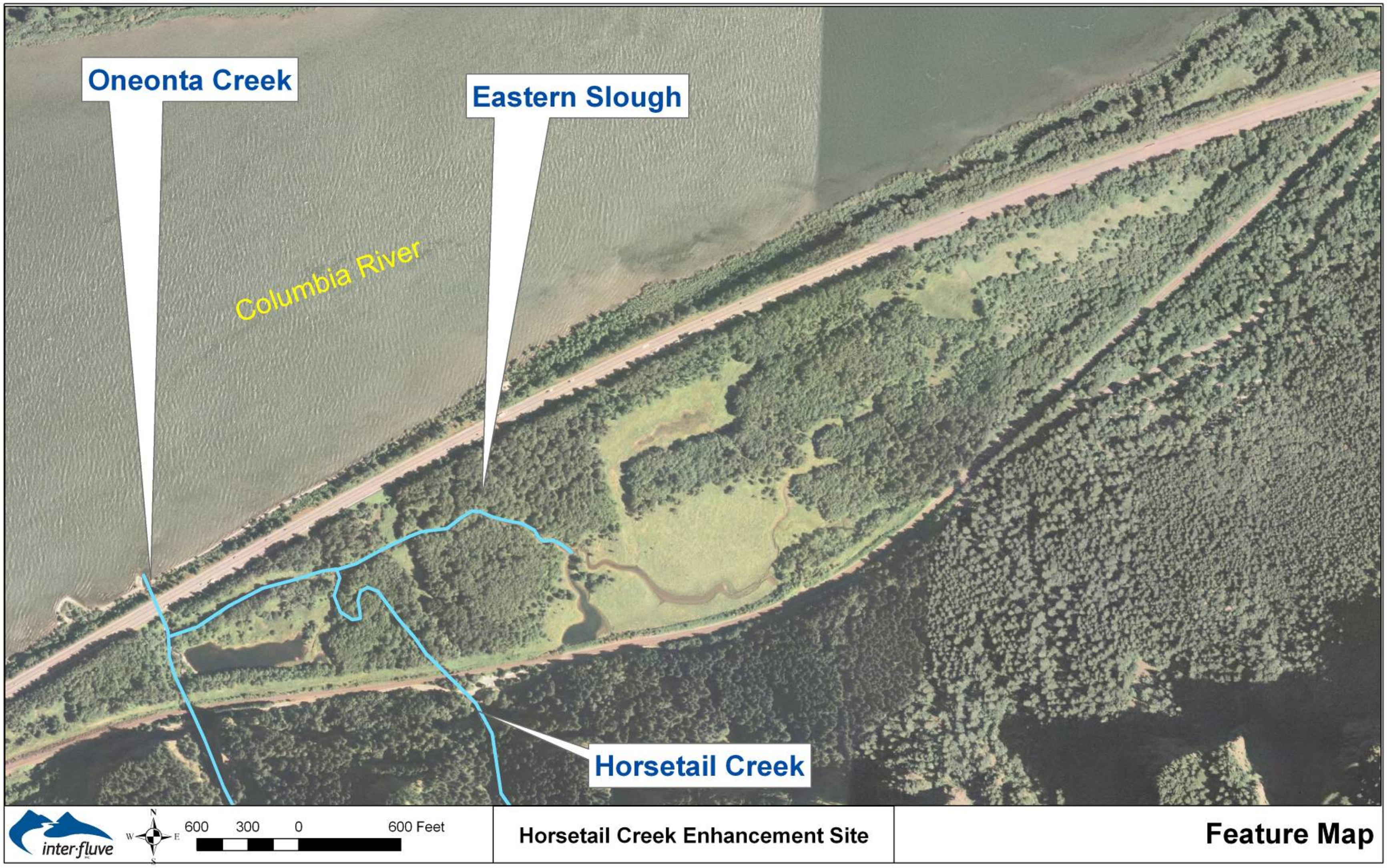


Figure 3. Site map of Horsetail Creek site showing primary drainages.

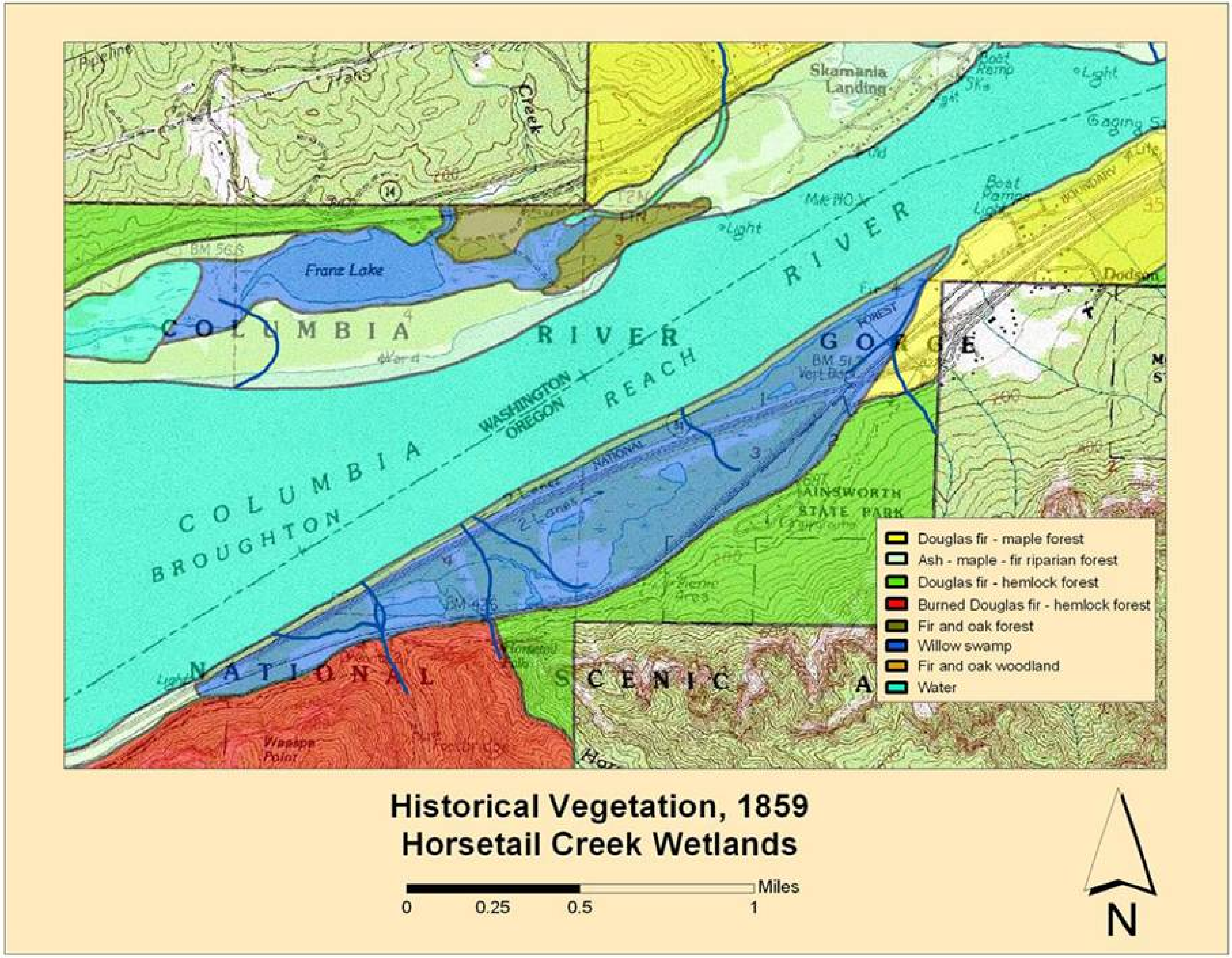


Figure 4. Vegetation communities mapped by GLO in 1859 in vicinity of Horsetail Creek site. ***Source: Christy 2010.***

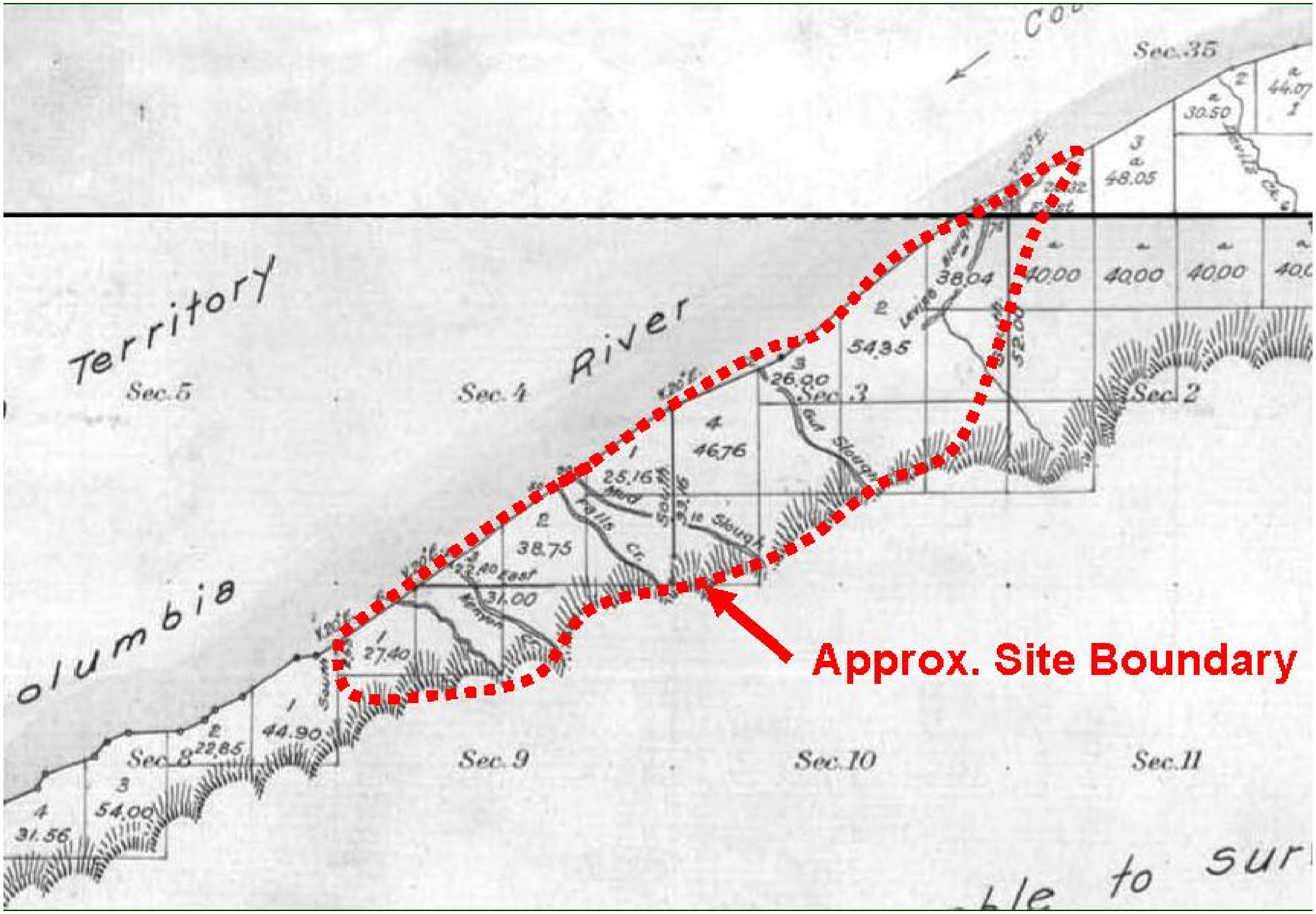


Figure 5. GLO map showing six separate streams draining to Columbia River across the Horsetail Creek site. ***Source: Christy 2010.***

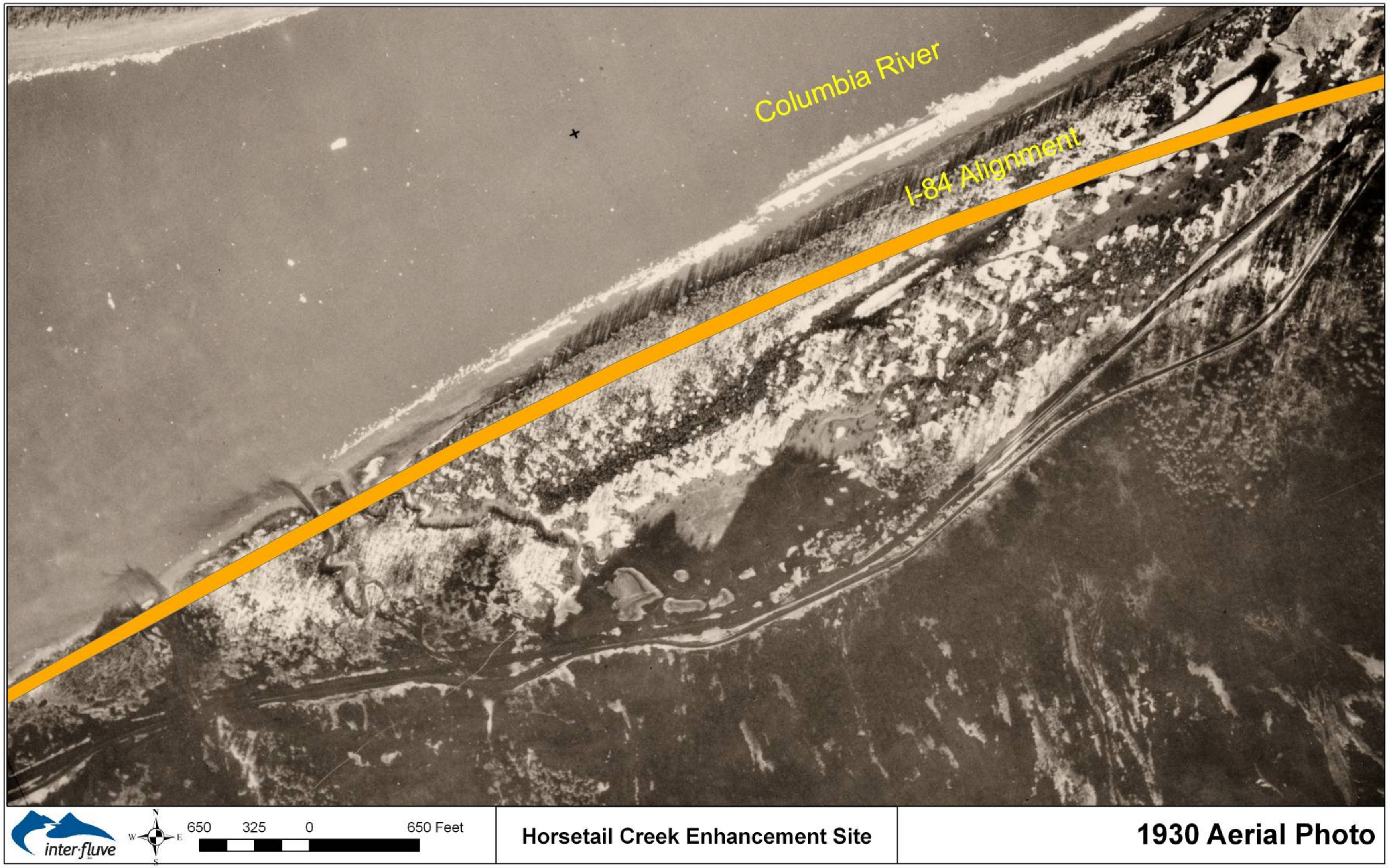


Figure 6. 1930 Aerial Photo.

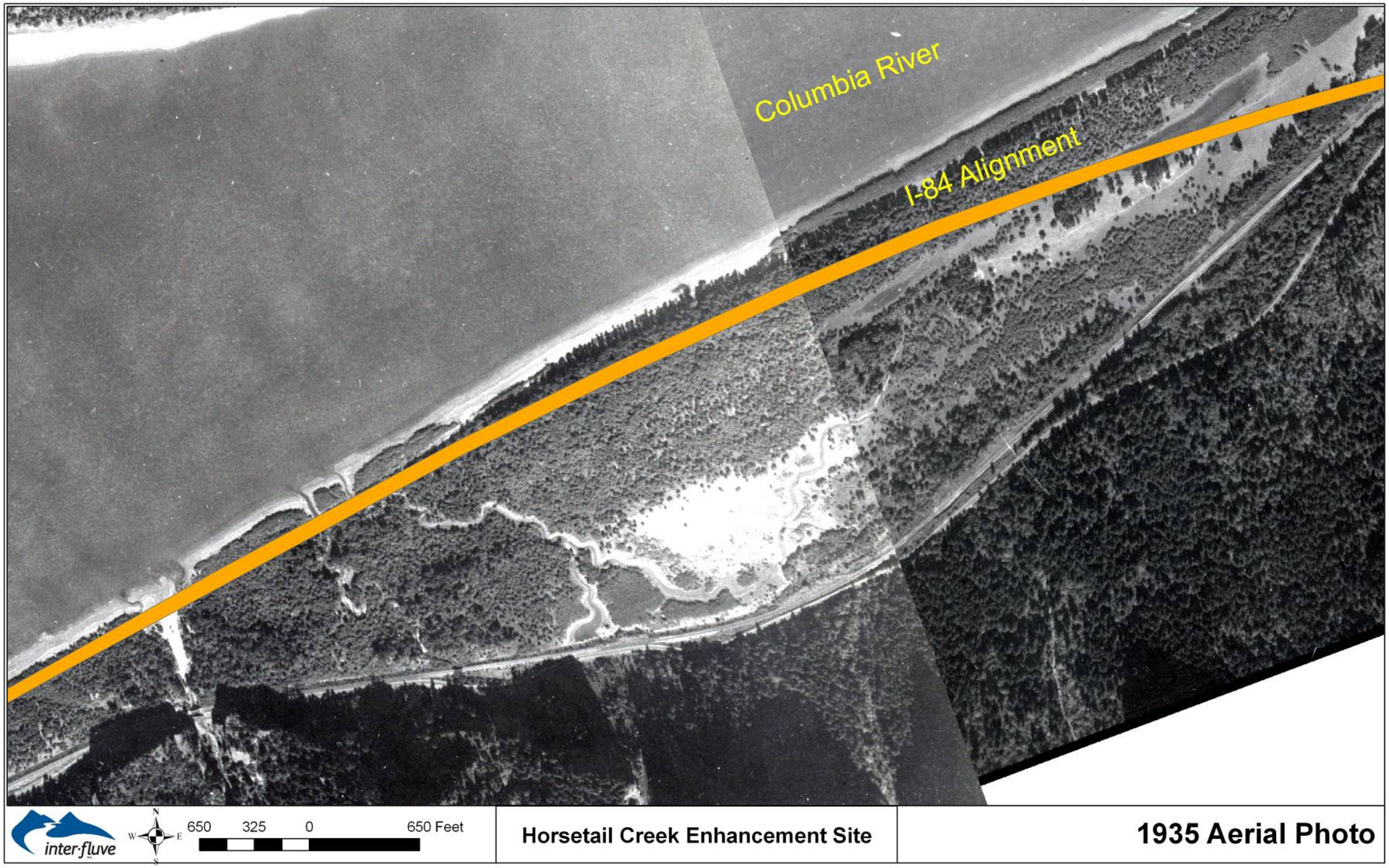


Figure 7. 1935 Aerial Photo.

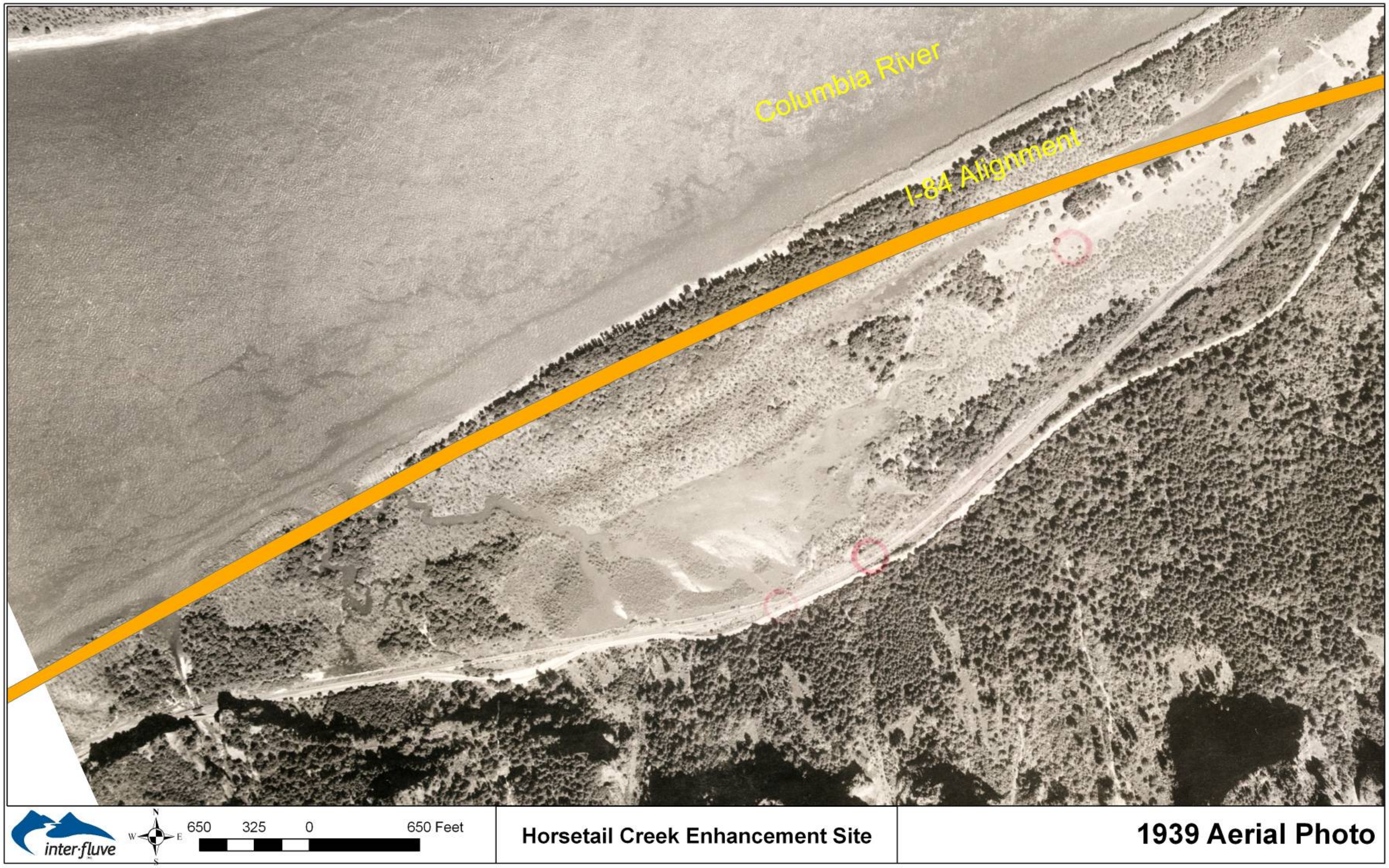


Figure 8. 1939 Aerial Photo.

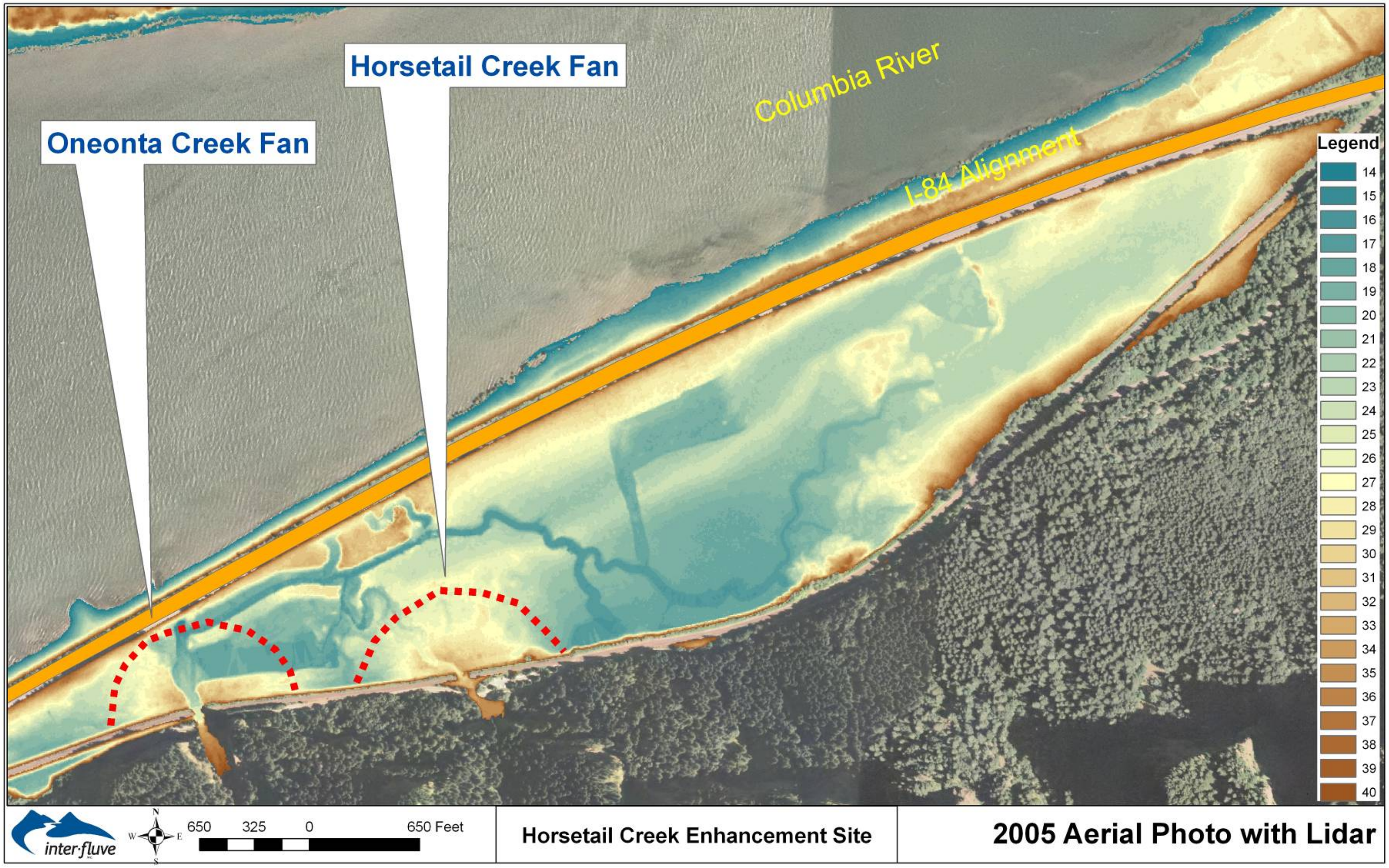


Figure 9. Lidar data overlain on 2005 aerial photograph showing alluvial fans associated with Horsetail and Oneonta Creeks.

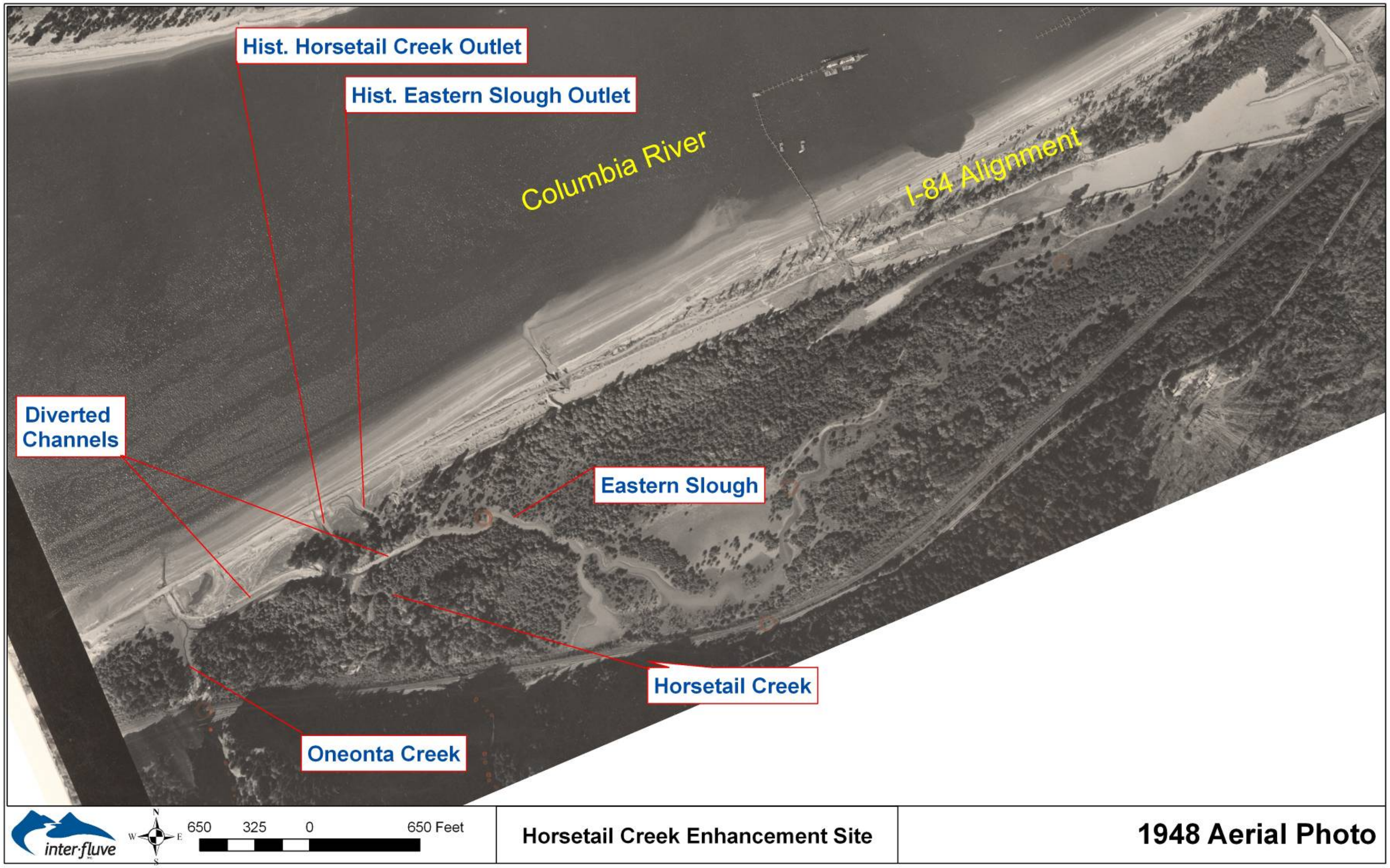


Figure 10. 1948 Aerial Photo.

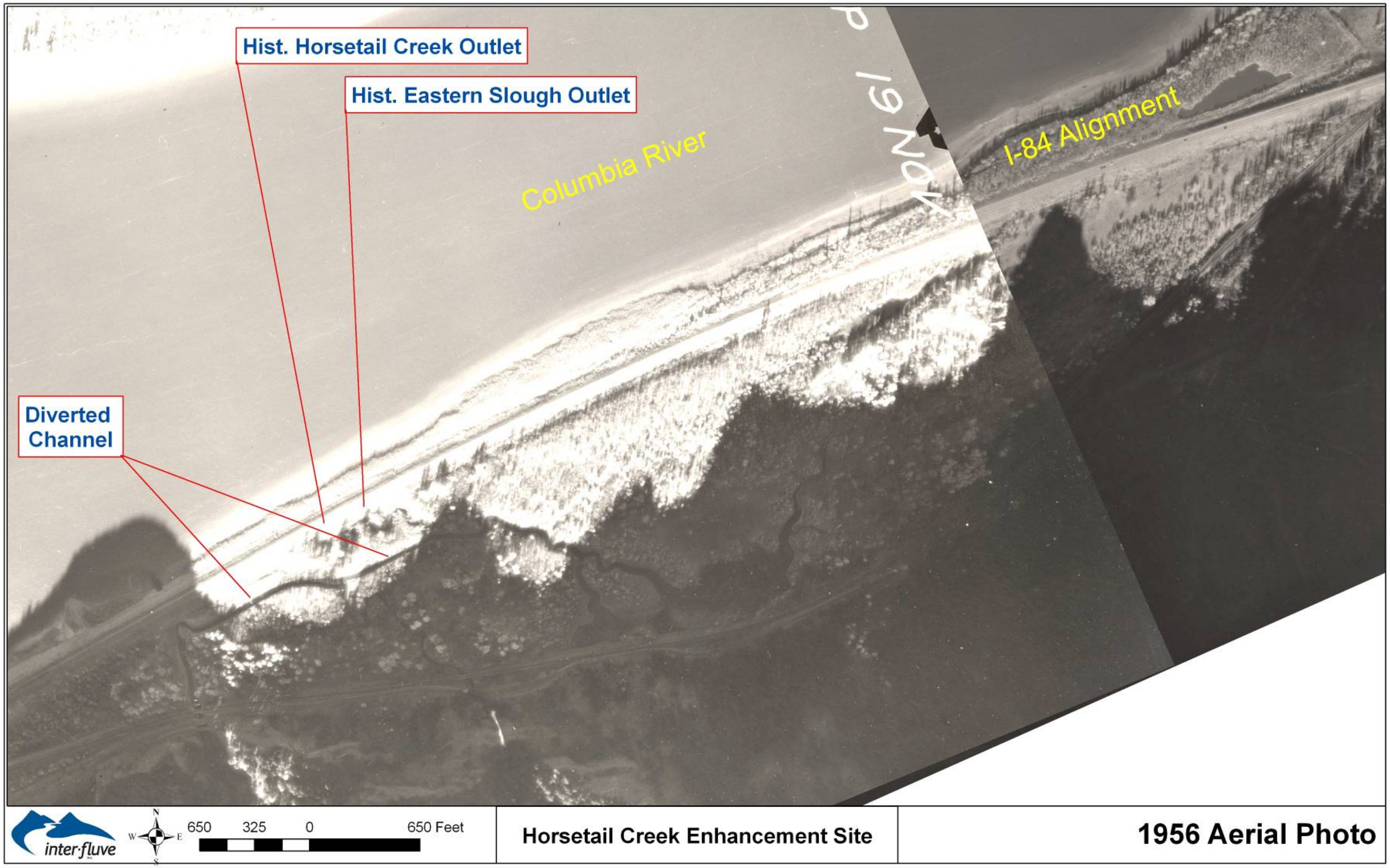


Figure 11. 1956 aerial photo.

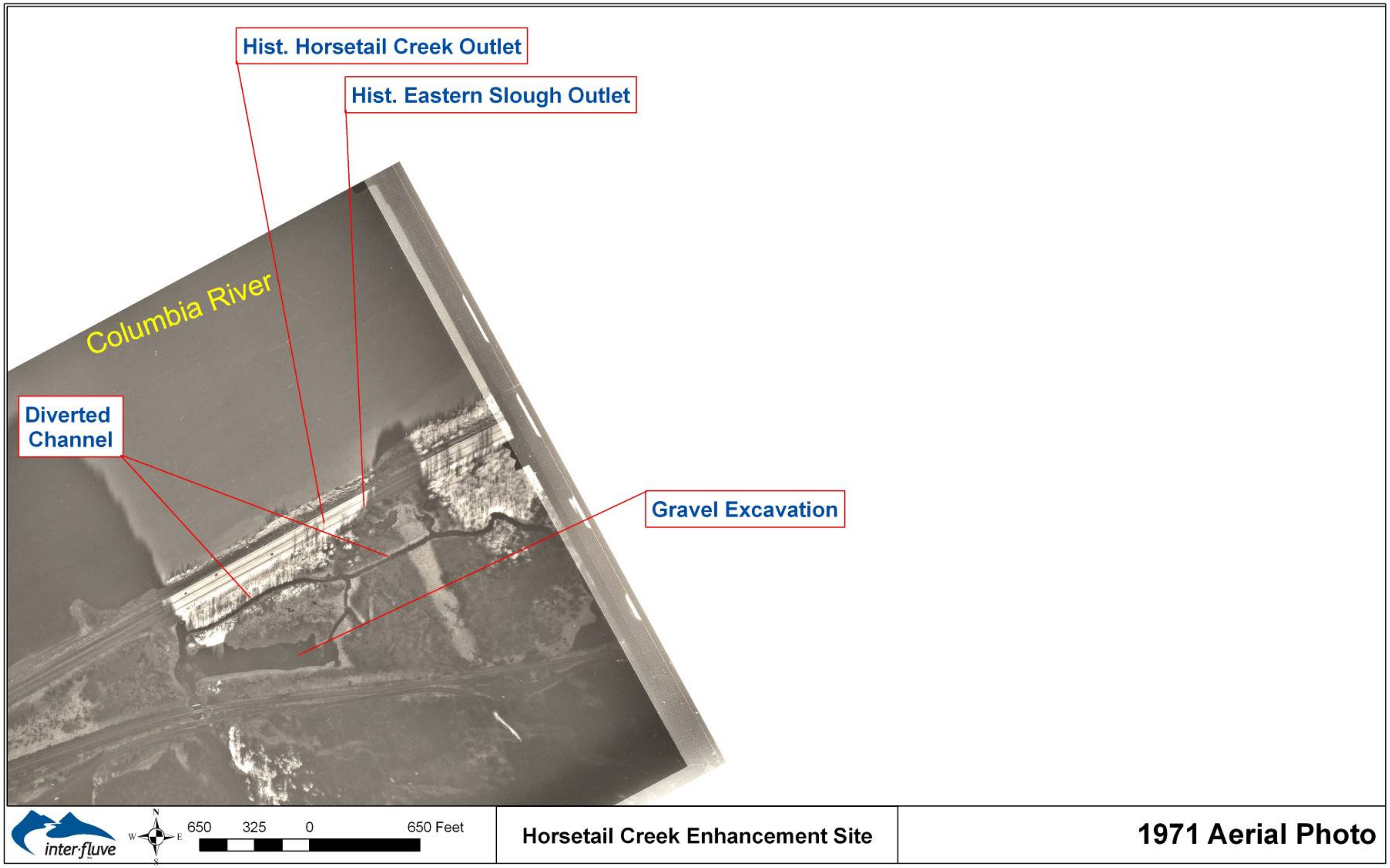


Figure 12. 1971 Aerial Photo.

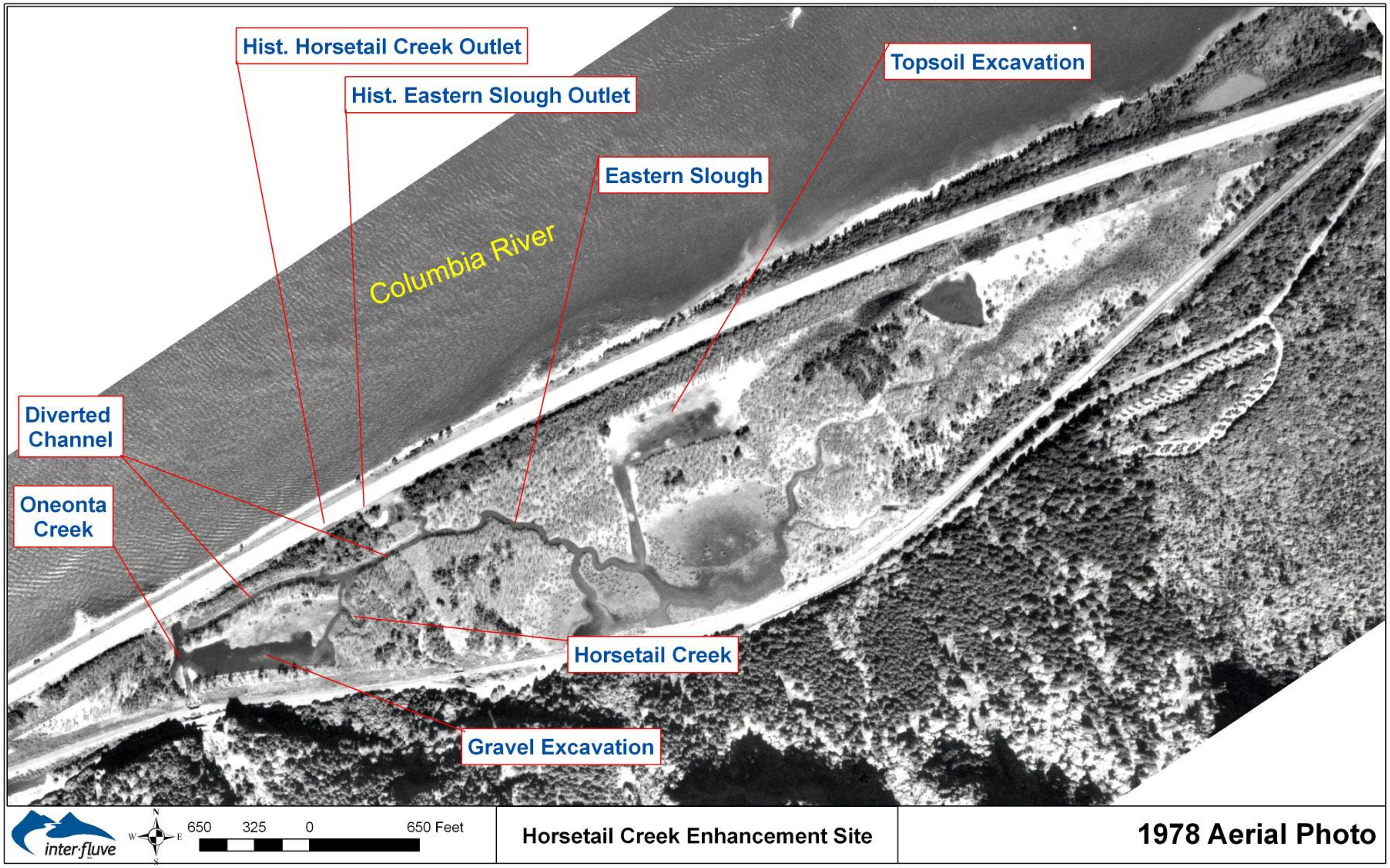


Figure 13. 1978 Aerial Photo.

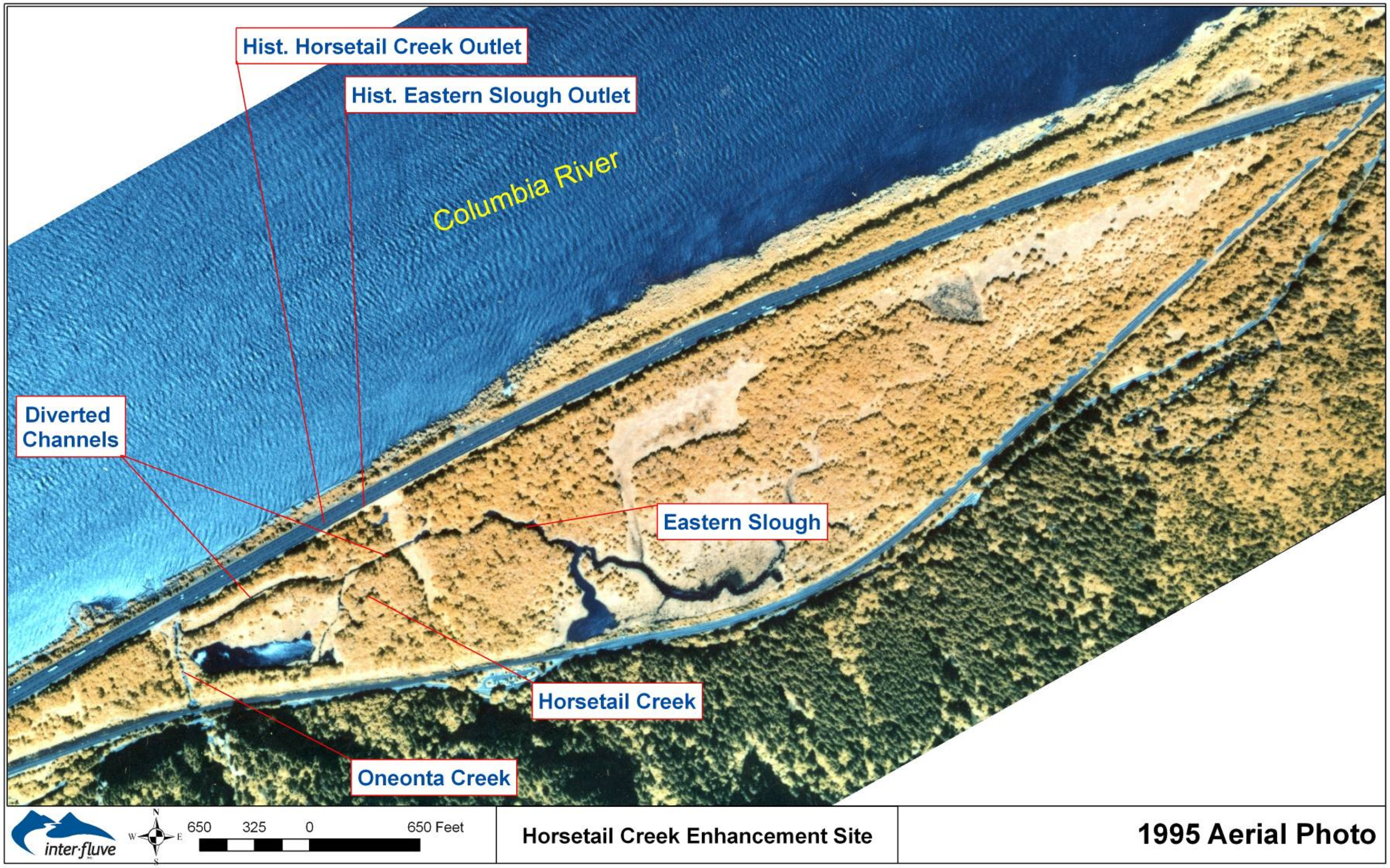


Figure 14. 1995 Aerial Photo.

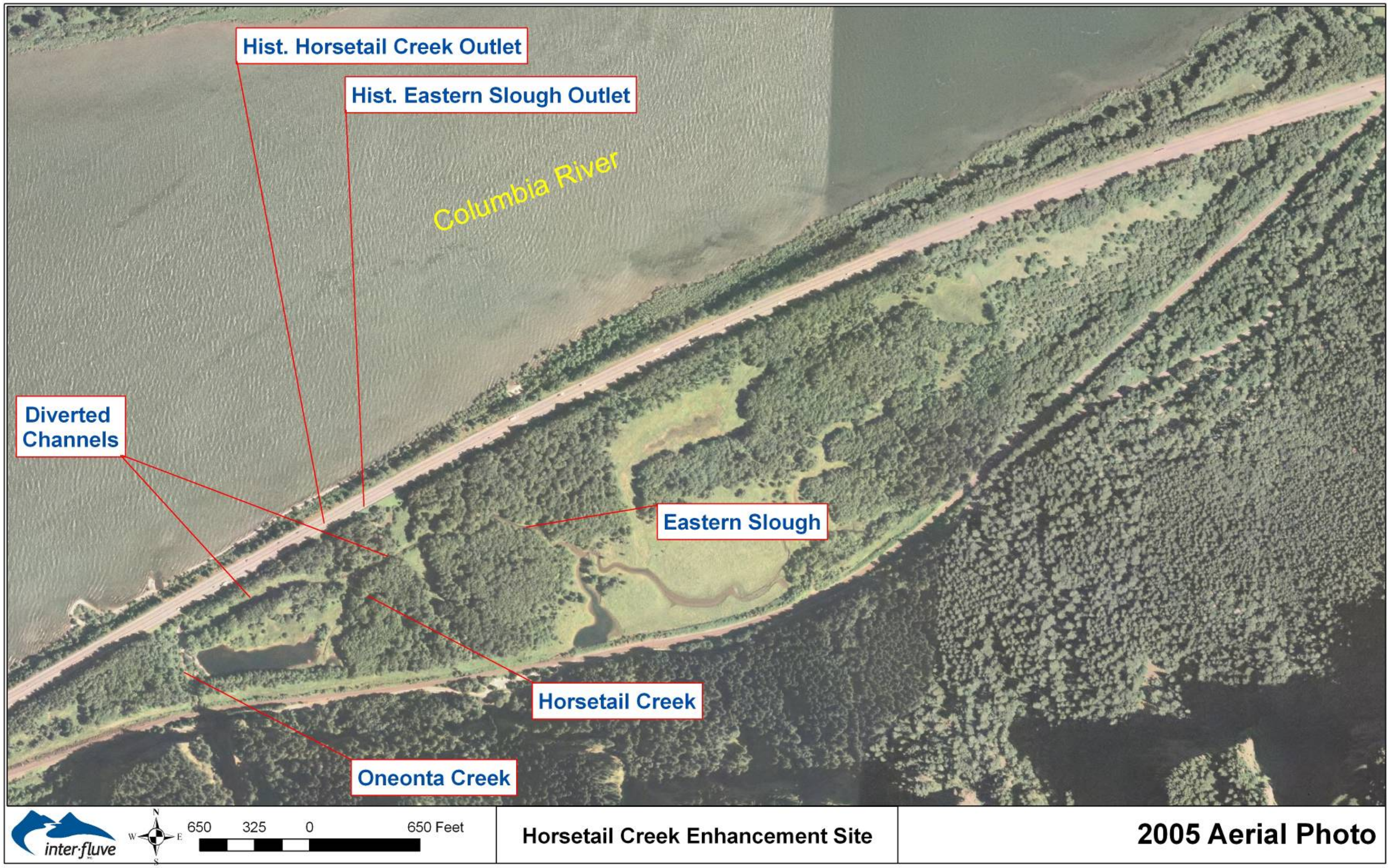


Figure 15. 2005 Aerial Photo.

2.2 PROJECT SUBREACHES

Based on review of site characteristics, the site was delineated into sub-reaches or sub-areas having common characteristics, in order to organize site investigations. Nine sub-reaches were identified (Figure 16), including the following:

- Oneonta Creek I-84 Culvert
- Oneonta Creek Alluvial Fan Reach
- Horsetail Creek Highway Reach
- Horsetail Creek Meander Reach
- Horsetail Creek Alluvial Fan Reach
- Eastern Slough
- Historic Outlet Channels
- Gravel Pond
- Oneonta Gorge Crossings

2.3 SITE SURVEY

Portions of the site were ground surveyed with total station and survey grade RTK-DGPS technology. The intent of the survey was to support development of a hydraulic model for Horsetail Creek, hydraulic evaluations of fish passage at the culverts and bridges on the site, and other considerations described below. Given this, within the stream channels survey data was collected primarily in the form of cross sections to be input in the hydraulic models. The distribution of survey data points is shown in Figure 17.

2.3.1 Assessment of accuracy of existing Lidar data

Lidar data in the vicinity of the site were obtained from the Puget Sound Lidar Consortium (http://pugetsoundlidar.ess.washington.edu/lidardata/index.html) for use in general site assessment and project planning. To assess the relative accuracy of the lidar data, transects were measured with survey grade GPS. The locations of the transects are shown in Figure 17, with comparison plots of the surveyed transects shown in Figure 18 - Figure 19. In general, lidar elevations are within 0.5 to 1 foot of surveyed elevations, with lidar elevations tending to be higher than surveyed elevations.

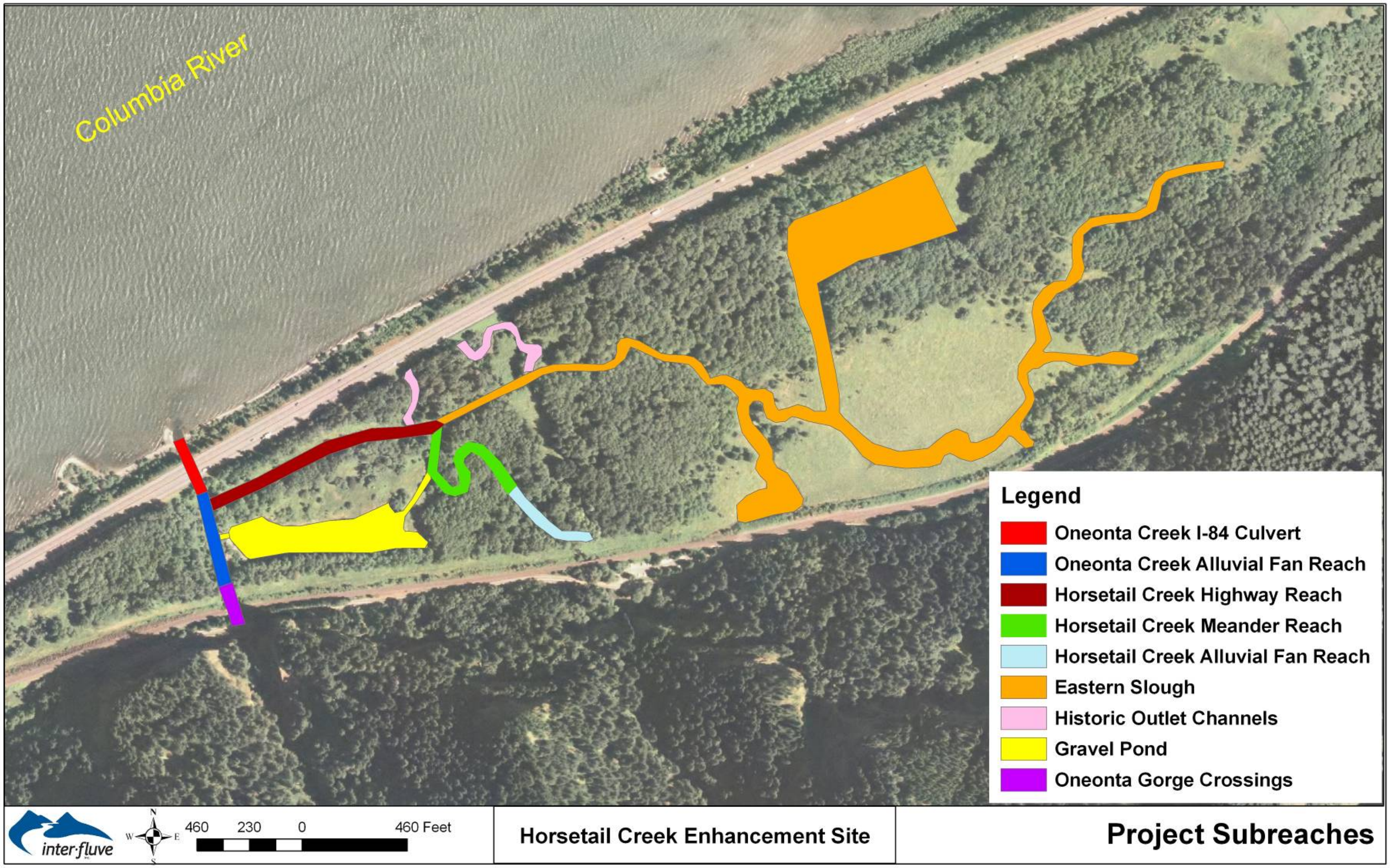


Figure 16. Horsetail Creek Project Site Sub-reaches.

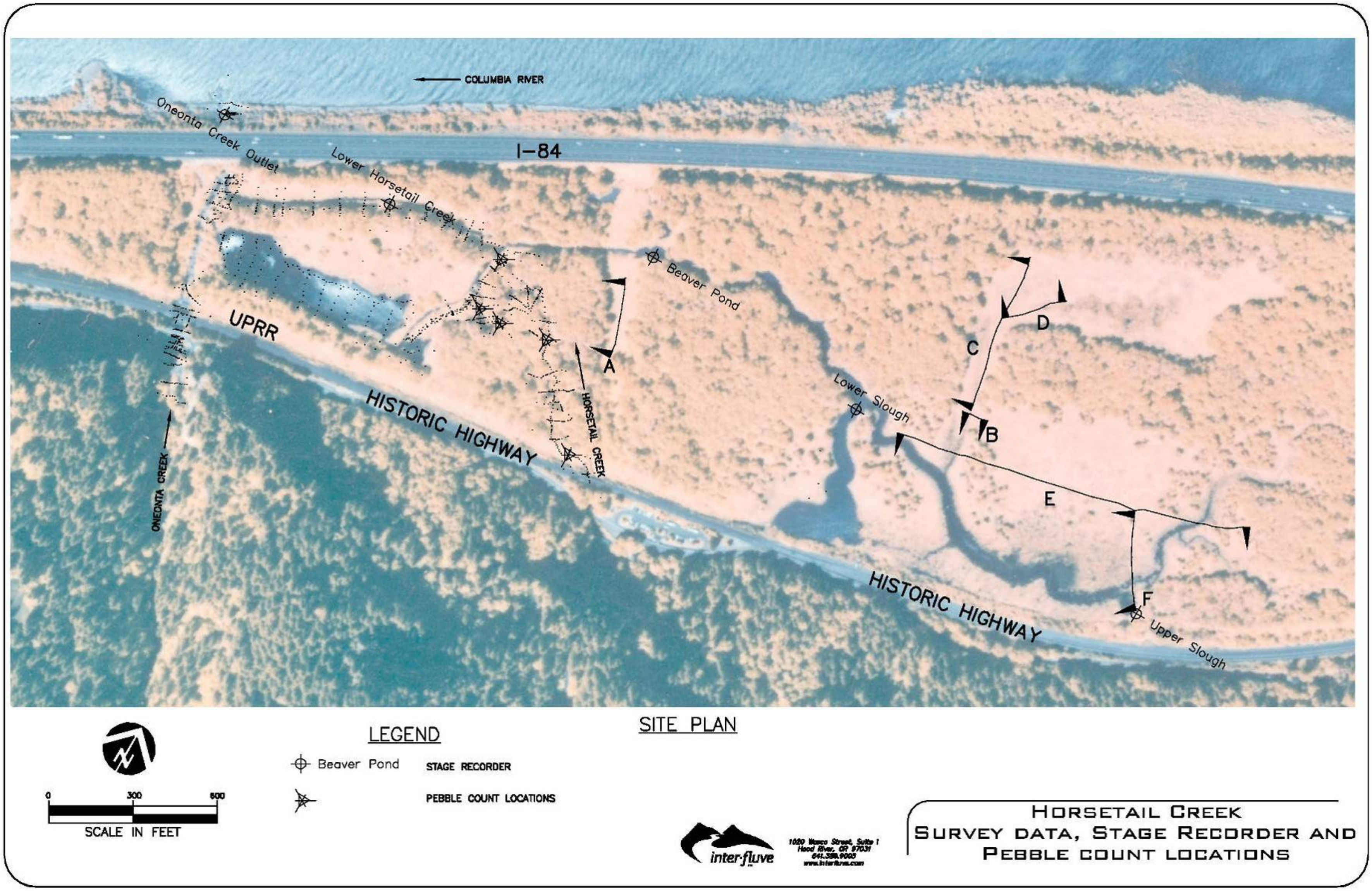


Figure 17. Distribution of survey data collected in spring 2010. Also shown are stage recorder and pebble count locations.

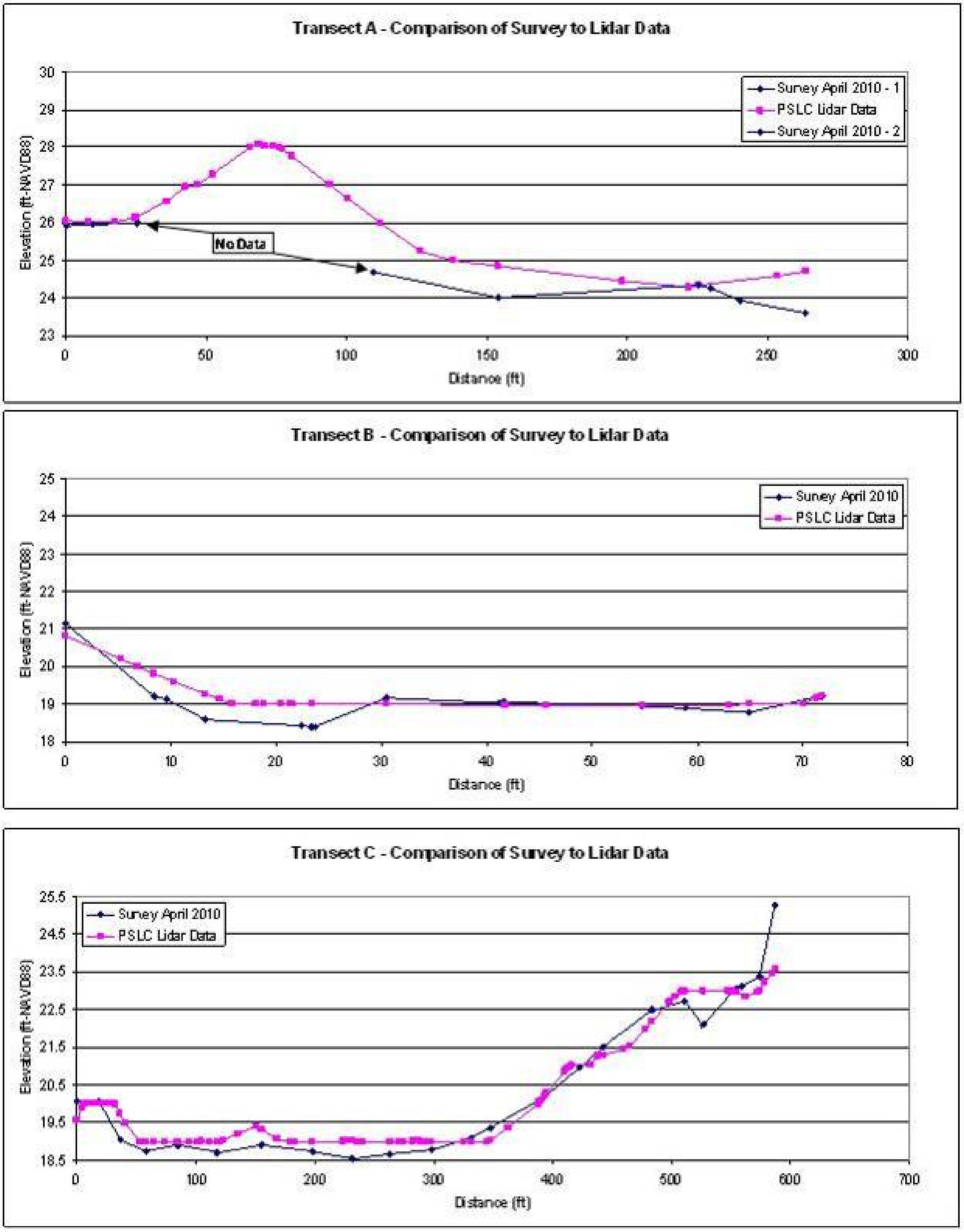
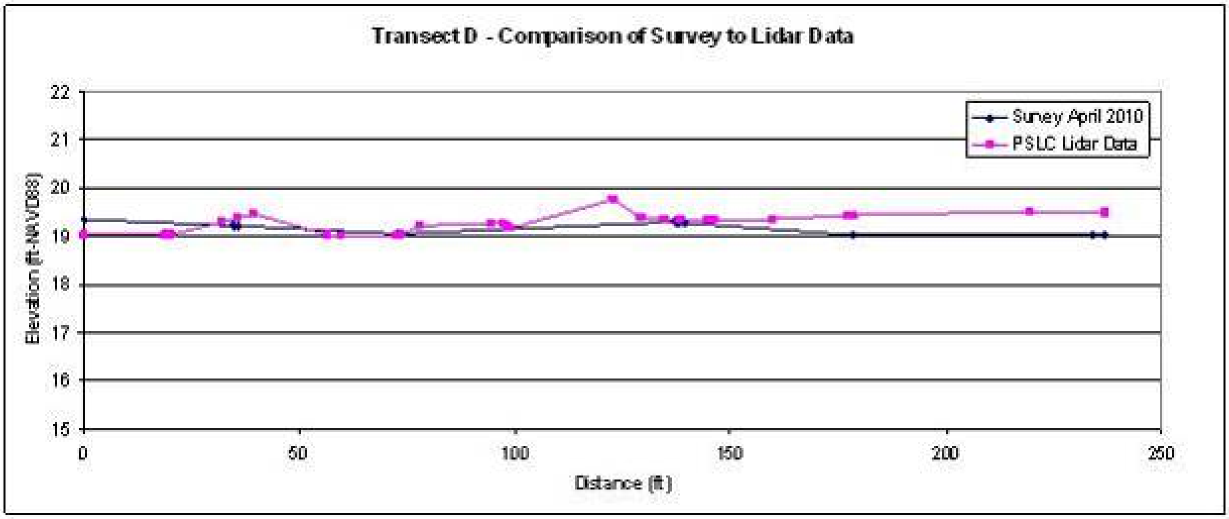
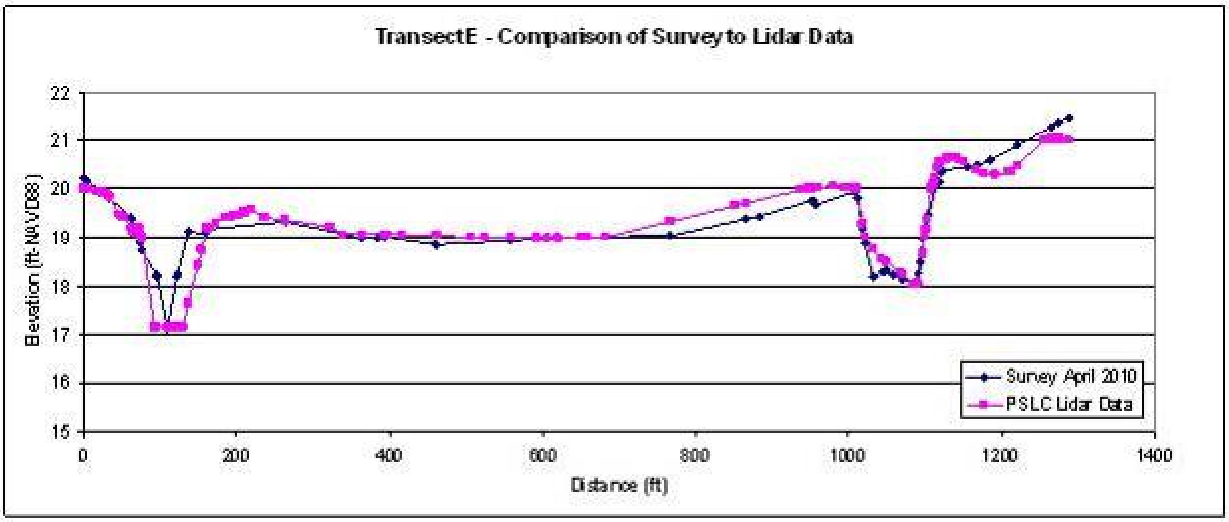


Figure 18 a-c. Transects A-C comparing surveyed ground elevations to PSLC lidar data.





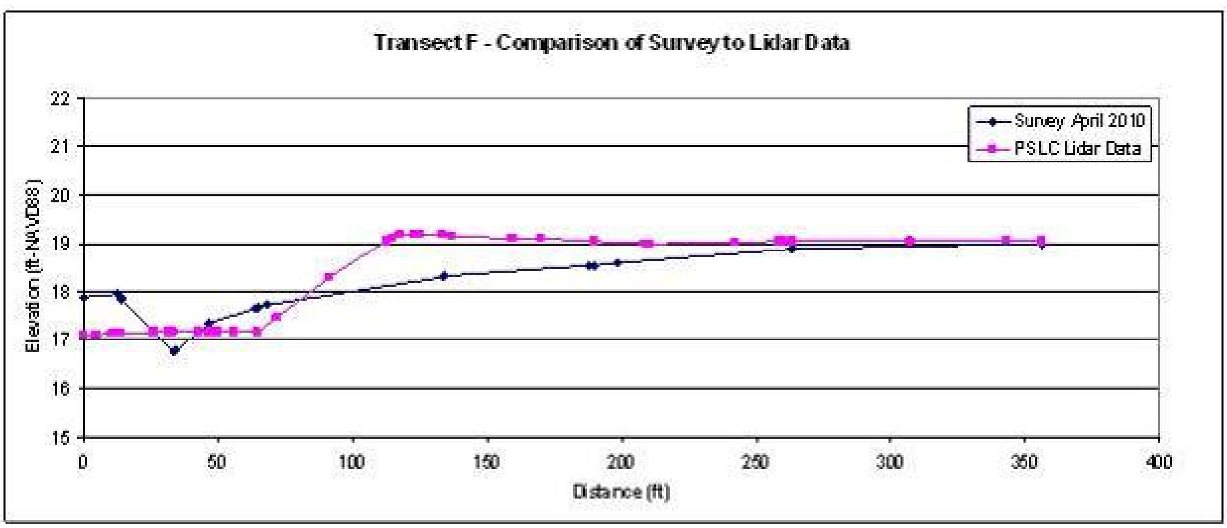


Figure 19 a-c. Transects D-F comparing surveyed ground elevations to PSLC lidar data.

2.4 ASSESSMENT OF GRAVEL POND VOLUME

The gravel borrow pond adjacent to Oneonta Creek was surveyed in April 2010 to develop an estimate of the volume of the pond. This will be used to assess the potential earthwork volumes for alternatives that consider filling the pond to reduce the residence time of Oneonta Creek flow that is routed through the pond. The pond shallows from west to east. The maximum depth at the time of the survey was 9.5 feet towards the west end of the pond, with most depths less than 6 feet in the eastern half of the pond. The volume of the pond at the time of the survey was 11.8 acre feet, or 19,000 cubic yards. If the pond were allowed to drain to the lowest elevation at the outlet, the volume would be 9.0 acre feet. Based on low-flow discharge data collected in July and September 2010, the estimated residence time for water entering the pond during low flow periods averages 3-4 days.

2.5 STREAMBED PROFILES

Streambed profiles for Horsetail and Oneonta Creeks were sampled from the site survey data (Figure 20). The profiles show clear breaks in channel slope in Horsetail Creek corresponding with the channelized highway reach, the middle meandering reach, and the upper reach which traverses the Horsetail Creek alluvial fan. The Oneonta Creek alluvial fan extends from the railroad bridge to the I-84 culvert.

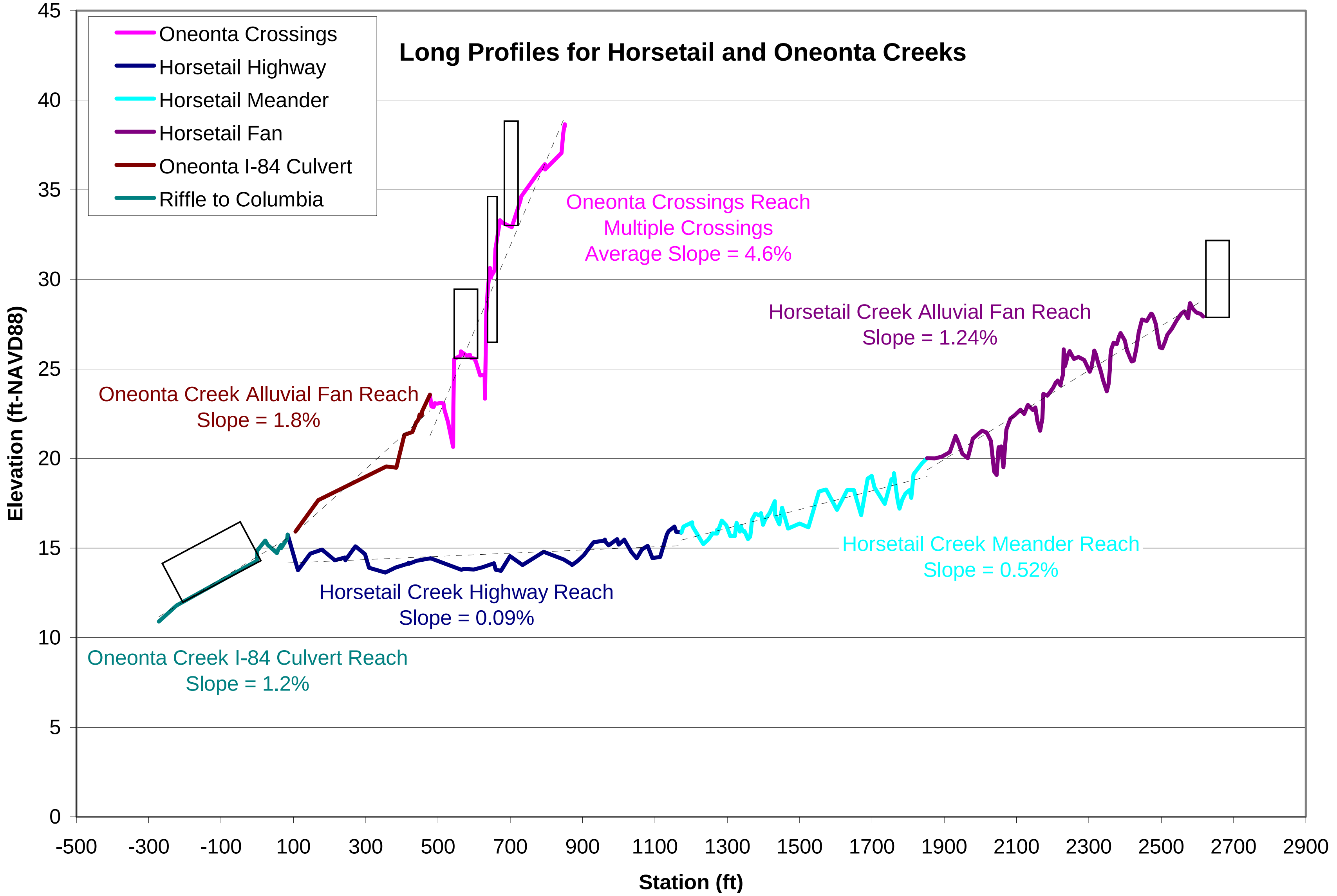


Figure 20. Longitudinal thalweg profiles for Horsetail and Oneonta Creeks.

2.6 SITE FLOODPLAIN, BED AND BANK MATERIALS

2.6.1 Floodplain Soils

The Multnomah County Soil Survey (USDA Soil Conservation Service 1983) mapped the non-water portion of the site as Sauvie Silt Loam, which is a poorly drained soil found on the broad floodplains of the Columbia River. The soil is formed in recent alluvium with some mixing of volcanic ash. Subsoil is described as silty clay loam and substratum as very fine sandy loam. Permeability of the soil is moderately low, with mottling indicating prolonged inundation. Site observations are consistent with the soil survey.

2.6.2 Streambed Materials

Streambed materials vary from cobble to sand across the site. The surface streambed materials in Oneonta Creek include coarse gravel to large cobble over the full reach on the site (Figure 21). In Horsetail Creek, surface substrate varies by reach, and becomes finer with decreasing channel slope in the downstream direction. Figure 22 correlates surface pebble count data to channel slope. Based on these data, median surface substrate size ranges from 55 mm (station 2475) to 42 mm (station 1570) over the alluvial fan reach. Surface substrate sizes become progressively smaller through the meander reach, decreasing to 10 mm just upstream of the confluence with the eastern slough (station 1175). Substrate in the highway reach is primarily silty sand, with local spots of pea gravel size material. At the downstream end where the backwater reach encounters the Oneonta Creek alluvial fan, surface substrate materials match those of Oneonta Creek.

Gravel bed streams tend to develop a surficial 'armor' layer where the materials found on the surface are coarser than those found deeper in the bed. The grain size distribution of the subsurface materials is considered to be representative of the sediment load that is delivered by floods, whereas the grain size distribution of the surface layer tends to be coarser because smaller particles are selectively removed by subsequent flows after a flood has passed. The comparison of the sizes of the surface to the subsurface sediments is often termed an armoring ratio, and is considered indicative of the relative supply of sediment to the reach.

To assess relative sediment supply at the site and to understand the grain size distribution that is moving through Horsetail Creek during floods, bulk subsurface grab samples were collected at stations 1570 and 2475 and processed for grain size distribution (Figure 23). The median sizes of these samples were 17 mm and 27 mm respectively. When compared to surficial pebble count data collected at the same locations, this results in armoring ratios of 2.5 and 2.0, which are indicative of moderately armored conditions, with relatively balanced sediment supply and channel capacity to move sediment at these locations.

In addition, the subsurface sediment distribution was reviewed to assess the quality of gravel in Horsetail Creek for spawning. Reiser (1998) suggests that when fine sediment smaller than 0.84 mm is greater than 10% of the sediment distribution, hatching survival by salmonids is curtailed. Likewise, when sediment smaller than 6.4 mm comprises 25% of the sediment distribution, Reiser (1998) suggests that survival to emergence is reduced. The gravel in Horsetail Creek meets the first criteria in both sample locations. The gravel in Horsetail Creek has 27% and 26%

finer than 6.3 mm at stations 1570 and 2475, respectively, which is close to but just above the second benchmark.

Substrate sampling data sheets are found in Appendix A.

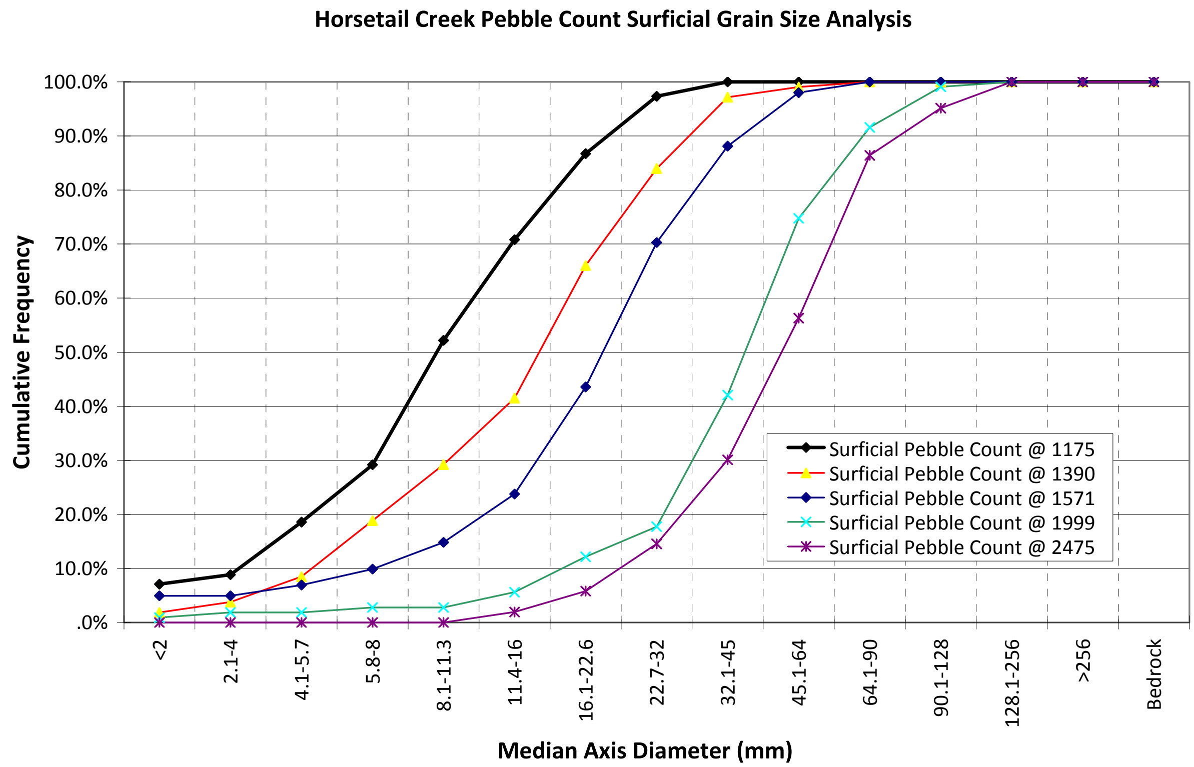


Figure 21. Surficial pebble count data.

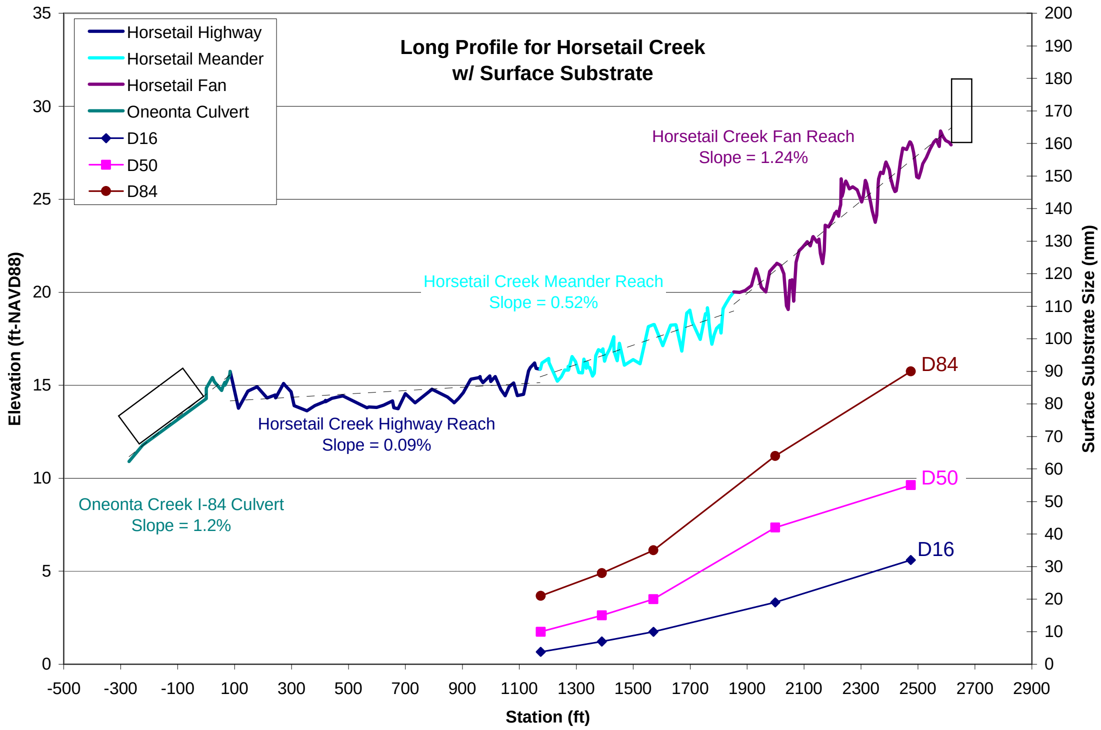


Figure 22. Comparison of surface substrate size to channel slope in Horsetail Creek.

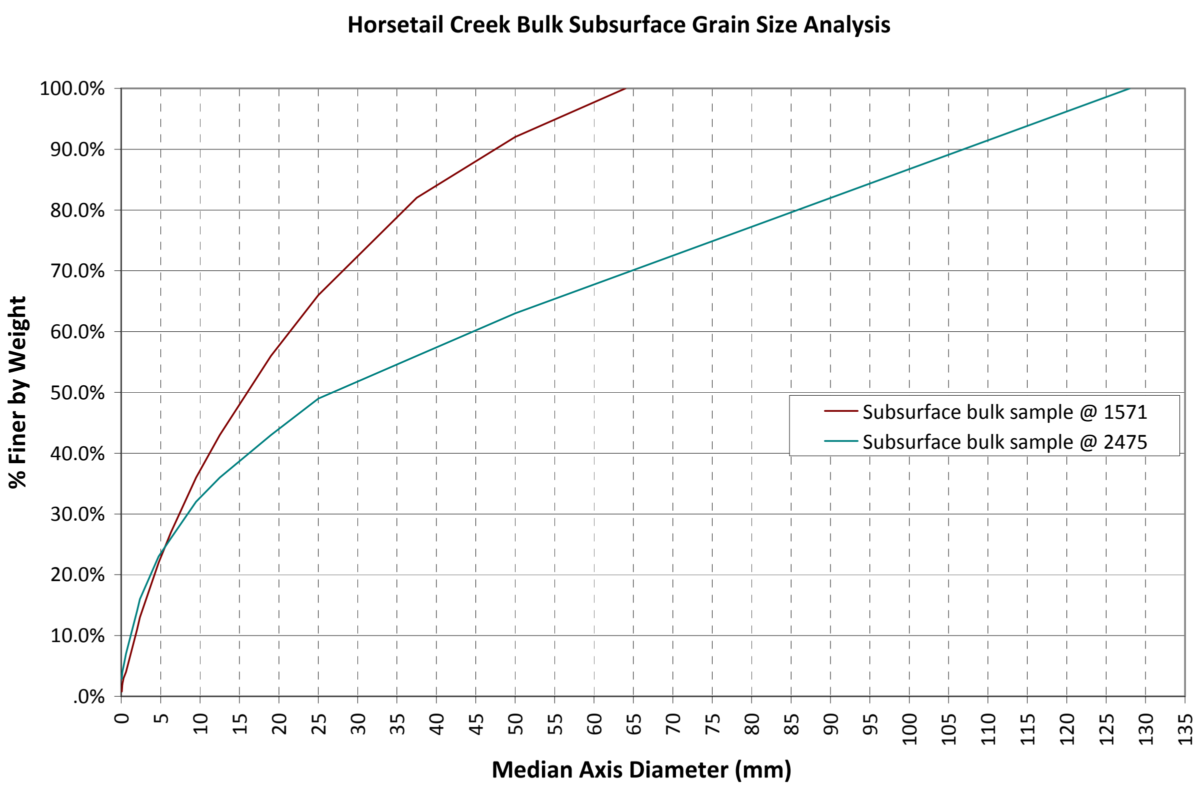


Figure 23. Subsurface bulk sediment data results.

2.6.3 *Streambank Materials*

Prior to disturbance, Horsetail Creek drained off of its alluvial fan and traversed the Columbia River floodplain to its confluence with the mainstem at a gradient that was steeper than the flat floodplain surface, i.e., the creek became more entrenched into the Columbia River floodplain as it approached the river. Evidence of this pattern is apparent in the streambank condition and materials. In the alluvial fan reach, streambank heights are relatively low and the banks are primarily composed of alluvial gravel and sand, with a thin layer of organic topsoil on the surface (Figure 24). Moving downstream, streambanks become progressively taller and the bank materials are dominated by Columbia River floodplain soils (silty loam), with lenses of gravel present in select locations (Figure 25). In the areas of greatest entrenchment, the lower portions of the streambanks include exposed layers of hardpan clay soils, which would represent old floodplain materials (Figure 26). Streambank materials in the diverted highway reach consist of fine-grained silty loam materials, and also include relatively common exposed layers of hardpan clay soils.

Figure 24. Streambank in Horsetail Creek alluvial fan reach, composed primarily of coarse alluvial materials.

Figure 25. Streambank in lower section of Horsetail Creek, composed of fine-grained Columbia River floodplain soils overlaying alluvial gravel lense.

Figure 26. Streambank in Horsetail Creek lower meandering reach, composed of fine-grained floodplain soils with exposed hardpan clay lense near bottom of bank.

3 AQUATIC SPECIES USE OF THE SITE

3.1 SALMONIDS

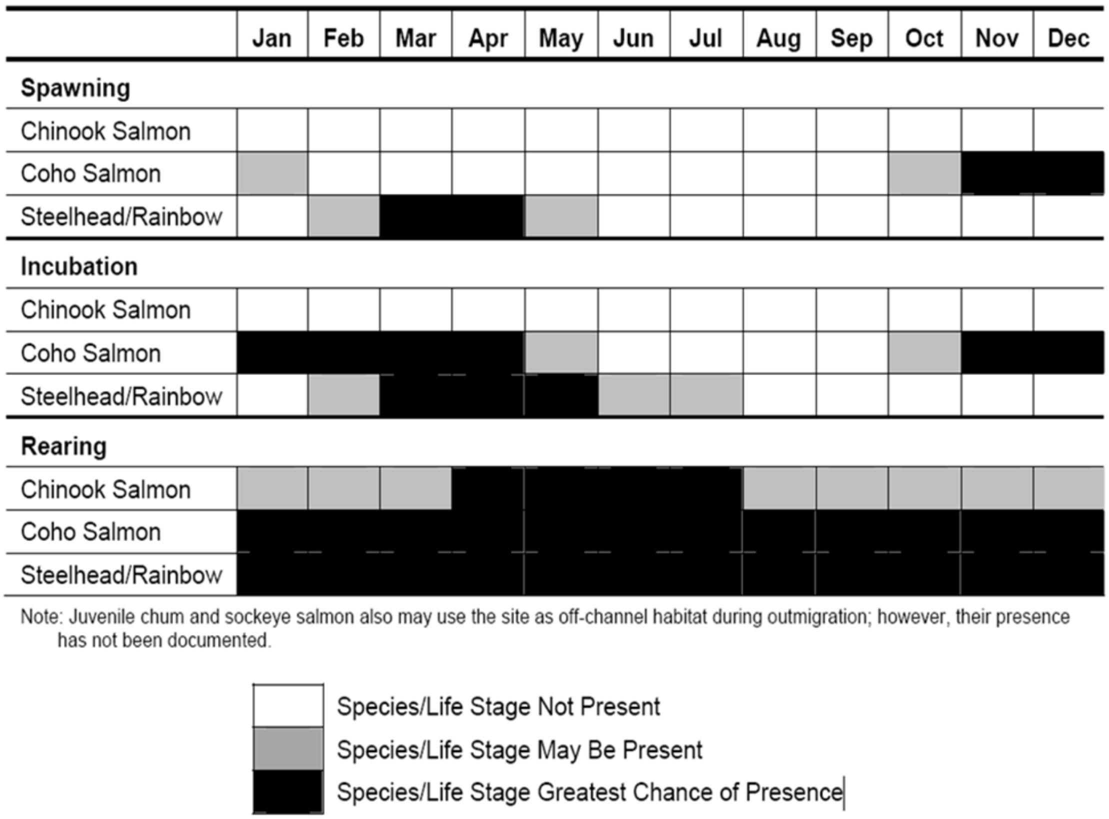
The Horsetail Creek site is known to support ESA-listed salmonids. This section details known and presumed use of the site by both local stocks (Lower Columbia River [LCR] evolutionary significant units [ESUs]) and up-river stocks (those spawned above Bonneville Dam).

3.1.1 Lower Columbia ESUs

Based on StreamNet (2010), Oregon Department of Fish and Wildlife (ODFW) spawning survey data, and observations by Estuary Partnership and Inter-Fluve scientists, the Horsetail Creek project site is known to support spawning and rearing of LCR coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*O. mykiss*). As detailed below, LCR Chinook salmon (*O. tshawytscha*) also use the site for rearing (StreamNet 2010). However, spawning adults have not been observed by ODFW during fall spawning surveys (ODFW 2009) and flow conditions appear to be too low during August and September to support Chinook salmon spawning. LCR cutthroat trout (*O. clarki*) may also use the site for spawning and/or rearing. Based on information presented below, Columbia River chum salmon (*O. keta*) may use the site as off-channel habitat during their outmigration through the estuary, but do not spawn on-site.

Table 2 summarizes the timing of use by the key salmonid species and life stages found at the Horsetail Creek project site. Spawning and incubation likely occur throughout Oneonta Creek and within the alluvial fan and meander reaches of Horsetail Creek. No spawning occurs in the eastern slough or Horsetail Creek's highway reach. Rearing likely occurs site-wide, except within areas that are temperature limited during low-flow periods (see Section 0 for detail regarding the site's thermal regime).

Table 2. Timing of use among key salmonids.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Spawning												
Chinook Salmon												
Coho Salmon												
Steelhead/Rainbow												
Incubation												
Chinook Salmon												
Coho Salmon												
Steelhead/Rainbow												
Rearing												
Chinook Salmon												
Coho Salmon												
Steelhead/Rainbow												

Note: Juvenile chum and sockeye salmon also may use the site as off-channel habitat during outmigration; however, their presence has not been documented.

3.1.2 *Up-river ESUs*

To date, no sampling has occurred to determine whether juvenile salmonids from up-river ESUs use the Horsetail Creek project site as off-channel habitat as they outmigrate through the LCRE towards the Pacific Ocean. In lieu of direct observation, this section presents available data from sites within the Columbia River Gorge with similar habitat conditions. Based on these data, it is likely that both ESA-listed and non-listed salmonids from ESUs above Bonneville Dam utilize the site during outmigration.

As detailed in Jones et al. (2008), during the spring and summer of 2008, NOAA Fisheries sampled four sites in the Columbia River Gorge as part of an Estuary Partnership monitoring effort (Figure 27). NOAA also has sampled fish populations at the Mirror Lake site (Figure 27) during the past three years (Sol et al., 2008; Sol et al., 2009; Sol et al., 2010). Using beach seines, all sites were sampled once per month from April through August. However, due to extreme water levels during the 2008 freshet, NOAA was unable to sample two sites (Franz Lake and Sand Island; Figure 27) during June. Also due to high water levels, NOAA also was unable to sample portions of the Mirror Lake site during June of all three years.

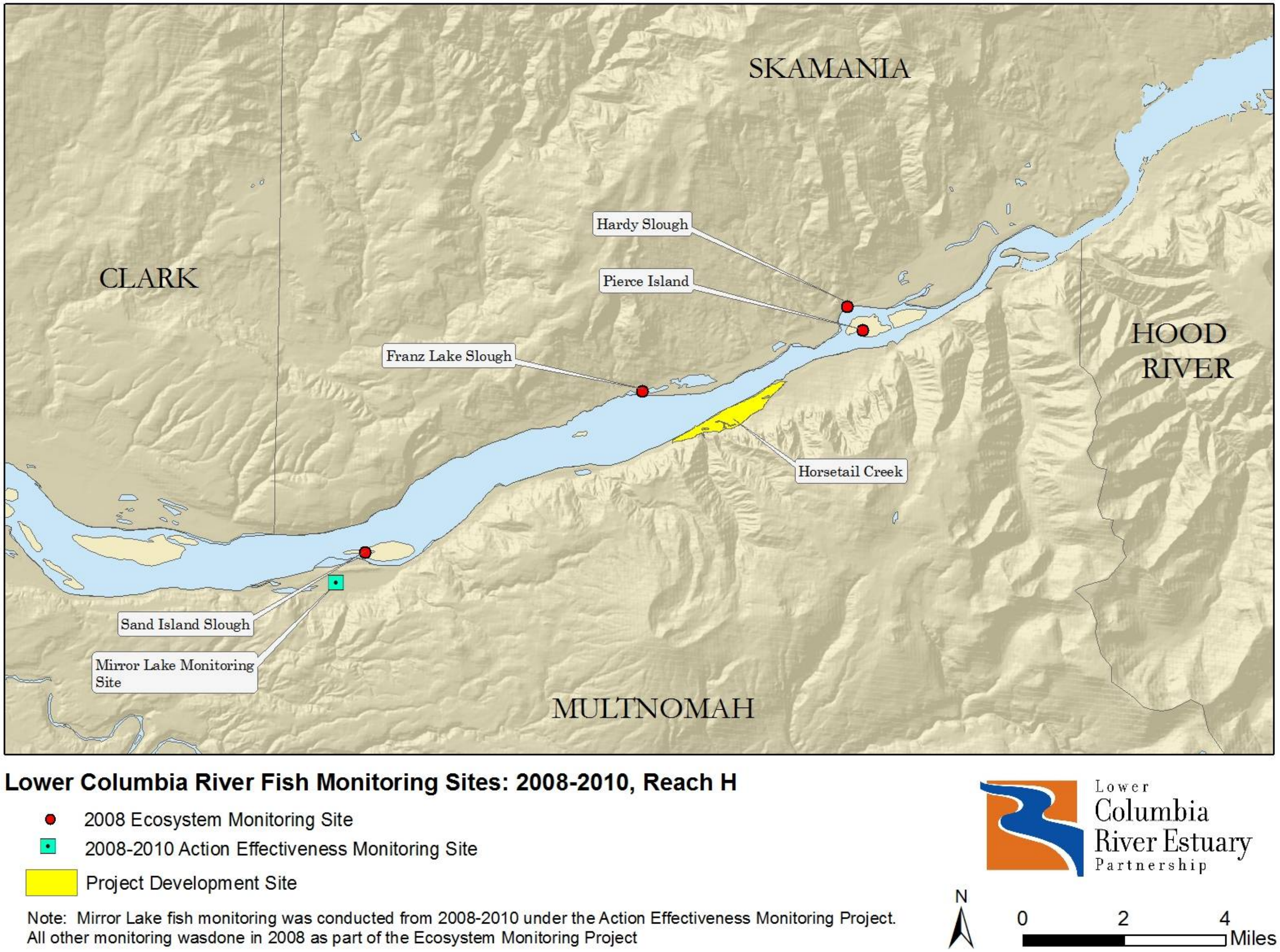


Figure 27. Lower Columbia River Fish Monitoring Sites.

Results from these sampling efforts are summarized in Table 3. NOAA captured juvenile Chinook, coho, and chum salmon at all sites, while juvenile steelhead were captured at Mirror Lake only. Overall, Chinook salmon were the most abundant juvenile salmon species at the four sites for which we have detailed data; coho salmon also were relatively abundant. Chum salmon were found at all sites except Pierce Island, but represented a small portion of the salmon captured. Generally, NOAA collected chum salmon only in April, Chinook from April to July, and coho from April to August (though not at all sampling sites).

Catch rates were highest during April, May, and June. No salmon were captured during August sampling efforts, except in the upper portions of Mirror Lake, which supports a spawning population of wild coho salmon that uses the site year-round for rearing.

Genetic stock data are available for juvenile Chinook salmon sampled at all sites in 2008 as well as for 2009 sampling at the Mirror Lake site. The following reporting groups (listed along with the relevant ESU and ESA status) were detected; relative abundance of these reporting groups varies between sites.

- Upper Columbia River Summer/Fall – Upper Columbia River Summer/Fall ESU (not listed)
- Snake River Fall – Snake River Fall Run ESU (threatened)
- Deschutes River Fall – Deschutes River Summer/Fall Run ESU (not listed)
- Spring Creek Fall – Lower Columbia River ESU (threatened)
- West Cascades Spring – Lower Columbia River ESU (threatened)
- West Cascades Fall – Lower Columbia River ESU (threatened)
- Willamette Spring – Upper Willamette River (threatened)

The majority of fish from the Lower Columbia River and Willamette River ESUs were marked hatchery fish. The majority of fish collected from the other three reporting groups were unmarked (presumably wild).

Preliminary results of 2010 fish sampling and genetics analyses conducted by NOAA Fisheries, OHSU, WDFW, and the University of Washington in the Columbia River Gorge below Bonneville Dam report a similar array of ESUs present in off-channel habitats within this reach. In their study, Willamette River fish were not reported; however, Snake River Spring Chinook juveniles were present (Bottom 2010).

Table 3. Fish species captured and percent of each species at 2008 (April – August) fishing sites. Raw data for Mirror Lake were not available, therefore presence/absence is indicated by a "P" or "A".

Species	Beacon Slough	Franz Lake	Pierce Island	Sand Island	Mirror Lake (08',09',10')	Native / Non-native
salmon, Chinook	0.71	5.32	32.52	0.55	P	Native
salmon, coho	2.50	3.01	9.38	2.73	P	Native
salmon, chum	0.12	0.53	3.87	0.14	P	Native
steelhead/rainbow	0	0	0	0	P	Native
bass, smallmouth	0	1.95	0	0.38	P	Non-native
bass, largemouth	0	0	0	0	P	Non-native
bluegill	0	0	0.10	0.24	P	Non-native
bullhead, brown	0	0	0	0.10	A	Non-native
bullhead, yellow	0	7.00	7.34	0.03	P	Non-native
carp, sp.	0.06	31.29	0	0.79	P	Non-native
catfish, blue	0	0	0	0.03	A	Non-native
catfish, channel	0	0.09	0	0	A	Non-native
chiselmouth	1.14	29.08	4.99	41.23	P	Native
crappie, sp.	0	0	0	0	P	Non-native
killifish, banded	0.06	7.54	6.63	1.62	P	Non-native
northern pikeminnow	0	0.27	0.20	1.04	P	Native
peamouth	0.03	0.27	0	5.70	P	Native
perch, yellow	0	0	0	0	P	Non-native
pike, walleye	0	0.09	0	0	P	Non-native
pumpkinseed	0.99	5.67	1.43	4.90	P	Non-native
sandfish	0	0	0	0	P	Non-native
sculpin, sp.	0.37	0.35	0.61	0.28	P	Native
shad, American	0	0	0	0	P	Non-native
stickleback, threespine	94.01	7.45	32.82	39.78	P	Native
sturgeon, white	0	0	0	0.21	A	Native
sucker, largescale	0	0.09	0	0.24	P	Native
Total species captured	**11**	**16**	**11**	**18**	**22**	**Native = 11** **Non = 15**
Total fish captured	**3237**	**1128**	**981**	**2896**	**NA**	**NA**

3.1.3 Summary of Salmonid Presence at the Project Site

The following ESUs are documented as using the Horsetail project site for spawning and rearing:

- Lower Columbia River Coho Salmon (ESA listed – threatened)
- Lower Columbia River Steelhead (ESA listed – threatened)

Based on data available from sampling in similar off-channel habitats in the Columbia River Gorge and hydrologic conditions, i.e., Columbia River inundation patterns at the site, summarized in Section 4 below, the following ESUs may utilize the Horsetail project site for rearing and/or off-channel habitat:

- Lower Columbia River Chinook Salmon (ESA listed – threatened)
- Columbia River Chum Salmon (ESA listed – threatened)
- Snake River Chinook Salmon Fall Run (ESA listed – threatened)
- Upper Willamette River Chinook Salmon (ESA listed – threatened)
- Upper Columbia River Chinook Salmon Summer/Fall Run (not listed)
- Deschutes River Chinook Salmon Summer/Fall Run (not listed)

3.2 OTHER AQUATIC SPECIES

The following non-salmonid aquatic species have been observed on-site:

- threespine stickleback *(Gasterosteus aculeatus)*
- sculpin (*Cottus* spp.)
- crayfish (unknown)
- red-legged frog *(Rana aurora)* – ESA Species of Concern
- common carp *(Cyprinus carpio)*
- largemouth bass *(Micropterus salmoides)*

Other non-salmonid aquatic species identified in Table 3 also may occur on-site.

4 HORSETAIL CREEK SITE HYDROLOGY

4.1 WATERSHED HYDROLOGY

4.1.1 Peak Flows

The site is located is in a transitional climactic zone between western and eastern Oregon. Local topographic factors (i.e., location against the steep Columbia Gorge valley wall, near the axis of the Cascade Range) lead to substantial variability in precipitation within these watersheds. Winter rain storms dominate the flood flow hydrology at the site. Although the watersheds are generally lower in elevation than the typical elevation range for rain on snow events (4000 feet), the unique topography and air circulation patterns in the area lead to periodic heavy snow falls which may lead to this type of flooding, in addition to purely rainfall-generated floods. The watersheds are forested and in generally intact condition. Land ownership includes lands of the CRGNSA administered by the U.S. Forest Service, and a small area of the City of Portland's protected Bull Run area.

Horsetail and Oneonta Creeks are ungaged streams, with no applicable nearby gaging station to enable estimation of peak flows based on observed data. Therefore, peak flows were estimated using regional regression equations, which are developed based on statistical modeling of gage data over broad physiographic areas. Two sets of regression equations were determined to be most appropriate for the analysis, including the 1993 United States Geological Survey (USGS) regression equations for Western Oregon, and the 2005 Oregon Water Resources Department (OWRD) regression equations for Western Oregon. Because the Columbia River Gorge is a transitional hydroclimatic zone, regression equations were utilized for areas bounding the Gorge, with an average of the values predicted by the two sets of equations used in the analysis.

The USGS (1993) developed regional regression equations for ungaged watersheds in the western United States to estimate 2-, 5-, 10-, 25-, 50- and 100-year peak flows. For this set of equations, Horsetail and Oneonta Creeks fall into the Willamette Region of Western Oregon. Willamette Region peak flows are estimated as a function of drainage area and 2-year, 24-hour rainfall intensity. Watershed and climatic data used for calculating peak flows were obtained separately for the three sub-watersheds of the study area: Horsetail Creek, Oneonta Creek, and the Eastern Slough (Figure 28). Drainage areas were delineated using USGS topographic quad maps in geographic information system (GIS; Table 4; Figure 28). Rainfall intensity estimates were found using StreamStats, a web-based GIS tool developed by the USGS that allows users to analyze drainage-basin characteristics for a given watershed.

OWRD similarly developed regional regression equations to estimate peak flows, specific to rural, unregulated streams in Western Oregon (OWRD, 2005). Per this method, Horsetail Creek falls into Region 2b (western interior with average elevation < 3000 feet), with peak flows estimated as a function of watershed area, mean watershed slope, and 2-year, 24-hr rainfall intensity. Mean watershed slope and rainfall intensity were determined using the StreamStats web-based tool.

Table 4. Characteristics of sub-watersheds included in the peak flow analysis.

Sub-Watershed	Total Drainage Area (mi^2)	Mean Watershed Slope (deg.)	Mean Watershed Elevation (ft)	2-year, 24-hr rainfall intensity (in.)
Horsetail Creek @ Railroad	3.73	15.5	2700	4.38
Eastern Slough @ Confluence with Horsetail Creek	0.97	8.6	1370	3.8
Oneonta Creek @ Railroad	5.23	18.9	2600	4.24

The average peak flow estimates for the 2-year to 100-year events were calculated separately for the three sub-watersheds and then combined at each stream junction. The regional regression methods do not provide an estimate of the 1-year return period peak flow discharge. This discharge was estimated by extrapolation of the values obtained for the less frequent peak flows (2-year to 100-year events). Table 5 summarizes the peak discharge estimates for the three sub-watersheds considered in this study.

Regional regression equations explicit to this zone and specific setting are unavailable; therefore, the equations utilized were determined to be the best available method. Due to the unique nature of the study area, uncertainty exists in using the regional regression equations for estimating peak flows. The OWRD method provides an estimate of the average predication error associated with the calculated peak flows, which encompasses model error and sampling error. Model error is the uncertainty due to a model that does not account for all the variability in peak discharges, while sampling error is the uncertainty due to estimating model parameters from a sample, i.e. not from the whole population (OWRD 2005). The estimated average prediction error for each of the three sub-watersheds ranges from 32% to 39% for flows from the 2-yr to the 100-yr, with error increasing as flood magnitude increases.

The uncertainty in these estimates could be improved through collection of empirical data at the site. However, a minimum of ten years of peak flow data would be required to begin to develop statistically valid estimates of the peak flow hydrology which is impractical from a logistical and project planning perspective.

There is uncertainty in the peak flow discharge estimates included here. However, it can be concluded with some certainty that these values bracket the true range in peak flow discharges. Because the restoration design will consider the full range of flood flows instead of being keyed to a single flow, the estimates included here are adequate for advancing restoration planning at the site.

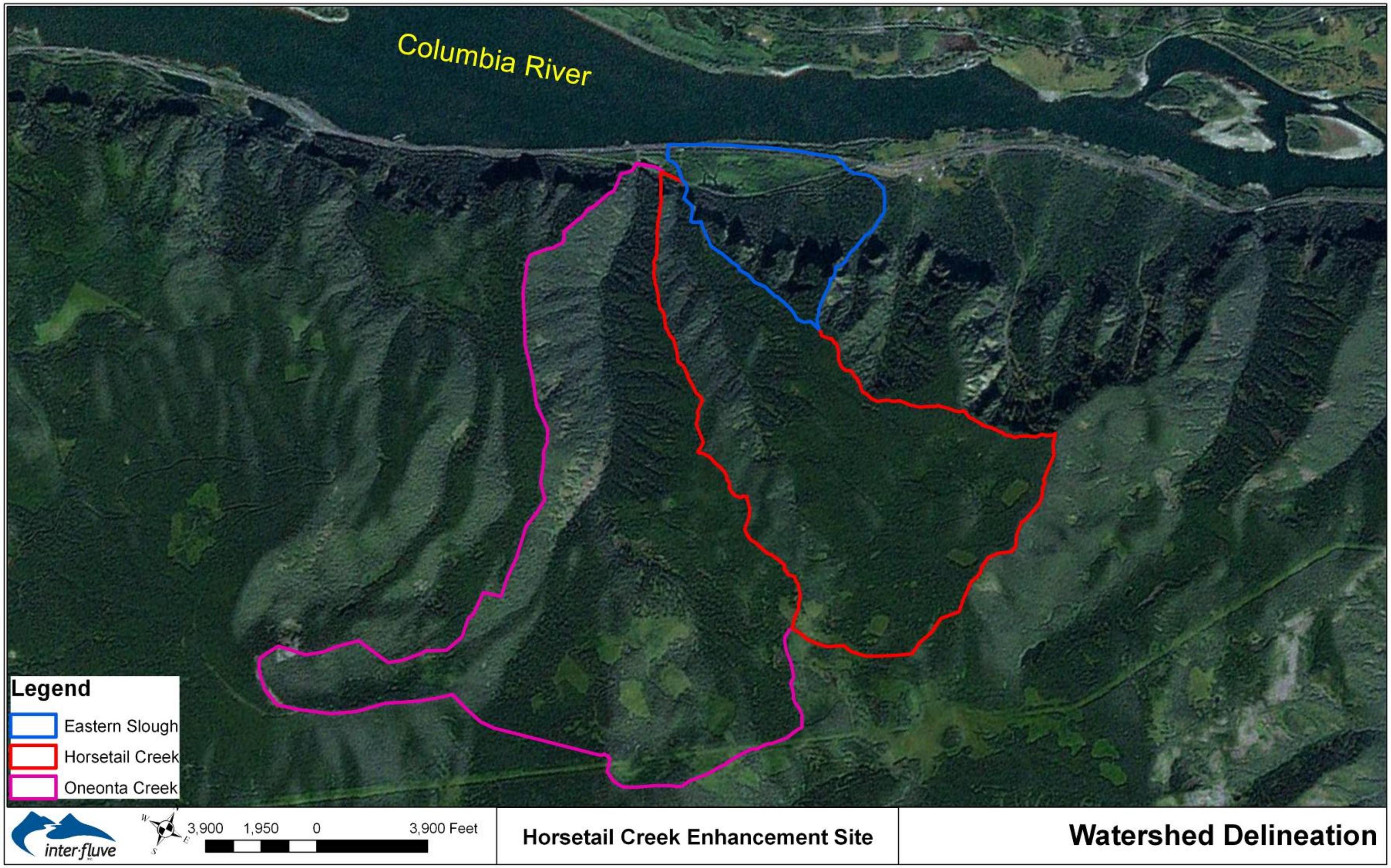


Figure 28. Sub-watershed delineation.

Table 5. Peak flow estimates for three sub-watersheds. Estimates are in units of cubic feet per second (cfs).

Flow Event	Horsetail Creek (at RR)			Eastern Slough (at Horsetail Creek)			Oneonta Creek (at RR)		
	USGS	OWRD	Avg	USGS	OWRD	Avg	USGS	OWRD	Avg
1-year	Extrapolated		263	Extrapolated		56	Extrapolated		399
2-year	337	376	356	83	76	79	477	604	541
5-year	483	515	499	120	105	112	691	833	762
10-year	584	610	597	147	125	136	836	987	911
25-year	721	730	725	184	150	167	1035	1181	1108
50-year	828	820	824	213	169	191	1190	1326	1258
100-year	936	909	922	242	188	215	1346	1470	1408

4.1.2 Low Flow Stream Discharge Monitoring

To inform the stream temperature assessment at the site (Section 0), streamflow was monitored on two occasions during the summer low flow period in 2010. Although it has a larger watershed than Horsetail Creek ($5.2mi^2$ vs. $3.7mi^2$), discharge in Oneonta Creek was lower than in Horsetail Creek (53% and 42% of that in Horsetail Creek during the July and September flow monitoring events, respectively; Table 6). A notable portion of Oneonta Creek's low flow (ranging from 20-85% based on the 2010 discharge measurements) is diverted into the gravel pond, which subsequently discharges to Horsetail Creek. The magnitude of this diversion is highly dependent on flow in Oneonta Creek and water surface elevation in the pond, which in 2010 was controlled in part by beaver activity in the outlet channel.

Table 6. Low Flow Discharge Measurements at Temperature Monitoring Stations (discussed further in Section 0).

Monitoring Station	July 17 Discharge (cfs)	September 15 Discharge (cfs)
Oneonta – RR	3.3	1.1
Oneonta Pond – Outlet	2.8	0.2-0.9[b]
Slough Outlet	0.2[b]	<0.1[b]
Horsetail – Pond Confluence	6.2	2.6
Horsetail – Oneonta Confluence	9.3	2.8

Notes: [a]Discharge measurements also were taken in Oneonta Creek below the pond diversion. These measurements (0.6cfs on 7/17/10 and 0.2cfs on 9/15/10) provided a reference to back-calculate the accuracy of other discharge measurements.
[b]Velocities at these locations were below detection limits, therefore discharge at these locations could not be measured in the field. Estimates are provided based on surrounding discharge measurements.

4.1.3 Fish Passage Evaluation Flows

Fish passage evaluation flows were developed for the existing culvert and bridge locations on Oneonta Creek. These locations include the I-84 culvert (Figure 29) and the series of three bridges extending from the railroad (Figure 30) to the historic highway (Figure 31-Figure 32). ODFW (2004) and NMFS (2008) upstream fish passage guidelines require high and low flow estimates for fish passage evaluation. For high flow, the flow that is exceeded 10% (Q10%) of the time during periods of fish use is recommended by ODFW, and the flow that is exceeded 5% of the time (Q5%) is recommended by NMFS. For low flow, the flow that is exceeded 95% of the time (Q95%) during periods of fish use is recommended by both sets of criteria. The ODFW criteria also include a convention to estimate the 10% excedence flow from the 2-year storm estimate.

Figure 29. Inlet to Oneonta Creek culvert at I-84.

Figure 30. Downstream view of UPRR bridge over Oneonta Creek.

Figure 31. Downstream view of Historic Highway bridge over Oneonta Creek.

Figure 32. Downstream view of Pedestrian Bridge (old historic highway bridge) over Oneonta Creek.

As discussed in Section 4.1.1, Horsetail and Oneonta Creeks are ungaged watersheds, and no applicable gaged watershed data is available for a gaging station transfer to estimate flow duration statistics for these creeks. Therefore, a regional regression technique developed by the U.S. Geological Survey (Risley et. al. 2008) was utilized to develop flow duration statistics for the fish passage evaluation. The site falls within Region 3 (northern Cascade region). The applicable equations for each month include combinations of the following watershed characteristics: drainage area, mean annual precipitation, maximum elevation, mean watershed slope, mean watershed elevation, minimum elevation, annual maximum and minimum air temperature, drainage density, January maximum and minimum air temperature, percent forest cover, and soil permeability. Values for each sub-watershed were determined using the Streamstats web-based watershed information query tool.

The flow duration estimates are shown in Figure 33 - Figure 34 for Oneonta Creek at the UPRR and I-84 crossings, respectively. Also shown are the estimates of Q10% developed using the ODFW convention, based on the 2-year return period flood.

The Q5% and Q10% estimates resulting from the USGS method for the months of Jan-Feb and Nov-Dec exceed the estimated 1-year return period flood discharge and are therefore considered to overestimate the flow statistics. To compensate, the high fish passage flow statistics were truncated at the 1-year return period flood discharge estimates for the two locations. The flow duration statistics utilized in the evaluation are summarized in Table 7 below.

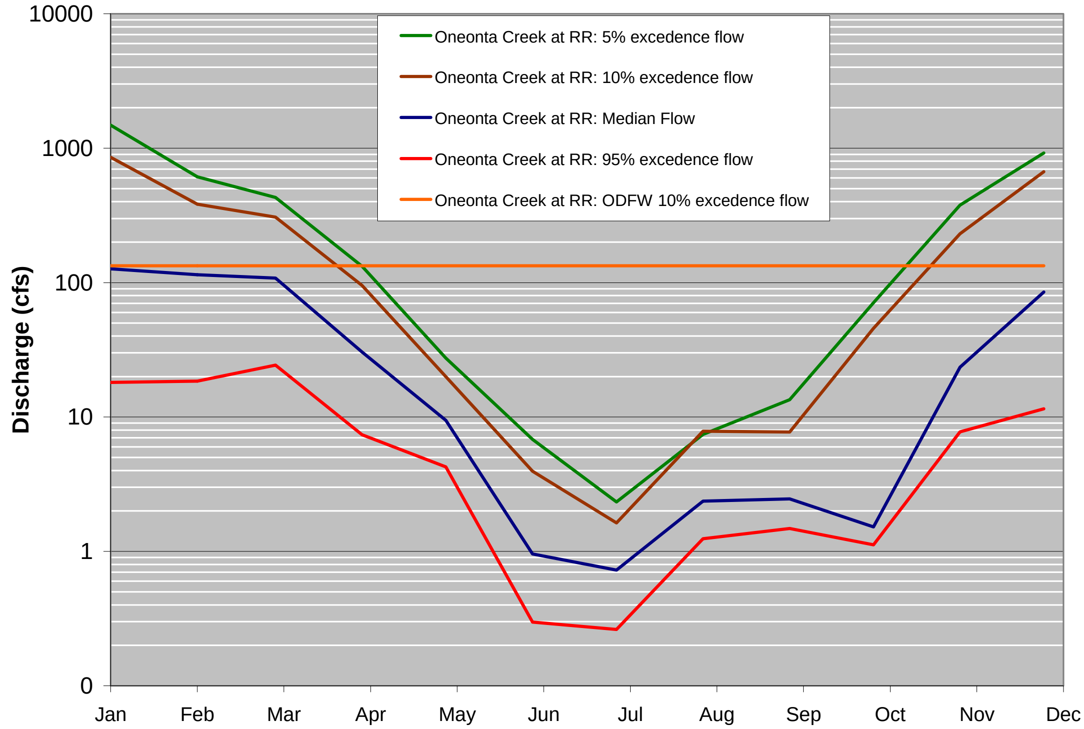


Figure 33. Fish passage flow duration statistics for Oneonta Creek at the UPRR bridge.

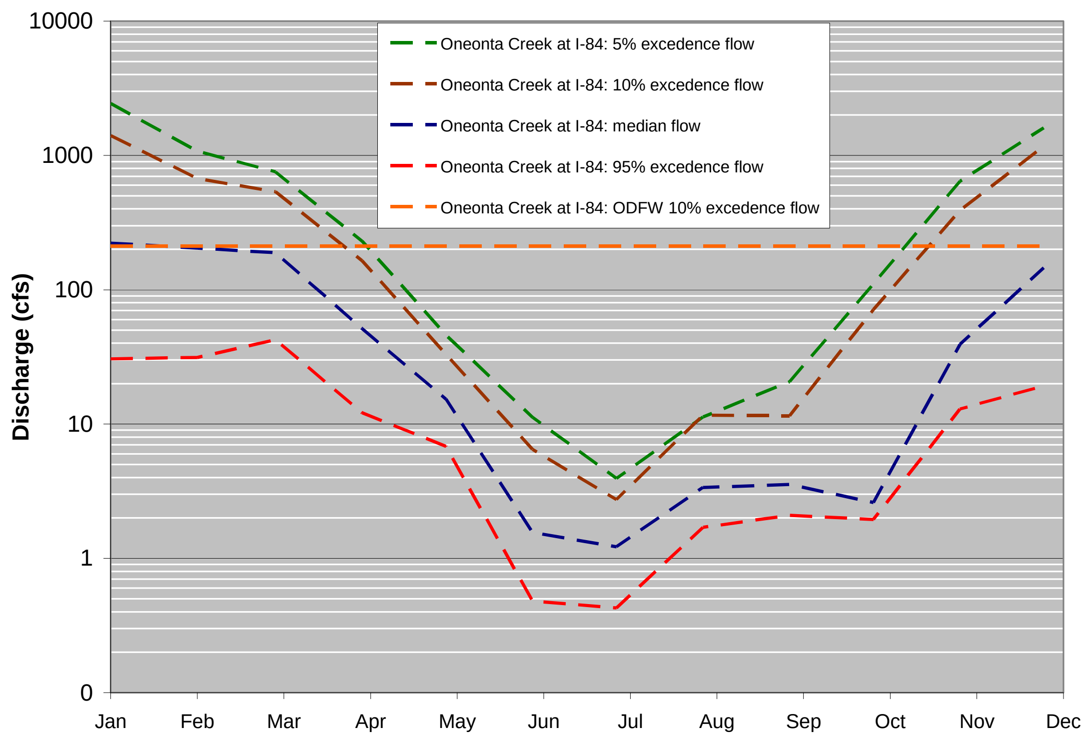


Figure 34. Fish passage flow duration statistics for Oneonta Creek at the I-84 crossing.

Table 7. Flow duration statistics used in fish passage evaluation.

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
	(cfs)	**(cfs)**	**(cfs)**	**(cfs)**	**(cfs)**	**(cfs)**	**(cfs)**	**(cfs)**	**(cfs)**	**(cfs)**	**(cfs)**	**(cfs)**
Oneonta Creek at Union Pacific Railroad												
High Fish Passage Flow	399	399	399	132	27	7	2	7	13	71	377	399
ODFW Equation High Flow Estimate	133	133	133	*	*	*	*	*	*	*	133	133
50% Excedence Flow	127	114	108	30	9	1	1	2	2	2	23	85
95% Excedence Flow	18	18	24	7	4	0.3	0.3	1	1	1	8	12
Oneonta Creek at Interstate 84												
High Fish Passage Flow	717	717	717	230	46	11	4	11	21	111	642	717
ODFW Equation High Flow Estimate	212	212	212	*	*	*	*	*	*	*	212	212
50% Excedence Flow	222	204	188	51	15	2	1	3	4	3	39	145
95% Excedence Flow	31	31	43	12	7	0	0	2	2	2	13	19

As discussed with the peak flow estimates in Section 4.1.1, the location of the study area is in a transitional climactic zone between western and eastern Oregon. Local topographic factors (i.e., location against the steep Columbia Gorge valley wall, near the axis of the Cascade Range) also lead to substantial variability in precipitation within these watersheds.

The regional regressions equations utilized to estimate fish passage flows were determined to represent the best presently available method for this application. However, due to the unique nature of the study area, uncertainty exists in using these equations for estimating flow duration characteristics. When considering all ten regions across the state, Risley et al. (2008) reported median standard errors of 42% and 64%, respectively, for the high flow (Q5%) and low flow (Q95%) estimates. They suggest accuracy tends to increase from southeastern to northwestern parts of the state, from low-flow to high-flow conditions, and from dry months to wet months.

The uncertainty in these estimates could be partially improved through collection of empirical data at the site. It would be difficult to collect sufficient data to better define the high flow estimates during the project planning horizon in order to be provide timely data. It is likely that the summer low flow estimates could be improved through additional streamflow monitoring in 2011.

While there is uncertainty in the flow duration estimates included here, it can be concluded with some certainty that the estimated values likely bracket the true range in values, and provide a reasonable range of variability in flow over which to assess fish passage characteristics. Given the fact that the Q5% and Q10% estimates for the months of Jan, Feb, Nov and Dec exceeded the 1-year return period flood discharge (and were thus truncated as described above), it is likely that the fish passage assessment will present a conservative assessment of high flow passage conditions at the site. The low flow estimates are within the same order of magnitude as were measured at the site in summer 2010 (Section 4.1.2) and likely represent reasonable estimates.

4.2 INTERACTION WITH COLUMBIA RIVER HYDROLOGY

4.2.1 Tide Characteristics Local to the Site

The Columbia River experiences tidal variation from the mouth of the river to Bonneville Dam. At upstream locations such as near the Horsetail Creek, the tidal signal can be obscured by manipulation of the outflow from Bonneville Dam in particular. The NOAA tide observation station nearest to the site is located approximately 33 miles downstream of the site at Vancouver, Washington (NOAA station 9440083). The mean[1] and great diurnal[2] tide ranges at the Vancouver station are estimated to be 2.4 and 3.3 feet, respectively (NOAA 2011). Parametrix (2006) report a tide range (criteria unspecified) of 1 foot at Bonneville Dam, located 8 miles upstream of the Horsetail Creek site. Assuming a simple linear interpolation between these two points, the tide range local to the site is estimated at approximately 1.5 feet. This compares to daily stage fluctuations downstream of Bonneville averaging 2 feet over the study period (04/01/10-09/29/10), with fluctuation as great as 5 feet in stage.

4.2.2 Stage Characteristics

Five Hobo U20 stage recorders were deployed at the site over the period April-September 2010 to assess the hydrologic connectivity of the Horsetail Creek site with the mainstem Columbia River. The stage recorder locations are shown in Figure 17 and are summarized in Table 8. The logger deployed at the confluence of Oneonta Creek and the Columbia River (outboard of the Interstate 84 road prism) was used to develop a correlation between mainstem river stage at the site with the long-term USGS gage station 14128870 Columbia River below Bonneville Dam. The other loggers were deployed to assess correlation of water levels across the site, and with the Columbia River.

Figure 35 summarizes the water level data collected April-September 2010, in combination with stage data from Bonneville Dam gage over the same period. The Oneonta Creek culvert outlet data show close correlation with the Bonneville Dam gage over the period of observations when Columbia River stage exceeds 13 feet NAVD 88 (Figure 36). At river stages below this elevation, there is a short reach of free flowing creek between the outlet and the edge of the Columbia River. Because the monitoring well had to be mounted to the culvert outlet wingwall, the actual stage measurement at the location shifts from Columbia River stage to Oneonta Creek stage below 13 feet. This empirical correlation is simplistic in that it does not explicitly separate tidal effects from hydropower ramping patterns in a multivariate correlation. However, this correlation is adequate for the present use to establish a clear relationship between stage below Bonneville Dam and stage at the outlet to Oneonta Creek. The estimated tidal range at the site is approximately 1.5 feet and hydropower ramping fluctuations appear to range from 0 to 5 feet below Bonneville Dam over the 2010 observation period. Hydropower ramping fluctuations may either dampen or accentuate the effects of tide, depending on whether their respective patterns are in phase.

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[1] Mean high water minus mean low water.

[2] Mean higher high water – mean lower low water

Table 8. Stage recorder locations, loggers ID numbers, and sample dates for Hobo U20 data loggers.

Stage Recorder Station	Location	Logger ID	Date Deployed	Date Retrieved
Oneonta-Columbia Confluence[1]	Wingwall at outlet of Oneonta Creek culvert at I-84	874173	04/14/10	09/29/10*
Lower Horsetail	Midpoint of Horsetail Creek highway reach	874180	03/24/10	09/29/10
Beaver Pond	Immediately upstream of beaver dam in Eastern Slough adjacent to junction with historic slough outlet channel	874179	03/24/10	09/29/10
Lower Slough	Approximate 1500 feet US of confluence with Horsetail Creek	876184	04/14/10	09/29/10**
Upper Slough	Approximate 2800 feet US of confluence with Horsetail Creek	876266	04/14/10	09/29/10**
Atmospheric	For barometric pressure compensation, deployed in Lower Slough well 04/14-08/06, upland location thereafter	874177	04/14/10	09/29/10***
Atmospheric	For barometric pressure compensation, upland location	N/A	06/22/10	07/07/10***

[1]Due to site characteristics, at water level less than 13 feet NAVD88 logger measures water surface elevation of free-flowing Horsetail Creek. At water level greater than 13 feet NAVD88, logger measures Columbia River stage at culvert outlet.

*Data over period 08/17/10-09/29/10 suspect with logger intermittently out of water

**Data over period 08/26/10-09/29/10 suspect with logger intermittently out of water

***First barometric compensation logger under water 06/04/10-07/01/10. Second barometric compensation logger deployed 06/22/10-07/07/10. Barometric pressures 06/04/10-06/22/10 estimated from comparison of records and from data at Cascade Locks.

During periods of higher stage on the Columbia River, backwater enters the site through the Oneonta Creek culvert. As the stage of the river local to the site rose above the elevation of the riffle at the downstream end of Horsetail Creek, the Lower Horsetail Creek logger also shows close correlation with the Bonneville Dam gage (late May). During the period of highest stage in the Columbia, much of the site was backwatered by the mainstem river. All of the loggers on the site show close correlation with the Bonneville Dam gage for the period of June through early July. Finally, during periods when the site is not backwatered by the Columbia there is little correlation in stage between the Columbia and the loggers on the site, and the loggers in the eastern portion of the site (Beaver Pond, Lower Slough and Upper Slough) maintain a similar, stable water level largely controlled by a beaver dam located downstream of the Beaver Pond logger.

Interestingly, it would appear that the beaver dam was altered during the recession of the Columbia River backwater as the stage at the three upstream locations was approximately 1.2 feet lower immediately after the period of backwater (07/05) then it had been immediately before (06/02). It would appear that subsequent beaver activity or accumulation of woody debris at the location during recession of the backwater resulted in a shift towards re-establishing the earlier condition (07/05-07/27). However, it appears that either the new beaver activity or the accumulated debris subsequently cleared over the period 07/27-08/26 as the water levels measured at the three upper loggers reverted to a condition similar to that present immediately following the backwater recession.

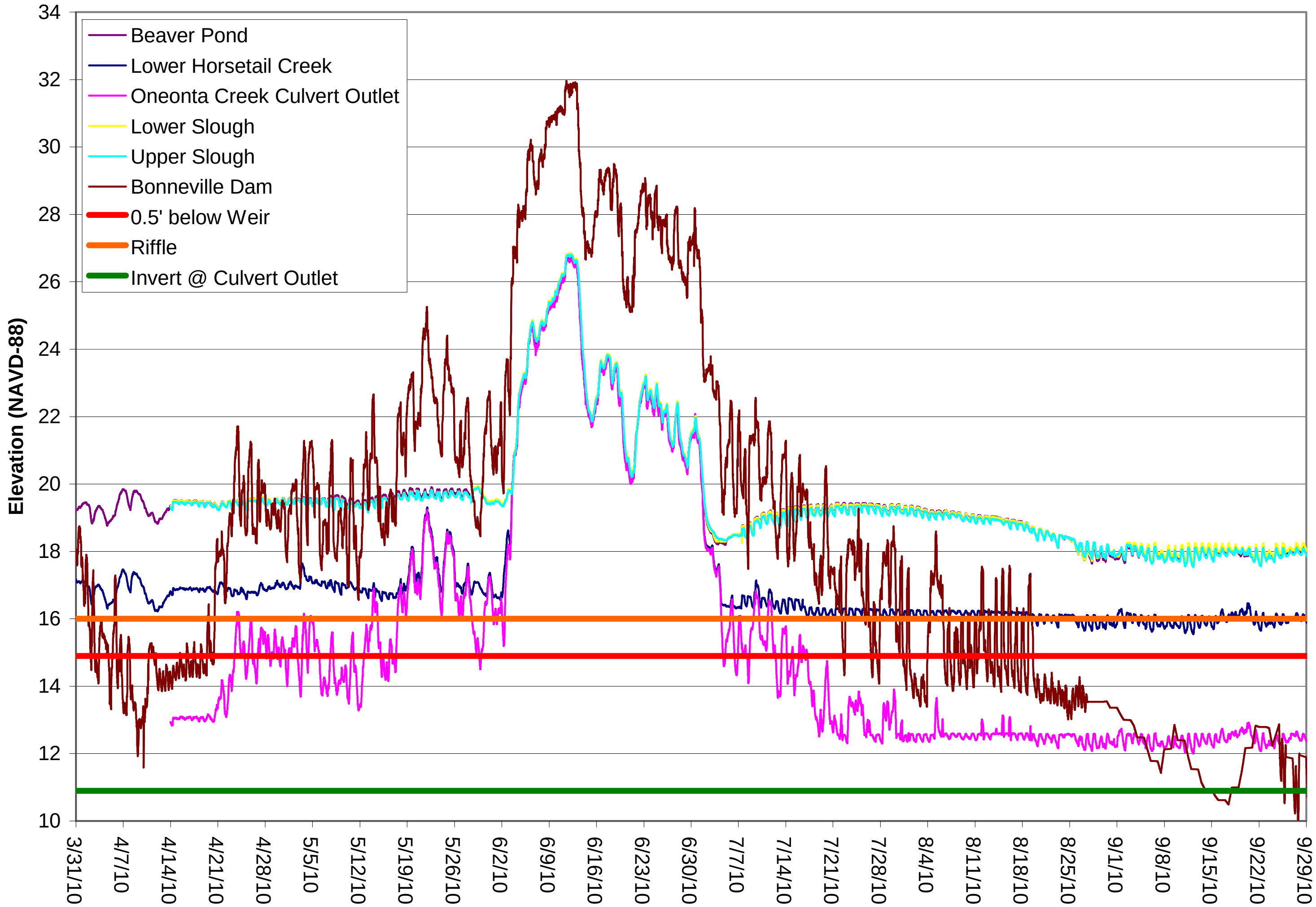


Figure 35. Measured stage at Horsetail Creek site with locally deployed pressure transducers 04/01/10 to 09/29/10. Bonneville Dam data from USGS gage 14128870 Columbia River below Bonneville Dam. See footnotes to Table 8 for additional explanations of data. Red horizontal line labeled 0.5' below weir corresponds to the water surface elevation for which the hydraulic drop over the concrete weir upstream of the Oneonta Creek culvert would match fish passage criteria for juvenile salmonids. Orange horizontal line corresponds to the elevation of the crest of the first riffle in Horsetail Creek upstream of the Oneonta Creek culvert. Green horizontal line corresponds to invert elevation at outlet of Oneonta Creek culvert.

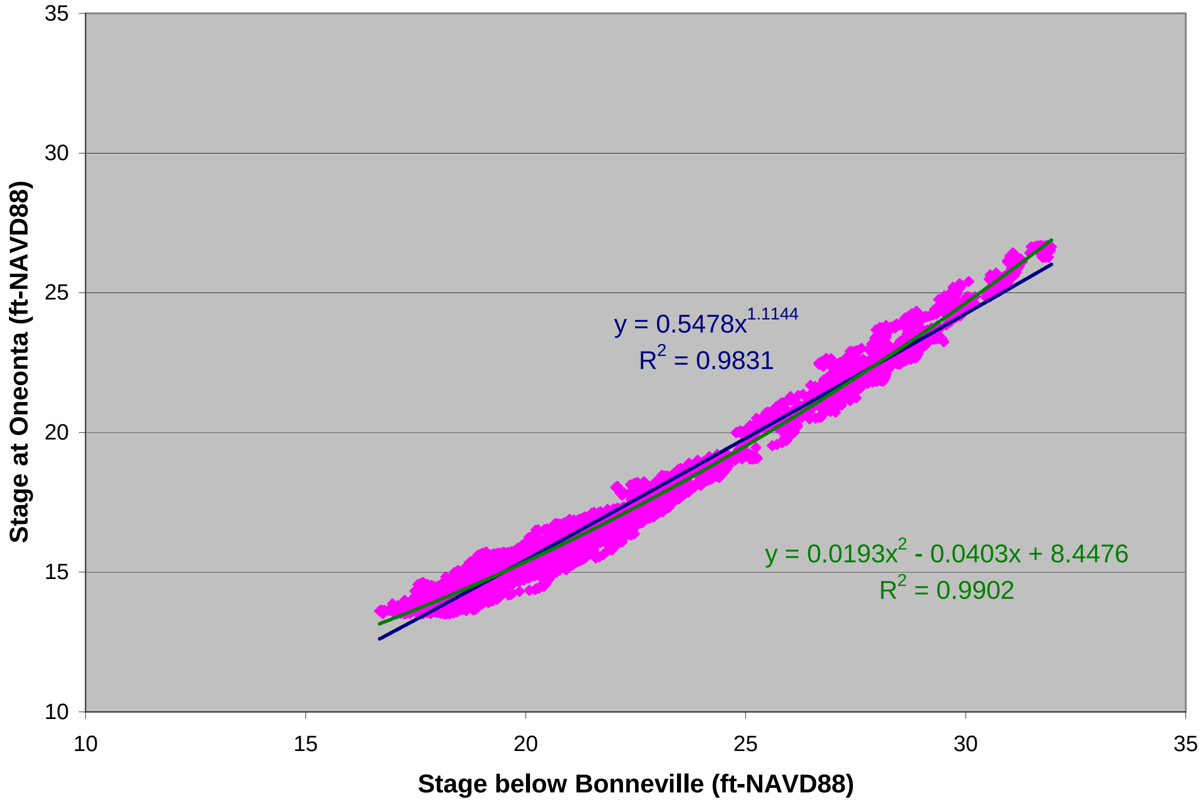


Figure 36. Correlation between river stage at the outlet of Oneonta Creek and below Bonneville Dam, using 15 min data over the period 04/01/10 – 09/29/10, assuming a 2-hour lag between the two locations. Data was constrained to period when stage observations at Oneonta Creek outlet were greater that 13.5 ft NAVD88. Two alternate regressions of the data are shown.

The Oneonta Creek confluence data was subsequently correlated with the Bonneville Dam data for mean daily values over the period April – August, 2010 to extrapolate local stage characteristics beyond the range in stage observed in 2010 (Figure 37). This empirical correlation is simplistic in that it does not explicitly separate tidal effects from hydropower ramping patterns in a multivariate correlation; since it utilizes mean daily data more explicit correlation of shorter period effects is not practical. However, this correlation is adequate for the present use to understand general trends in stage at the site in order to characterize observations made in 2010 within the range of variability in river stage that can be expected through time. As discussed above, the estimated tidal range at the site is approximately 1.5 feet and hydropower ramping fluctuations appear to range from 0 to 5 feet below Bonneville Dam over the 2010 observation period. Hydropower ramping fluctuations may either dampen or accentuate the effects of tide, depending on whether their respective patterns are in phase.

Based on this correlation, Figure 38 includes a time series of the estimated mean daily river stage which reflects the range of variability in stage for the Columbia River at Oneonta Creek Outlet over the period 1980-2010. Figure 39 includes the average daily mean stage for the Columbia River at Oneonta Creek over the same period. Figure 40 reflects mean daily stage duration curves for the Columbia River at Oneonta Creek over the period 1981-2010.

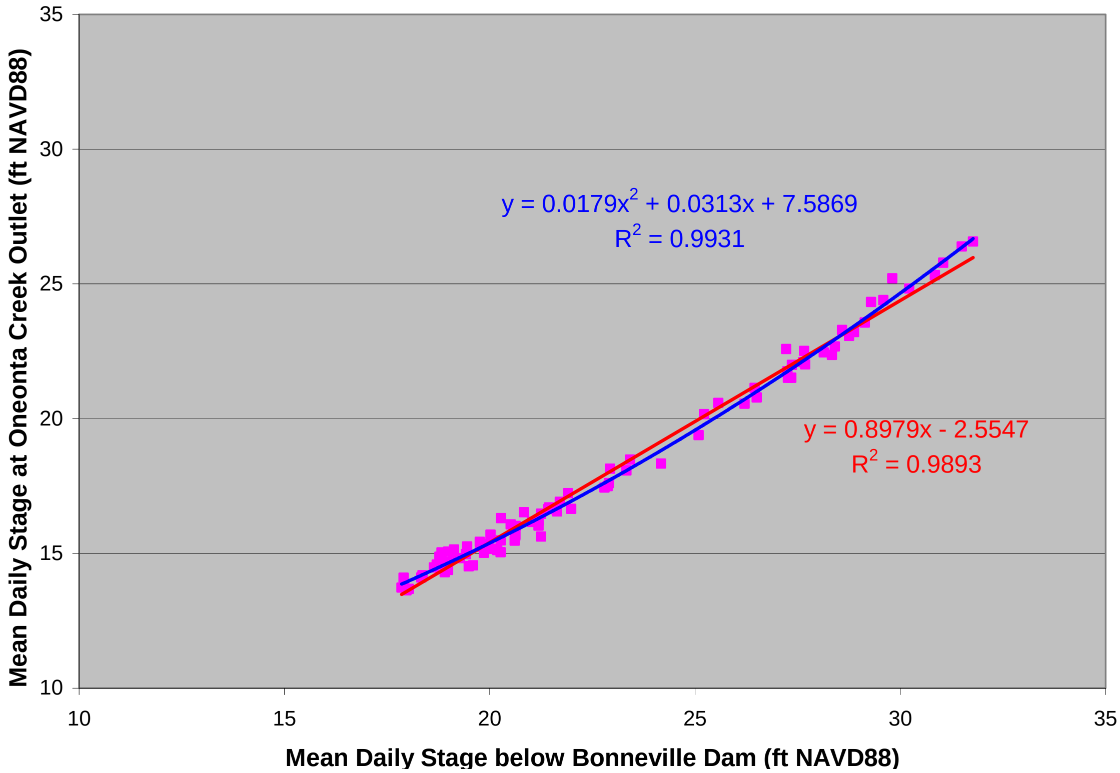


Figure 37. Correlation between daily mean river stage at the outlet of Oneonta Creek and below Bonneville Dam, over the period 04/01/10 – 09/29/10. Data was constrained to period when stage observations at Oneonta Creek outlet were greater that 13.5 ft NAVD88. Two alternate regressions of the data are shown.

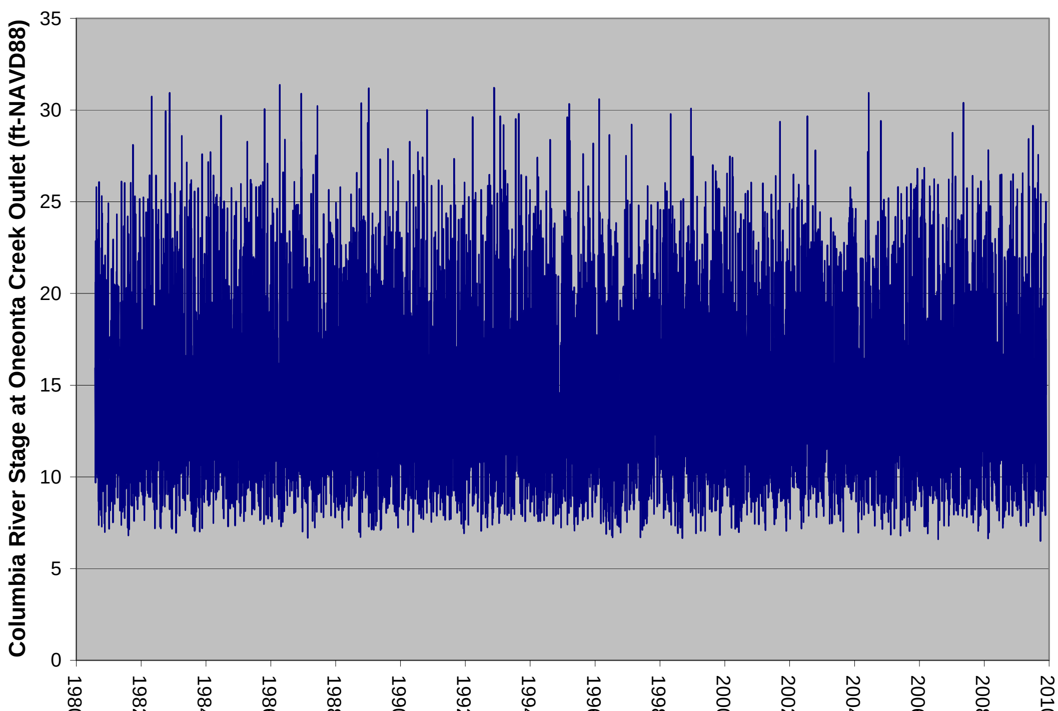


Figure 38. Time series of estimated Columbia River daily mean stage at outlet of Oneonta Creek, over the period 1980 – 2010.

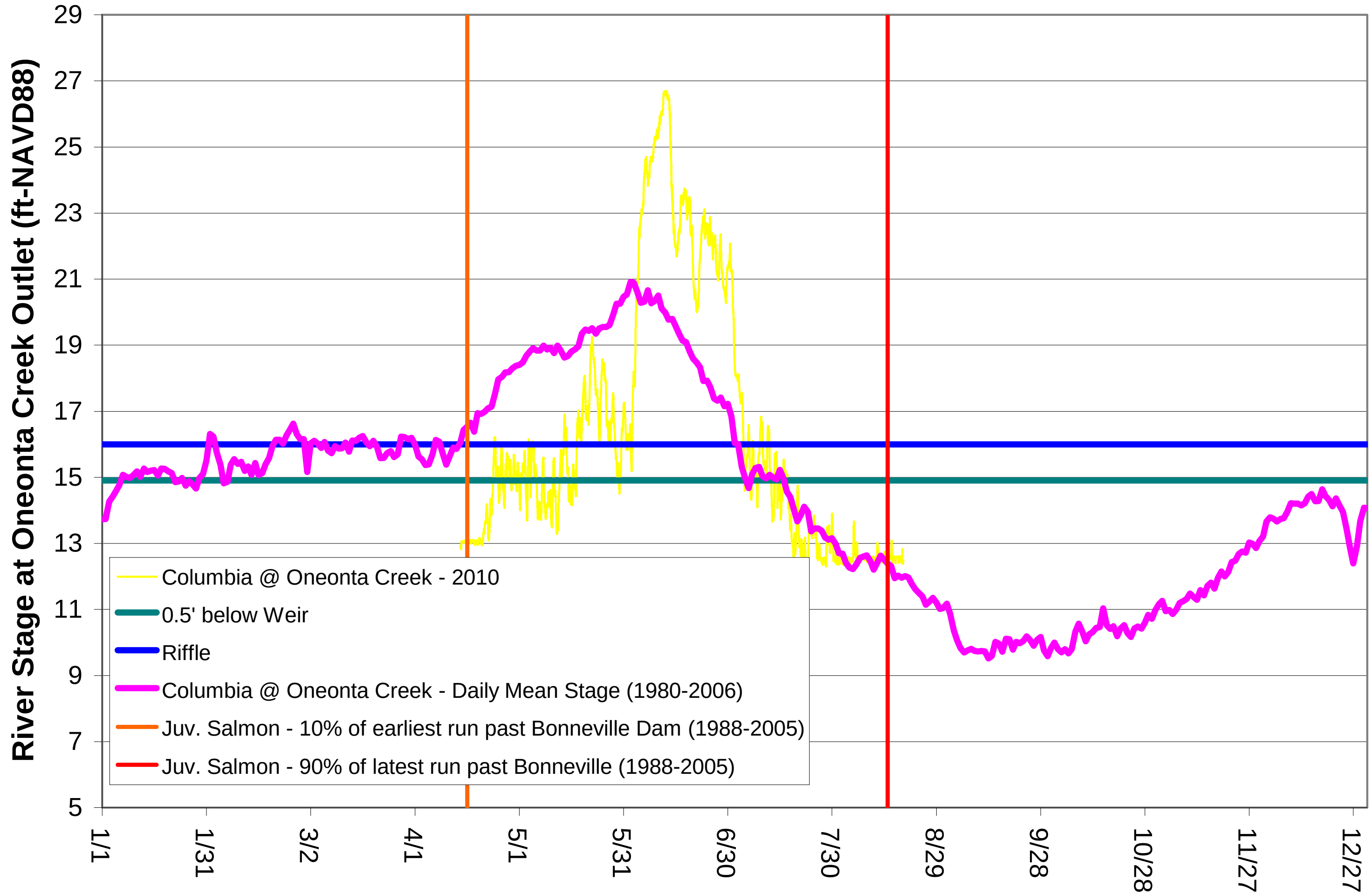


Figure 39. Plot of estimated mean daily river stage at the outlet to Oneonta Creek, averaged over the period 1980-2010. Green horizontal line labeled 0.5' below weir corresponds to the water surface elevation for which the hydraulic drop over the concrete weir upstream of the Oneonta Creek culvert would match fish passage criteria for juvenile salmonids. Blue horizontal line corresponds to the elevation of the crest of the first riffle in Horsetail Creek upstream of the Oneonta Creek culvert. Vertical lines correspond to period of juvenile salmonid outmigration discussed in Section 3.

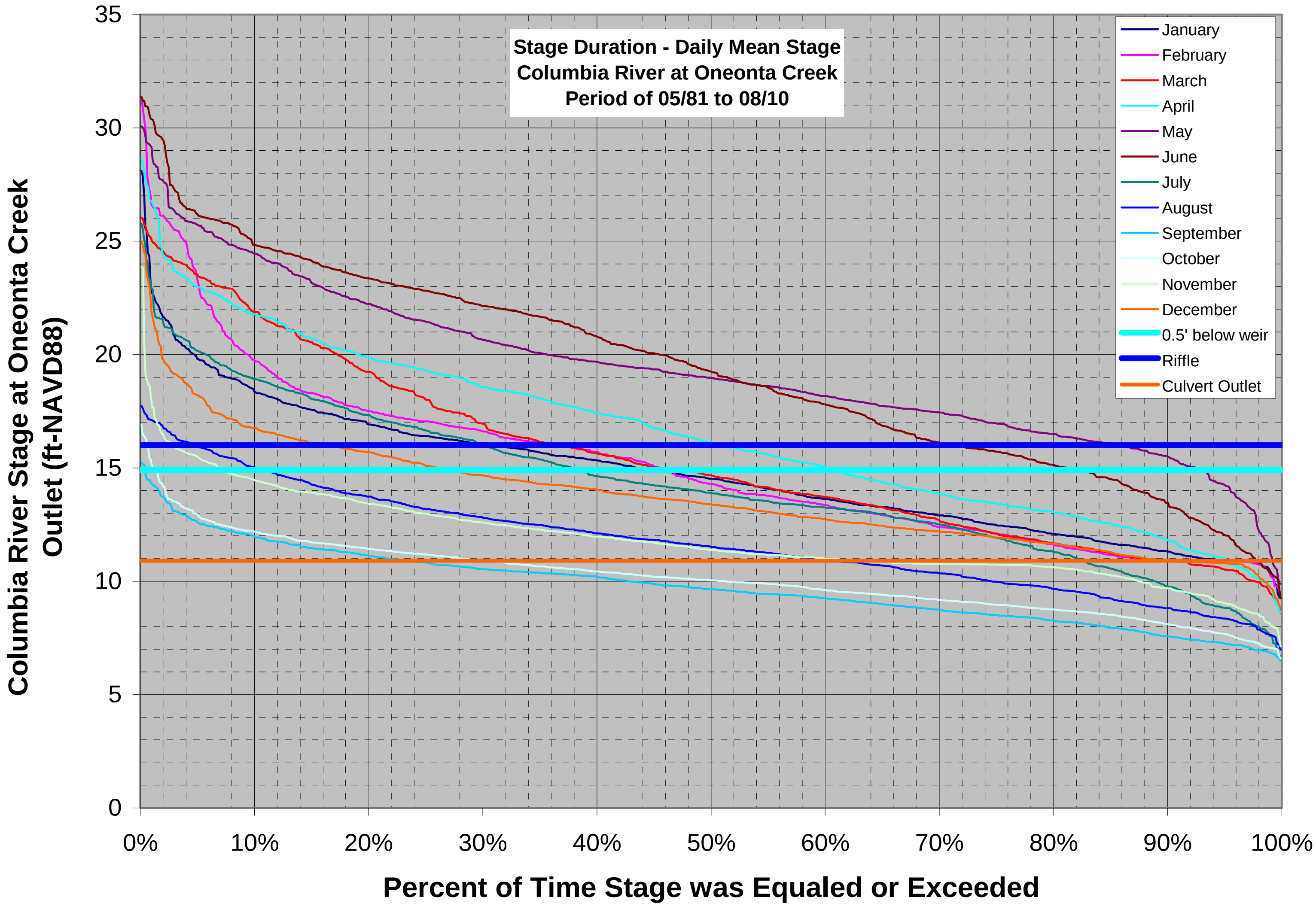


Figure 40. Mean daily stage duration curves for Columbia River at outlet of Oneonta Creek, estimated over the e period 1981-2010. Cyan horizontal line labeled 0.5' below weir corresponds to the water surface elevation for which the hydraulic drop over the concrete weir upstream of the Oneonta Creek culvert would match fish passage criteria for juvenile salmonids. Blue horizontal line corresponds to the elevation of the crest of the first riffle in Horsetail Creek upstream of the Oneonta Creek culvert. Orange horizontal line corresponds to invert elevation at outlet of Oneonta Creek culvert.

4.2.3 Site Inundation Patterns

Patterns of inundation across the site resulting from Columbia River backwater where assessed in terms of peak and maximum 7-day patterns.

4.2.3.1 Peak Inundation Patterns

Two peak stage levels were mapped in this analysis. These included the average of annual peak stage level over the period 1981-2010 of 23.5 ft NAVD 88, and the annual peak stage that is estimated to occur on average in 1 of every 2 years (i.e. the 2-year return period peak stage) of 24.5 ft NAVD 88. The inundation patterns are shown in Figure 41 and summarized in Table 9.

4.2.3.2 Maximum 7-day Inundation Patterns

Two stage levels were considered in this analysis. These included the average of the annual maximum 7-day continuous stage over the period 1981-2010 of 21.8 ft NAVD 88, and the annual maximum 7-day continuous stage that is estimated to occur on average in 1 of every 2 years (i.e. the 2-year return period) of 22.6 ft NAVD 88. Figure 42 shows the extent of the inundated area with minimum depth of 20 cm at these stage levels. These duration and depth criteria are based on criteria discussed in Bottom et al (2005). They suggest that 10 cm is the minimum depth for salmon fry and fingerlings in estuarine habitats. The minimum depth criteria was doubled to provide a conservative assessment of the acreage of juvenile salmon habitat provided by the site during the freshet.

The inundation patterns with minimum depth of 20 cm are shown in Figure 42 and summarized in Table 9.

Table 9. Summary of Inundation Analysis

Stage Level	Elevation (ft-NAVD88)	Area (acres)
Peak Inundation		
Average of annual peak stage 1981-2010	23.5	96.3
2-year return period peak	24.5	116.4
Maximum 7-day Continuous Stage with minimum depth of 20 cm		
Average of annual max. 7-day continuous stage 1981-2010	21.8	52.5
2-year return period max. 7-day continuous stage	22.6	56.4

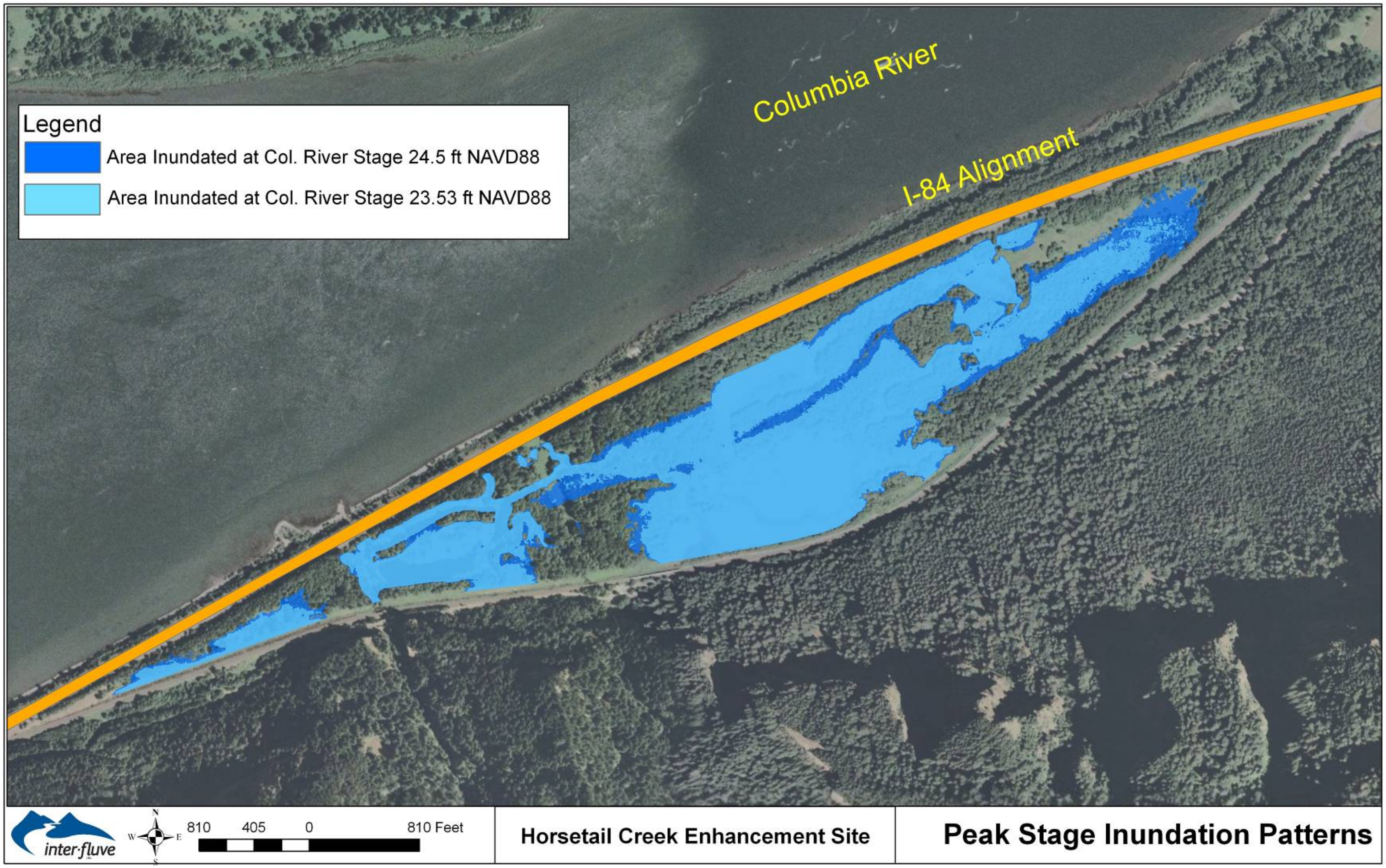


Figure 41. Inundation extents for the average of the annual peak stage over the period 1981-2010 (elevation 23.5) and the 2-year return period peak stage, based on data over the period 1981-2010 (elevation 24.5).

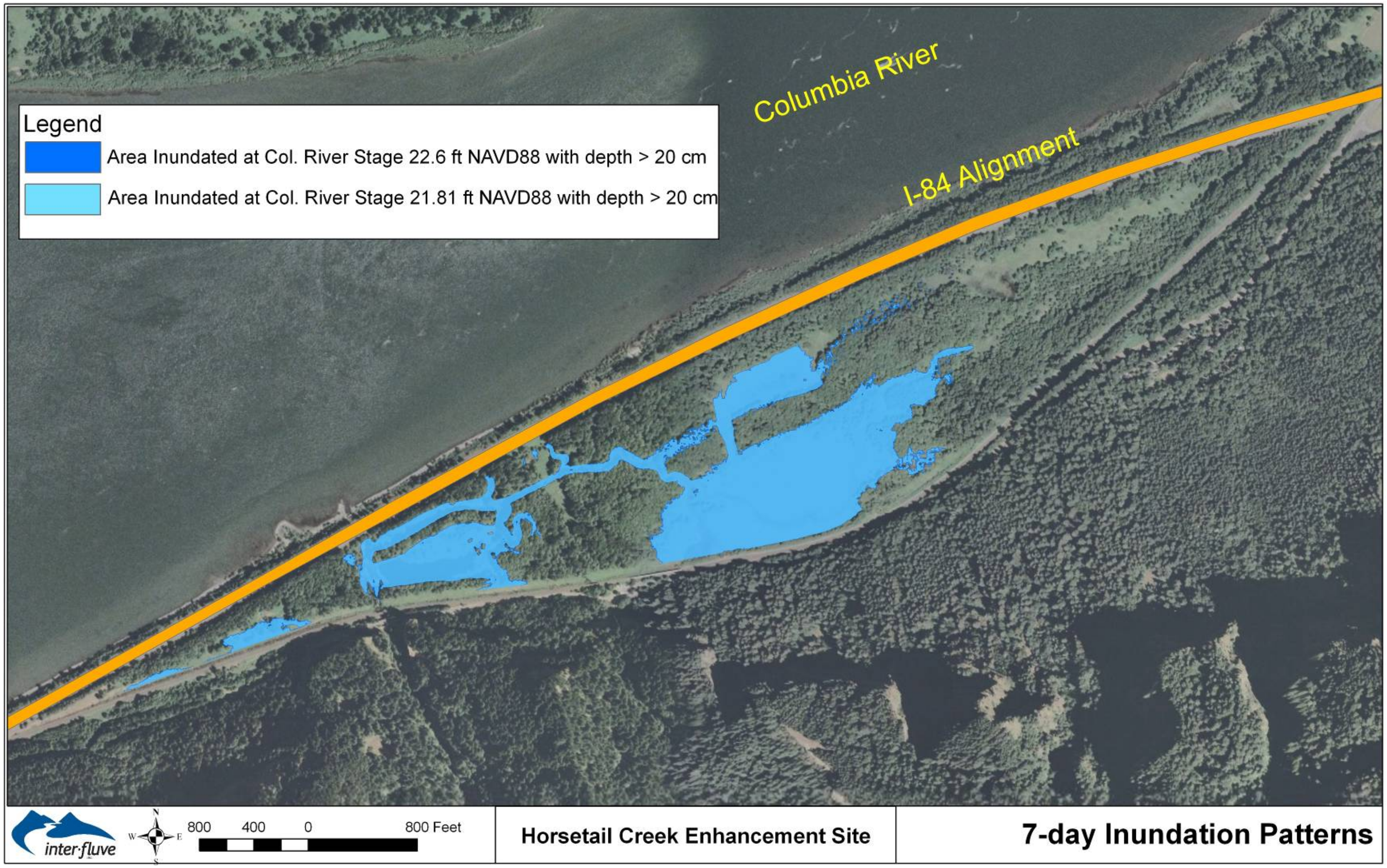


Figure 42. Inundation extents for areas with minimum 20 cm depth for the average of the annual maximum 7-day continuous stage over the period 1981-2010 (elevation 21.8) and the 2-year return period annual maximum 7-day continuous stage (elevation 22.6).

5 SITE TEMPERATURE CHARACTERISTICS

As detailed in Section 3, the Horsetail Creek site is known to support cold-water species, including three species of salmonids protected by the Endangered Species Act. Because these species require specific thermal regimes and because conditions at the site have been altered (as described in Section 2 of this report), the project team identified surface water temperatures as a potential limiting factor. The project team monitored temperatures during spring and summer 2010. Resulting data are used to assess the site's thermal profile, discrete thermal inputs, and the suitability of specific reaches of the site for species of interest. The specific goals of the temperature assessment are to provide data to:

- Quantify the baseline thermal regime of Horsetail Creek, Oneonta Creek, and the adjacent network of sloughs;
- Classify portions of the site that currently are/are not suitable for juvenile salmonids during critical rearing periods;
- Classify portions of the site that currently are/are not suitable for non-native predators; and,
- Help guide long-term management of the site and broad-scale planning of restoration/enhancement activities.

5.1 Methods

5.1.1 Study Timing

Summer low flow temperature data typically are collected beginning in June and extending through August. For this project, data were collected from May 28, 2010 through September 29, 2010. This period of the year typically experiences the lowest precipitation and highest temperatures and therefore would be expected to have the highest stream temperatures.

5.1.2 Study Layout and Implementation

The project team selected nine locations within the Horsetail Creek project site to monitor surface water temperature. The network of monitoring locations was chosen to provide a comprehensive assessment of the site's thermal profile, including the effect of different channel types, tributaries, and riparian conditions. Table 10 outlines the locations of the nine monitoring stations, along with their location titles and probe identification numbers. Figure 43 provides an aerial photograph with probe locations.

At seven of the nine monitoring locations, the project team deployed Hobo U20 temperature probes, which were set to record temperatures at 1/2-hour intervals. At the remaining two monitoring locations (Upper Slough and Middle Slough), the project team collected data from the Hobo water level loggers used in the site's hydraulic and hydrologic analysis (Section 4.2).

Table 10. Monitoring Station Titles, Locations, Probe ID Numbers, and Sample Dates

Monitoring Station	Location	Probe ID	Date Deployed	Date Retrieved
Oneonta Creek				
Oneonta – RR	Oneonta Creek – between railroad bridge and pond inlet	9724269	5/28/10	9/29/10
Oneonta Pond – Outlet	Pond Outlet Channel – immediately upstream of confluence with Horsetail Creek	9724270	5/28/10	9/29/10
Horsetail Creek				
Horsetail – RR	Horsetail Creek – 50 yards downstream of the railroad bridge	9724271	5/28/10	9/29/10
Horsetail – Pond Confluence	Horsetail Creek – immediately upstream of the confluence with the pond outlet	9724272	5/28/10	9/29/10
Horsetail – Slough Confluence	Horsetail Creek – immediately upstream of confluence with the Eastern Slough	9724273	5/28/10	9/29/10
Horsetail – Oneonta Confluence	Horsetail Creek – 30 yards upstream of confluence with Oneonta Creek	9724274	5/28/10	9/29/10
Eastern Slough				
Upper Slough	In the slough approximately 3000 feet upstream of confluence with Horsetail Creek	876266	4/13/10	9/29/10
Mid-Slough	In the slough approximately 1200 feet upstream of confluence with Horsetail Creek	874179	4/13/10	9/29/10
Slough Outlet	In the slough upstream of the confluence with the Horsetail	9724268	5/28/10	9/29/10

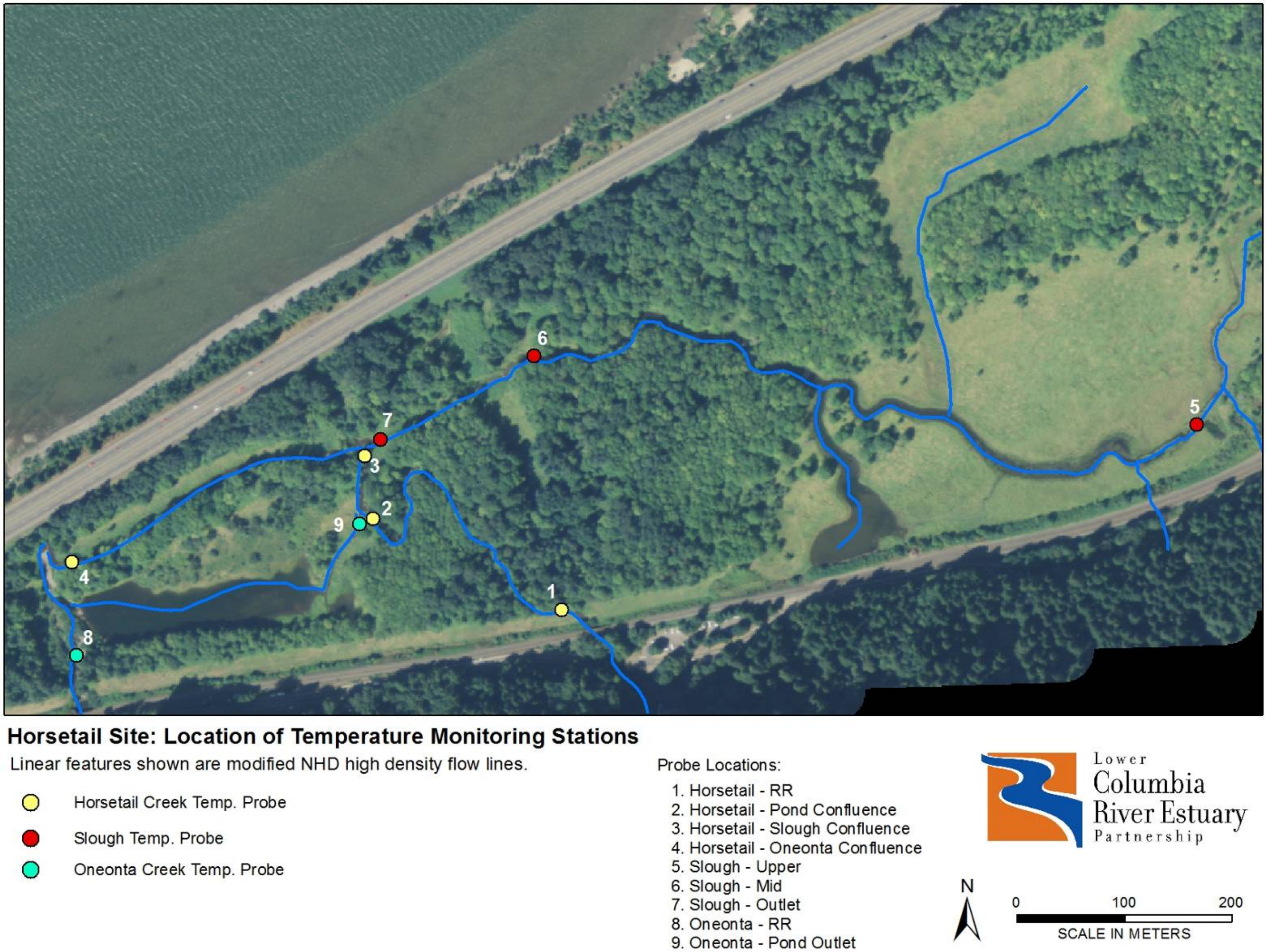


Figure 43. Location of temperature monitoring stations.

5.1.3 Data Analysis Criteria

As detailed in Sections 2 and 4 of this report, the Horsetail Creek site is located within the Columbia River floodplain and functions as a backwater area for the Columbia River during periods when Columbia River stage is high. As shown in Figure 39, the site is backwatered by the Columbia intermittently during winter storms, and typically for extended periods during spring runoff. This backwater, which typically does not recede until early to mid-July, significantly affects the site's hydrology and therefore also affects its thermal regime. As detailed in Section 3, the site likely is used as off-channel habitat by both LCR and up-river ESUs during this backwater period. Because the site's thermal regime and biological communities likely vary significantly during periods when Columbia River backwater inundates portions of the site, data for this report were separated into two monitoring periods:

1. Backwater: The backwater monitoring period refers to the date range when Columbia River stage is high enough to inundate the site. This includes periods when the extent of backwater at the site (its footprint) fluctuates and/or the presence of backwater is intermittent (even if intermittent on a daily basis).
2. Low-flow: The low-flow monitoring period refers to the date range when Columbia River stage is consistently below an elevation that would backwater the site. Flows within Oneonta and Horsetail Creeks typically are also at their lowest during this period.

Based on stage monitoring detailed in Section 4.2, Columbia River backwater affected the site to some degree from the beginning of the temperature monitoring period (June 1, 2010) through July 11, 2010 (Figure 39). Using this critical date, we subdivided our temperature monitoring efforts into two periods: a backwater period of June 1 – July 11 and a low-flow period beginning July 12.

Due to the failure of a beaver dam that was controlling water elevations in the eastern slough, the two easternmost probes went dry on August 26, 2010. Additionally, due to tampering with one of the monitoring stations, approximately one week of data were lost (July 7 through July 16). Using these two critical date ranges, we further refined our analysis into the following two periods:

- Backwater Period: June 1 – July 6
- Low-Flow Period: July 17 – August 25

5.1.4 Analysis Criteria Related to Juvenile Salmonids

As shown in Table 2, rearing is the only salmonid life history stage that occurs on-site during late spring and summer months when temperatures potentially are limiting. Consequently, this analysis focuses on water temperatures in relation to criteria for juvenile rearing only. When analyzing temperature data, the following thresholds were culled from the literature and used to interpret results as they relate to juvenile salmonids:

- Bjornn and Reiser (1991) report 10-13°C as the preferred temperature range for juvenile steelhead rearing, and 12–14°C as the preferred range for juvenile Chinook and coho salmon rearing. The present analysis uses 14°C as its threshold value since coho salmon are the primary LCR ESU known to rear on-site and Chinook salmon are the primary species targeted by the FCRPS BiOp for off-channel habitat mitigation.

- ODEQ reports 18°C in their 2003 Temperature Criteria as the maximum temperature for salmon and trout rearing and migration.
- Bjornn and Reiser (1991) report that most juvenile salmonids are at risk of mortality when temperatures exceed 23-25°C. This analysis uses the lower portion of that range (23°C) as a lethal threshold.

Table 11 below outlines the habitat classification categories that were developed based on these thresholds. These classifications account only for temperature as an indicator of habitat quality; other physical, chemical, and biological indicators are not considered in this analysis.

Table 11. Temperature-Based Habitat Classification for Juvenile Salmonids

Classification	Definition
Ideal Rearing Habitat	Stream reaches where average maximum daily temperatures are between 10°C and 14°C.
Functional Rearing Habitat	Stream reaches where average maximum daily temperatures are between 14°C and 18°C.
Poor Rearing Habitat	Stream reaches where average maximum daily temperatures are between 18°C and 23°C.
Unusable (Lethal) Rearing Habitat	Stream reaches where average maximum daily temperatures exceed 23°C.

5.1.5 Analysis Criteria Related to Non-native Predators

Based on an analysis of available habitat, water temperature data, fish sampling data from similar sites in the Columbia Gorge, field observations, and scientific literature, smallmouth bass are the non-native, piscivorous species most likely to inhabit the site and pose a threat to juvenile salmonids. This conclusion was drawn for the following reasons:

- Smallmouth bass are the non-native piscivorous species present in similar sites in the Columbia River Gorge that are most tolerant of cool-water temperatures;
- Largemouth bass have been observed in the gravel pond, and it is presumed that if suitable habitat exists for largemouth bass, smallmouth bass likely are present also; and,
- A recent report cites smallmouth bass as one of three major non-native predators of juvenile salmon (ISAB 2008); the two other species (walleye [*Sander vitreus*] and channel catfish [*Ictalurus punctatus*]) have been observed at much lower densities than smallmouth bass at similar sites in the Columbia River Gorge.

Moyle (2002) reports that smallmouth bass, “rarely establish where water temperatures do not exceed 19°C in summer for extended periods.” Moyle (2002) also reports that in California, smallmouth bass populations typically occur in areas where summer water temperatures are 21–22°C while a temperature range of 27–31°C is selected in a laboratory setting. Based on this research, we developed the habitat classification zones for smallmouth bass outlined in Table 12 below. As with the juvenile salmonid habitat classification, this system accounts only for temperature as an indicator of habitat quality; other factors are not considered.

Table 12. Temperature-Based Habitat Classification for Smallmouth Bass.

Classification	Definition
Poor Smallmouth Habitat	Stream reaches where average maximum daily temperatures do not exceed 19°C.
Functional Smallmouth Habitat	Stream reaches where average maximum daily temperatures are between 19°C and 21°C.
Ideal Smallmouth Habitat	Stream reaches where average maximum daily temperatures are between 21°C and 31°C.

5.2 RESULTS AND DISCUSSION

5.2.1 Backwater period

Table 13 and Figure 44 summarize the temperature monitoring results for the backwater period. Figure 46 to Figure 48 provide thermal profiles for each monitoring station.

Table 13. Summary of 2010 Temperature Monitoring Data for the backwater period (June 1 – July 6).

Station	Average Daily Low Temp.	Average Daily High Temp.	Average Diurnal Fluctuation	Average Hours <14ºC	Average Hours >18ºC	*Highest 7-day Avg. Maximum*
Oneonta Creek						
Oneonta – RR	9.6	11.2	1.6	23.6	0	*15.7*
Oneonta – Pond Outlet	9.2	11.3	2.1	23.6	0	*18.9*
Horsetail Creek						
Horsetail – RR	8.9	10.3	1.4	24.0	0	*14.2*
Horsetail – Pond Confluence	8.9	10.4	1.5	24.0	0	*14.4*
Horsetail – Slough Confluence	9.0	11.1	2.1	23.5	0	*13.1*
Horsetail – Oneonta Confluence	10.1	13.7	3.6	18.6	0.3	*17.9*
Eastern Slough						
Upper Slough	10.5	12.4	1.9	20.1	0.3	*19.7*
Mid–Slough	10.6	14.1	3.5	17.9	0.7	*20.3*
Slough Outlet	9.7	14.2	4.5	18.8	0.9	*19.7*

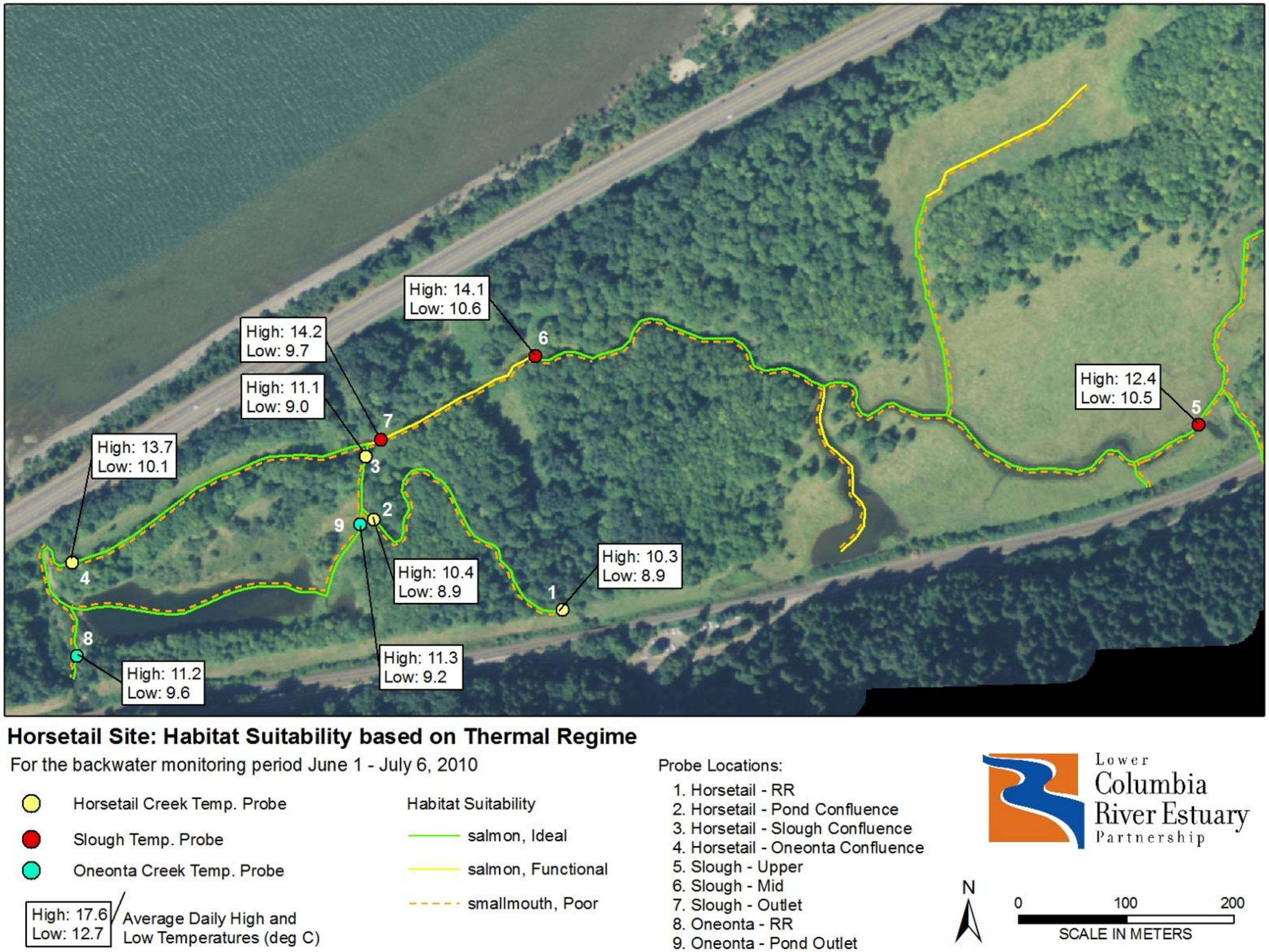


Figure 44. Temperature monitoring results for the backwater period.

As stated above, the purpose of this study is to identify conditions that may be limiting use of the site by juvenile salmonids. During the backwater period, inundation from the Columbia River not only is the primary driver of water temperatures at the site, it also presents an additional variable confounding the association between water temperature and other site conditions, such as vegetation/shading and channel morphology. Additionally, modifying water temperature characteristics in the mainstem Columbia River is outside the scope of future restoration efforts at the Horsetail Creek site. For these reasons, only an abbreviated review of the data from the backwater period is provided.

Throughout the duration of the backwater period, temperatures across the site were close to or within the "ideal" range for juvenile salmonids (as defined in Table 11 and shown in Figure 44). Average daily low and high temperatures for the site during June 1 through July 6, 2010 ranged from 8.9ºC to 14.2ºC, and no monitoring station averaged more than one hour per day above 18ºC. The highest temperatures occurred at the Mid-Slough, Slough Outlet, and Horsetail – Oneonta Confluence monitoring stations. These results are not surprising in that these sites were the warmest during the low-flow monitoring period and were most affected by Columbia River backwater, whose temperatures typically are several degrees warmer during this period.

Daily temperatures varied widely during the backwater period, particularly at the lower monitoring stations, which recorded the highest average temperatures. For example, daily maximum temperatures at the Horsetail – Oneonta Confluence monitoring station ranged from 8.9°C to 19.0°C; daily maximum temperatures at the Slough Outlet monitoring station ranged from 8.6°C to 21.6°C. At both of these sites, the higher temperatures were recorded after the Columbia River's stage had dropped and backwater inundation (and its thermal effects) were intermittent throughout the day. During this period of intermittent inundation, temperatures at these stations varied widely with diurnal fluctuations as high as 12.5°C. Temperature variations were lowest at the uppermost monitoring stations (Oneonta-RR, Horsetail-RR, and Upper Slough), which are not affected by degraded site conditions or as greatly by Columbia River inundation.

5.2.2 Low-Flow Period

Table 14 and Figure 45 summarize the temperature monitoring results for the low-flow period. Figure 46 to Figure 48 provide thermal profiles for each monitoring station.

Table 14. Summary of 2010 Temperature Monitoring Data for the Low-Flow period (July 17 – August 25, 2010).

Station	Average Daily Low Temp.	Average Daily High Temp.	Average Diurnal Fluctuation	Average Hours <14ºC	Average Hours >18ºC	*Highest 7-day Avg. Maximum*
Oneonta Creek						
Oneonta – RR	13.8	16.5	2.7	6.8	0.2	*18.1*
Oneonta Pond – Outlet	17.1	21.7	4.6	0.1	16.7	*23.6*
Horsetail Creek						
Horsetail – RR	12.2	14.2	2.0	17.7	0	*15.5*
Horsetail – Pond Confluence	12.3	14.3	2.0	16.9	0	*15.8*
Horsetail – Slough Confluence	12.9	15.5	2.6	11.6	0	*17.0*
Horsetail – Oneonta Confluence	13.7	17.1	3.4	6.3	1.1	*18.3*
Eastern Slough						
Upper Slough	15.7	17.5	1.8	1.6	2.3	*18.2*
Mid–Slough	19.7	23.7	4.0	0	21.5	*25.5*
Slough Outlet	18.2	23.0	4.8	0	20.5	*24.7*

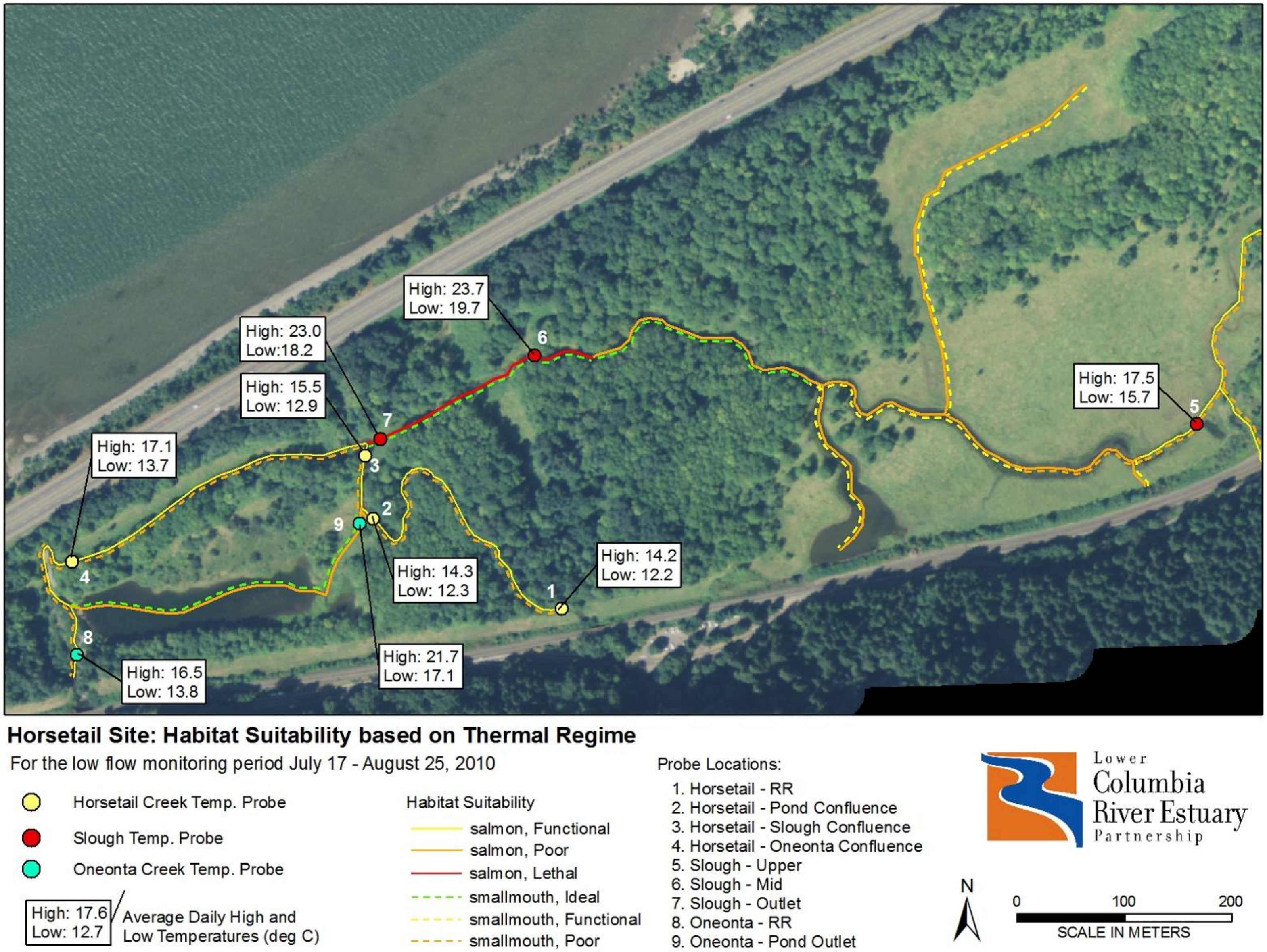


Figure 45. Habitat suitability results for the low flow period.

5.2.2.1 Average Daily High And Low Temperatures

During the low-flow period, average daily high temperatures at the Horsetail site ranged from 14.2°C at the Horsetail–RR monitoring station to 23.7°C at the Mid-Slough station. Average daily low temperatures ranged from 12.2°C at the Horsetail-RR station to 19.7°C at the Slough Outlet station. The project team also assessed 7-day average maximum temperatures at each station as that is the metric utilized by the Oregon Department of Environmental Quality (DEQ) to assess thermal suitability of juvenile salmon habitat.

Temperatures were lowest within the alluvial fan and meander reaches of Horsetail Creek (average daily high temperatures of 14.2°C and 14.3°C at Horsetail's two uppermost stations), where temperatures never exceeded 18.0°C. However, by the time the creek reached the I-84 culvert, the average daily high temperature had increased 2.9°C, registering an average daily high of 17.1°C at the Horsetail – Oneonta Confluence monitoring station with a total of eleven days exceeding 18.0°C. Similarly, average daily high temperatures in the Eastern Slough increased 5.5°C between the upper and outlet monitoring stations. Although warmer than Horsetail Creek at its entry into the site, Oneonta Creek (daily average maximum temperature of 16.5°C) flows a short distance through the site (approximately 500 feet) and likely increases very little in temperature before entering the Columbia River. During the low-flow period, Oneonta Creek exceeded 18°C five days.

The site-wide pattern of 7-day average maximum temperatures generally followed that of average high temperatures. Most notably, all monitoring stations within the slough and Oneonta Creek exceed the 18.0°C regulatory threshold. However, only the most downstream station in Horsetail Creek (Horsetail-Oneonta Confluence) exceeded DEQ's standard.

5.2.2.2 Average Diurnal Fluctuations

Average diurnal fluctuations are calculated as the difference between the average daily minimum and average daily maximum temperatures at each monitoring station. The largest diurnal fluctuations were noted at the Slough Outlet (4.8°C), Oneonta-Pond Outlet (4.6°C), Mid-slough (4.0°C) and Horsetail-Oneonta Confluence (3.4°C). These results are predictable in that each of these reaches has significant surface area and relatively long detention times, which combine to make them susceptible to rapid daytime warming. They then cool at night as most of the warmer water is replaced by cooler upstream sources and/or east-west orientations allow for mixing by cooler night-time winds.

The three monitoring stations with the lowest diurnal fluctuations are the Upper Slough and the two uppermost locations on Horsetail Creek: Upper Slough (1.8°C), Horsetail-RR (2.0°C), Horsetail-Pond Confluence (2.0°C). Although higher, the uppermost monitoring station on Oneonta Creek also had a relatively low diurnal fluctuation of 2.7 °C. Diurnal fluctuations at these stations likely are the lowest because their upstream reaches flow through narrow, moderate to high gradient channels flanked by relatively undisturbed, forested habitats. These reaches also may have groundwater inputs from Gorge valley walls. This combination of factors provides for limited warming during daylight hours, and therefore lower diurnal fluctuations.

5.2.2.3 Hours Per Day With Temperatures Below 14°C

Bjornn and Reiser (1991) report 12-14°C as the preferred temperature range for juvenile coho and Chinook salmon, with the preferred temperature range for steelhead trout being slightly lower (10-13°C). Throughout most of the site, average maximum daily temperatures are above this range; consequently, as an additional indicator of habitat quality, we calculated the number of hours per day temperatures are within the preferred range, i.e., below 14°C. It is interesting to note that temperatures typically fall below 14°C throughout the entirety of Oneonta and Horsetail Creeks for a portion of the 24 hour period (an average of approximately 6 hours). Only the two uppermost stations on Horsetail Creek average 12 hours or more per day below 14°C.

5.2.2.4 Hours Per Day With Temperatures Above 18°C

ODEQ and NMFS report 18°C in their 2003 Temperature Criteria as the maximum temperature for salmon and trout rearing and migration (ODEQ 2003). Average daily high temperatures exceeded this threshold in many monitoring locations; consequently, the duration of thermal stress was estimated by calculating the average number of hours per day temperatures exceeded 18°C. Results were predictable in that the site-wide pattern mimicked those for average daily maximum temperature and average diurnal fluctuation. Results were encouraging in that Horsetail Creek's alluvial fan and meander reaches never exceeded 18°C. Similarly, Horsetail Creek's highway reach and Oneonta Creek exceeded this threshold an average of less than 1.5 hours per day. Conversely, temperatures in the lower and middle portions of the slough exceeded the 18°C criteria an average of greater than 20 hours per day.

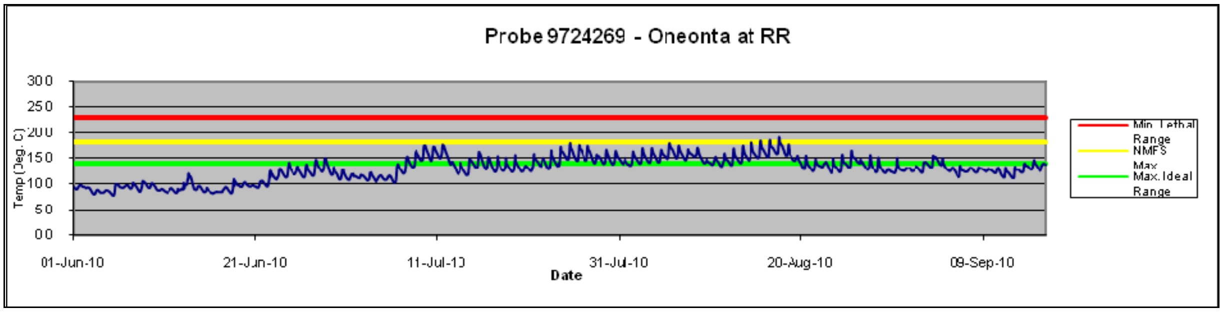
Although the thermal regime in many portions of the site (particularly the pond and slough) is not ideal, night-time temperatures below 18°C theoretically allow juvenile salmon to move throughout the site on a daily basis.

5.2.3 Thermal Profiles and Habitat Suitability of Individual Waterbodies

This section presents a summary of the thermal profiles of the site's three individual surface waterbodies, including an analysis of sources of thermal loading as well as rates of temperature increase. For analysis purposes, this section also presents low flow discharge data collected during summer 2010. It concludes with habitat suitability classifications (as defined in Table 11-Table 12) for both juvenile salmonids and smallmouth bass.

5.2.3.1 Oneonta Creek

Figure 46 shows the thermal profiles for the period of record at all Oneonta Creek monitoring stations.



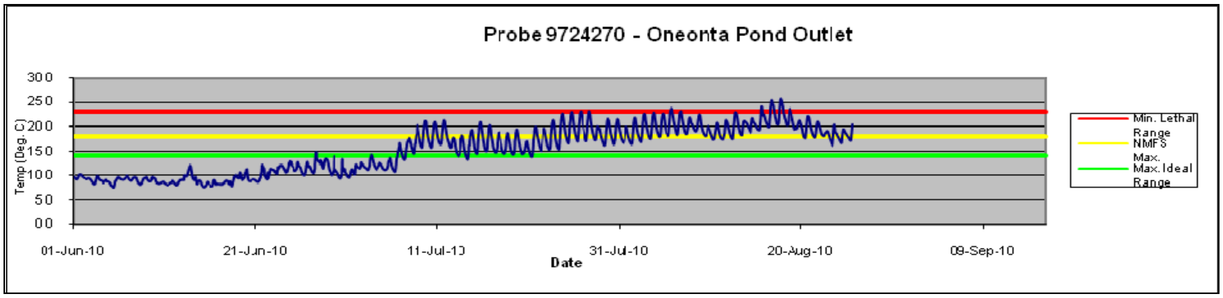


Figure 46 a-b: Thermal profiles for Oneonta Creek monitoring stations. Refer to Section 1.1.1 for detail regarding the threshold values presented in the graph.

Although it has a larger watershed than Horsetail Creek (5.2mi^2 vs. 3.7mi^2), discharge in Oneonta Creek was lower than in Horsetail Creek (53% and 42% of that in Horsetail Creek during the July and September flow monitoring events, respectively; Table 6 in Section 4.1.2). Given its larger watershed and lower discharge, it is not surprising that baseline temperatures (as measured at the two railroad monitoring stations) are higher in Oneonta Creek than in Horsetail Creek. Once on-site, Oneonta Creek flows a short distance (approximately 500 feet) before passing through the I-84 culvert and entering the Columbia River. Therefore, its temperatures exiting the site likely are similar to those measured at its railroad crossing.

The primary factor of interest in regards to Oneonta Creek's thermal regime is that a significant portion of the creek's flow (ranging from 20-85% based on 2010 discharge measurements) is diverted into the gravel pond, which subsequently discharges to Horsetail Creek. This diversion, the magnitude of which is highly dependent on flow in Oneonta Creek and water surface elevation in the pond, increased average daily high temperatures between the Oneonta – RR and Oneonta – Pond Outlet monitoring stations by an average of 5.2°C (the highest 7-day average maximum values increased by 5.5°C). This has a significant effect on Horsetail Creek's thermal regime (see next section for details). With an average increase of 0.43°C per 100 feet (Table 15), the pond has the highest rate of warming of any reach in the project area, except the Horsetail Creek reach into which it discharges.

Based on their thermal profiles, Oneonta Creek was classified as "functional" rearing habitat for juvenile salmonids while the pond was classified as "poor" (Figure 45). Conversely, the pond was rated as "ideal" habitat for smallmouth bass, while the creek was rated as "poor".

Table 15. Temperature Increases between monitoring stations and per 100 feet of stream.

Upstream Station	Downstream Station	Distance b/t Stations	Temp. Increase	Temp. Increase per 100 feet
Oneonta Creek				
Oneonta – RR	Pond Outlet	1,200	5.2°C	0.43°C
Horsetail Creek				
Horsetail – RR	Horsetail – Pond Confluence	1,050	0.1°C	0.01°C
Horsetail – Pond Confluence	Horsetail – Slough Confluence	200	1.2°C	0.60°C
Horsetail – Slough Confluence	Horsetail – Oneonta Confluence	1,050	1.6°C	0.15°C
Eastern Slough				
Upper Slough	Mid-Slough	2,350	6.2	0.26°C
Mid-Slough	Slough Outlet	550	-0.7	-0.13°C

Table 16. Habitat Classification Based on Thermal Regime

Monitoring Station	Distance from station (feet)	Temp. Increase per 100ft.	Average Daily Maximum Temperature	Salmon Habitat Classification	Smallmouth Habitat Classification
Oneonta Creek/Pond					
Oneonta-RR	0	NA	16.5	Functional	Poor
Oneonta Pond-Outlet	0	0.43°C	21.7	Poor	Ideal
Horsetail Creek					
Horsetail-RR	0	NA	14.2	Functional	Poor
Horsetail-Pond Confluence	0	0.01°C	14.3	Functional	Poor
Horsetail-Slough Confluence	0	0.60°C	15.5	Functional	Poor
Horsetail-Oneonta Confluence	0	0.15°C	17.1	Functional	Poor
Eastern Slough					
Upper Slough	0	NA	17.5	Functional	Poor
	200	0.26°C	18.0	Poor	Poor
	600	0.26°C	19.0	Poor	Functional
	1,400	0.26°C	21.0	Poor	Ideal
	2,200	0.26°C	23.0	Lethal	Ideal
Mid-Slough	0	0.26°C	23.7	Lethal	Ideal
Slough Outlet	0	-0.13°C	23.0	Lethal	Ideal

5.2.3.2 Horsetail Creek

Figure 47 shows the thermal profiles for the period of record at all Horsetail Creek monitoring stations.

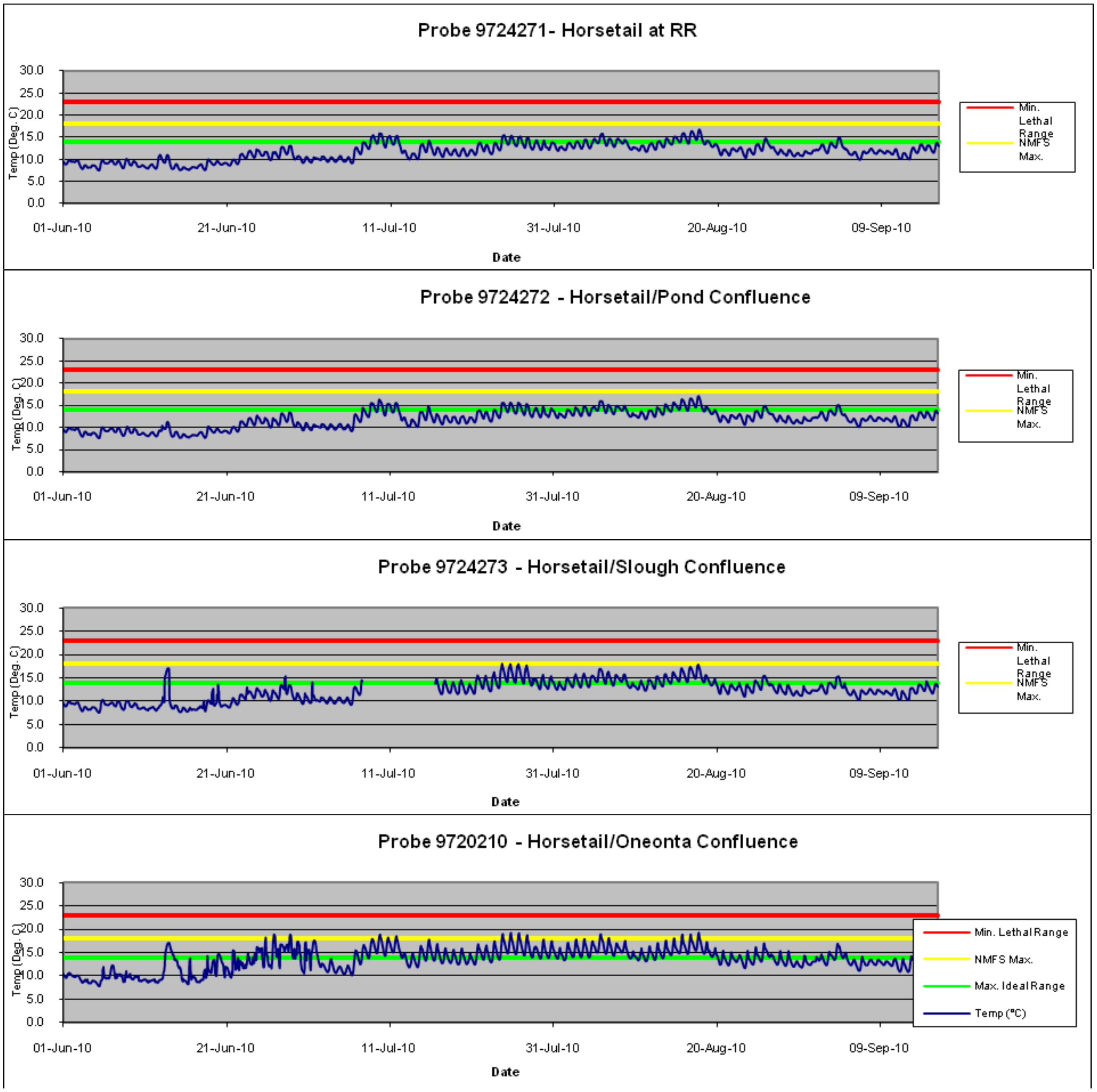


Figure 47 a-d. Thermal profiles for Horsetail Creek monitoring stations. Refer to Section 1.1.1 for detail regarding the threshold values presented in the graphs.

Horsetail Creek's average daily high temperature increased from 14.2°C to 17.1°C between the RR bridge and the I-84 culvert; the highest 7-day average maximum values increased from 15.5°C to 18.3°C between these two stations. A combination of site-wide monitoring results and targeted low-flow discharge measurements help identify sources of thermal loading to the creek.

Average daily maximum temperatures remained essentially stable (increase of 0.1 ºC) as the creek passed from the RR bridge down to the confluence with the pond's outlet channel (a distance of 1,050 feet). Due to lack of thermal inputs and relatively intact habitat conditions, this reach provides a valuable reference (control reach).

Horsetail Creek's average daily maximum temperature warms 1.2°C between the Horsetail-Pond Confluence and Horsetail-Slough Confluence monitoring stations (a distance of only 200 feet). This suggests that the pond is a significant source of thermal loading. Temperature and flow monitoring in the pond outlet channel confirms this, i.e., an average daily high temperature of 21.7°C and flows that range from approximately 10% to 45% of Horsetail Creek's flow indicate that discharge from the pond likely would have a significant impact on Horsetail Creek's thermal profile.

Horsetail Creek's average daily maximum temperature warms an additional 1.6°C between the Horsetail-Slough Confluence and Horsetail-Oneonta Confluence monitoring stations (a distance of 1,050 feet – the same as the upper reach of Horsetail Creek where temperatures increased only 0.1°C). Two potential sources may contribute to this rate of thermal loading (0.15°C per 100 feet). The first potential source is the eastern slough, which enters Horsetail Creek at the upstream end of the highway reach. The average daily maximum temperature at the Slough Outlet monitoring station was the second highest on-site (23.0°C); however, based on 2010 discharge measurements, discharge in the slough appears to be very low (less than approximately 0.2cfs during low-flow periods). Due to these low flows (which were less than approximately 2-3% of Horsetail Creek's flow at that location), the slough likely had little effect on temperatures in Horsetail Creek during the 2010 low-flow monitoring period. The remaining potential thermal source is degraded habitat condition in the highway reach. Portions of the highway reach have relatively little riparian vegetation and therefore have less shade than is found in the reference reach. Additionally, the reach has a relatively wide channel and is impounded by Oneonta Creek's alluvial fan, which backwaters the majority of the reach and results in low velocities and extended residence times during low-flow conditions (analogous to a long linear pond; see Section X for additional detail re: lower Horsetail Creek's hydrologic condition). These riparian and hydrologic conditions likely result in longer residence times and the opportunity for significant solar gain.

In summary, thermal conditions in Horsetail Creek degrade rapidly downstream of the Horsetail-Pond Confluence monitoring station. The two sources most likely responsible for the 2.9°C increase in average maximum temperatures between the Horsetail-Pond Confluence and Horsetail-Oneonta Confluence monitoring stations are the gravel pond and degraded conditions in the highway reach.

5.2.3.3 Eastern Slough

Figure 48 shows the thermal profiles for the period of record at all Horsetail Creek monitoring stations.

Figure 48 a-c. Thermal profiles for Horsetail Creek monitoring stations. Refer to Section 3.3.1.3.1 for detail regarding the threshold values presented in the graph.

Average daily high temperatures in the eastern slough increased from 17.5°C to 23.0°C between the Upper Slough and Slough Outlet monitoring stations (a rate of 0.26°C per 100 feet). No known surface water inputs exist between the two monitoring stations, therefore, a combination of very low discharge (i.e., long residence times), lack of riparian cover/shade, and wide, shallow channels appear to be responsible for these elevated temperatures. Based on temperature criteria during the low-flow period, the vast majority of the slough is designated as “poor” habitat for juvenile salmonids and as “functional” or “ideal” habitat for smallmouth bass.

Although no temperature monitoring was conducted above the Upper Slough monitoring station, observations made during other survey work indicate that during low-flow periods, the slough likely is fed by small surface and groundwater seeps. These sources likely have very cool temperatures and combined with physical habitat conditions, may provide suitable habitat for salmonids year-round. Additional monitoring in this area is recommended during future years.

5.2.4 Climate Data Comparison

Streamflow and ambient air temperature are the climate variables that have the greatest effect on surface water temperatures. Air temperature and flow data specific to the Horsetail and Oneonta Creek basins are not available. As a surrogate, air temperature and precipitation data from two weather stations located in the vicinity of the site were analyzed:

- Bonneville Dam (Station ID #350897) – located in the Columbia Gorge approximately 7 miles northeast of the site.
- Troutdale Airport (Station ID #358634) – located along the Columbia River approximately 17 miles west of the site.

The analysis detailed below indicates how precipitation (as a surrogate for streamflow) and air temperatures from the 2010 study period compared with historic averages at each of these sites. This analysis is intended to provide a general indication of how surface water temperatures at the site during the 2010 monitoring period may have varied from long-term average conditions.

5.2.4.1 Precipitation Data

In the months leading up to and during the 2010 monitoring period, total precipitation at the Bonneville Dam and Troutdale weather stations was 180% and 148% of long-term average levels respectively (

Table 17). However, total precipitation for the entire monitoring period masks monthly deviations from these long-term averages. During the backwater period (approximated by data from the month of June), precipitation was nearly three times the historic average at both stations, while during the low flow period (approximated by data from the months of July and August), precipitation was 26% and 17% of average at the Bonneville Dam and Troutdale weather stations respectively.

In summary, precipitation was well above historic averages before and during the backwater period, but was below average during the low-flow period (July and August). Additionally, precipitation patterns (relative deviations from historic averages) at the two reference weather stations (as compared to each other) did not vary considerably during the study period; consequently, these stations likely are a good indicator of how precipitation at the project site compared to historic conditions.

Table 17. 2010 and Historic Precipitation Data[1] from Bonneville Dam and Troutdale Airport Weather Stations.

Date	Bonneville Dam[2]			Troutdale Airport[3]		
	Historic	2010	Δ	Historic	2010	Δ
May	3.84	7.23	3.39	2.67	3.31[4]	0.64
June	2.82	8.05	5.23	2.00	5.90	3.90
July	0.85	0.55	-0.30	0.70	0.26	-0.44
August	1.31	0.02	-1.29	1.05	0.03	-1.02
Total (May 1 – August 31)	8.82	15.85	7.03	6.42	9.50	3.08

Notes:

1. All values reported in inches.
2. Historic data range for Bonneville Dam is from 1938–2010. Source: http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?or0897
3. Historic data range for Troutdale is from 1949–2010. Source: http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?or8634
4. Missing three days of data for this month.

5.2.4.2 Ambient Air Temperatures

Data from the Bonneville Dam and Troutdale weather stations (Table 18) indicate that during the 2010 study period, ambient air temperatures were cooler than historic averages. Overall, the average high temperature from June 1, 2010 through August 31, 2010 at the Troutdale Airport was 2.3°C (9%) below average, while the average high temperature at the Bonneville Dam station during the same period was 1.0°C (4%) below average. Although these cooler temperatures persisted throughout the entire study period, deviations from historic averages were greater during the backwater period (an average of 3.0°C below average) than during the low-flow period, when monthly temperatures averaged 1.1°C below average.

Based on these deviations from historic averages, ambient air temperatures may have caused surface water temperatures at the site to fall below historic averages during the 2010 study period.

Table 18. Historic and 2010 Average Maximum Air Temperature Data from Bonneville Dam and Troutdale Airport Weather Stations

Date	Bonneville Dam[1] (°C)			Troutdale Airport[2] (°C)		
	Historic	2010	Δ	Historic	2010	Δ
June	22.2	19.9	-2.3	23.7	20.1	-3.6
July	26.1	25.6[4]	-0.5	27.6	25.3[4]	-2.3
August	26.1	25.8	-0.3	27.3	26.2	-1.1
Average (June 1 – August 31)	24.8	23.8	-1.0	26.2	23.9	-2.3

Notes:

1. Historic data range for Bonneville Dam is from 1938–2010. Source: http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?or0897
2. Historic data range for Troutdale is from 1949–2010. Source: http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?or8634
3. Missing one day of data for this month.

5.2.4.3 Climate Summary

In conclusion, based on available data, air temperatures in the vicinity of the project site appear to have been 4-9% below historic averages during the 2010 study period. The deviation was greatest during the backwater period. Monthly precipitation totals varied considerably, but overall were almost 300% of the historic average during the backwater period, but only 17-26% of the historic average during the low-flow period. Based on these data, climate conditions likely resulted in below average surface water temperatures at the site during the backwater period; however, it is unclear how climate conditions (lower temperatures but also lower flows) may have affected surface water temperatures during the low-flow period.

6 HORSETAIL CREEK HYDRAULIC CHARACTERISTICS

6.1 HYDRAULIC MODEL DEVELOPMENT

Existing hydraulic patterns were assessed to develop a baseline understanding of Horsetail Creek flow characteristics through the study reach, primarily to assess routing of gravel in Horsetail Creek and fish passage characteristics at the two stream crossing locations (Section 7 below). The analysis was completed using the U.S. Army Corps of Engineers Hydraulic Engineering Center River Analysis System (HEC-RAS 4.1.0). HEC-RAS is a computer program that models the hydraulics of water flow through natural rivers and other channels. The program is one-dimensional, meaning that there is no direct modeling of the hydraulic effect of cross section shape changes, bends, and other two- and three-dimensional aspects of flow. The hydraulic model calculates channel and floodplain water surface elevations, velocities, depths and shear stresses for various input flows. The model geometry was developed using topographic and culvert data obtained during the supplemental topographic survey, supplemented with lidar data in select locations. The existing conditions model geometry includes 34 cross sections spaced over the 0.6 mile project reach in Horsetail Creek (Figure 49). A separate HEC-RAS model was developed to simulate hydraulic characteristics through the three stream crossings near the mouth of Oneonta Gorge, for purposes of fish passage assessment at that location (Section 7).

Summarized in Table 19, roughness coefficients (Manning's n values) applied at each model cross section were estimated from field observations, aerial photography and published methods (Arcement & Schneider 1989). The model should be considered uncalibrated, but acceptable for evaluation of the culvert hydraulic characteristics and evaluation of the performance of the design alternatives relative to existing conditions.

Table 19. Roughness coefficients used in the existing conditions model

Description	Manning's n values
Channel, Upper Horsetail Creek	0.04 - 0.05
Channel, Lower Horsetail Creek	0.03 – 0.04
Floodplain, dense deciduous, LWD	0.1
Floodplain, open deciduous, reed canary grass understory	0.08
Floodplain, reed canary grass	0.06
Floodplain, mowed grass (utility right of way)	0.05

The flood events utilized in the model to assess routing of gravel include the 1-, 2-, 5-, 10-, 50- and 100-year estimates described in Section 4.1.1. The discharge values used for the fish passage assessment were those described in Section 4.1.3. The simulations were executed for steady state flow conditions.

Figure 50 shows the simulated water surface profiles in Horsetail Creek under existing conditions for the range of simulated flows. Figure 51 through Figure 54 show simulated water surface elevations for four cross-sections along Horsetail Creek distributed over highway, meander and alluvial fan reaches.

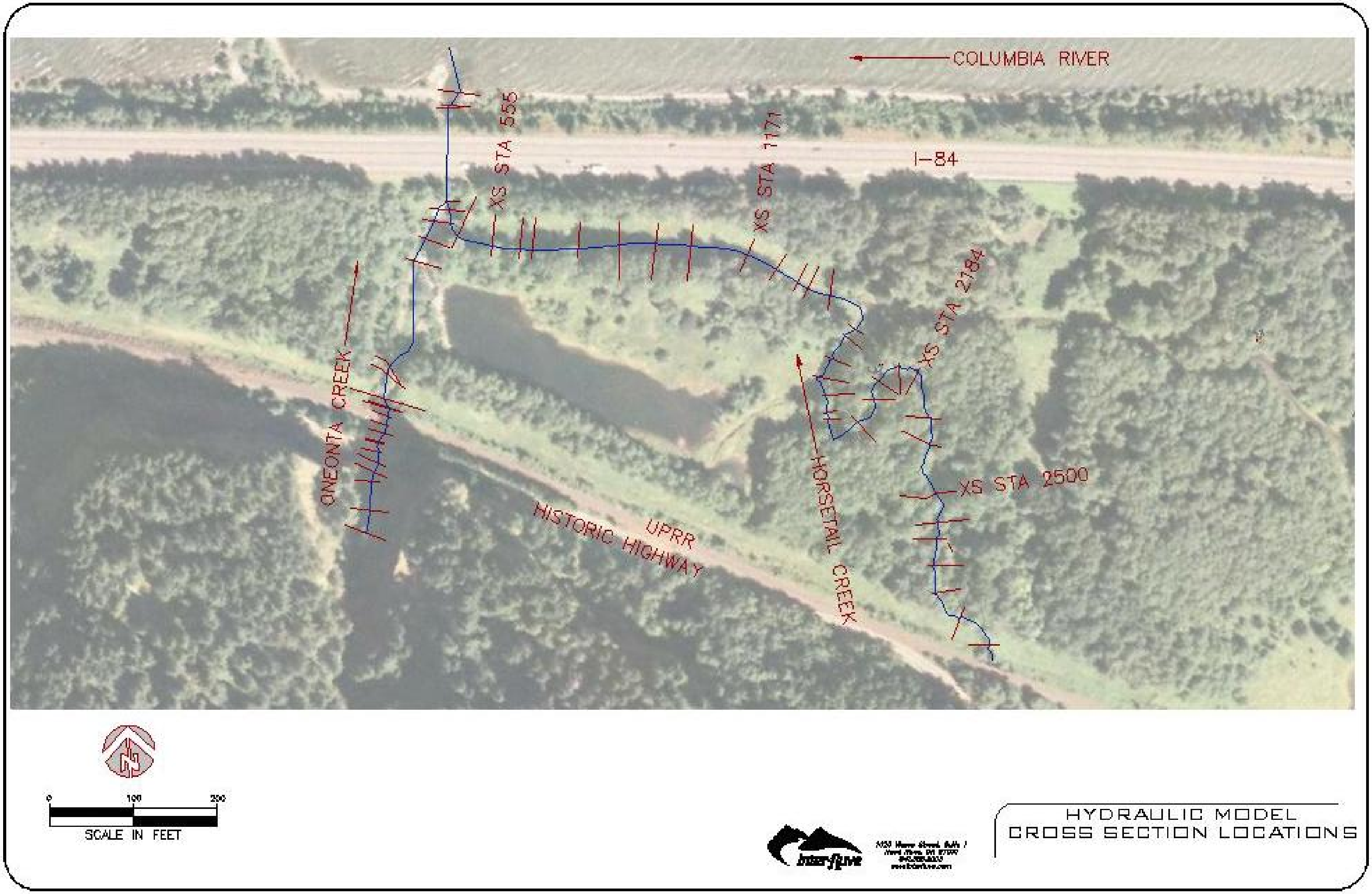


Figure 49. Hydraulic model cross section locations.

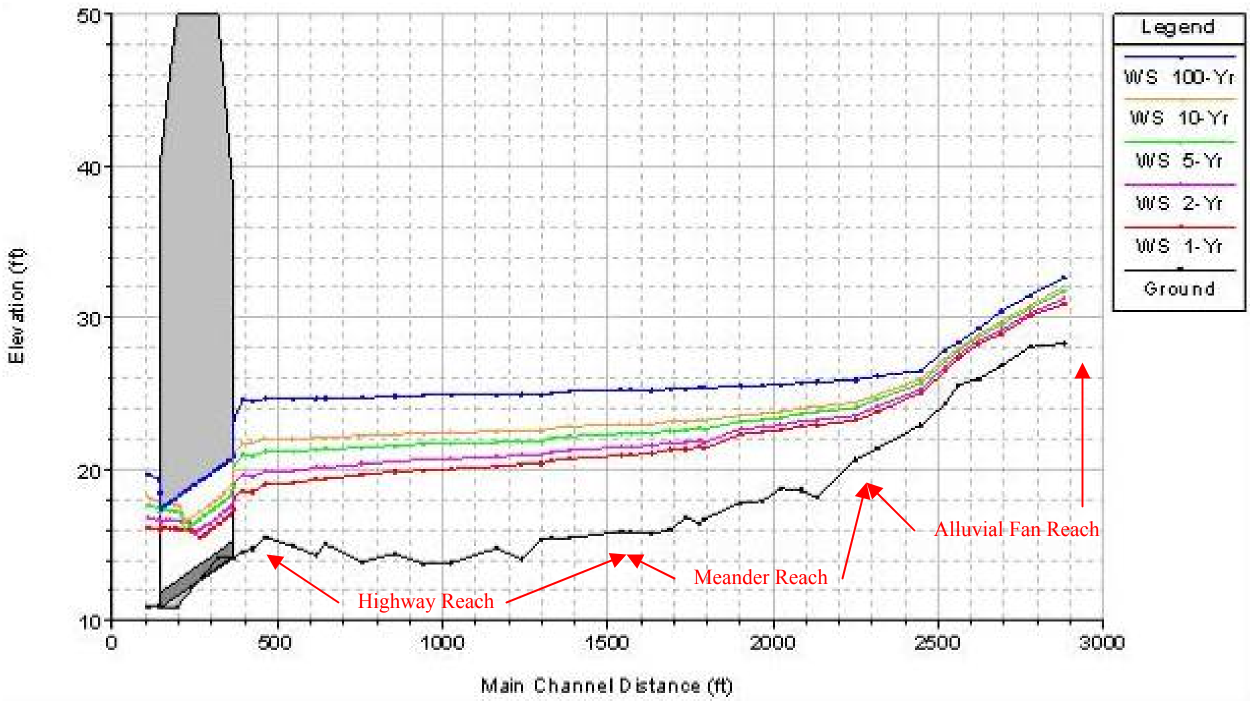


Figure 50. Simulated water surface profiles for existing conditions at a range of high flow events.

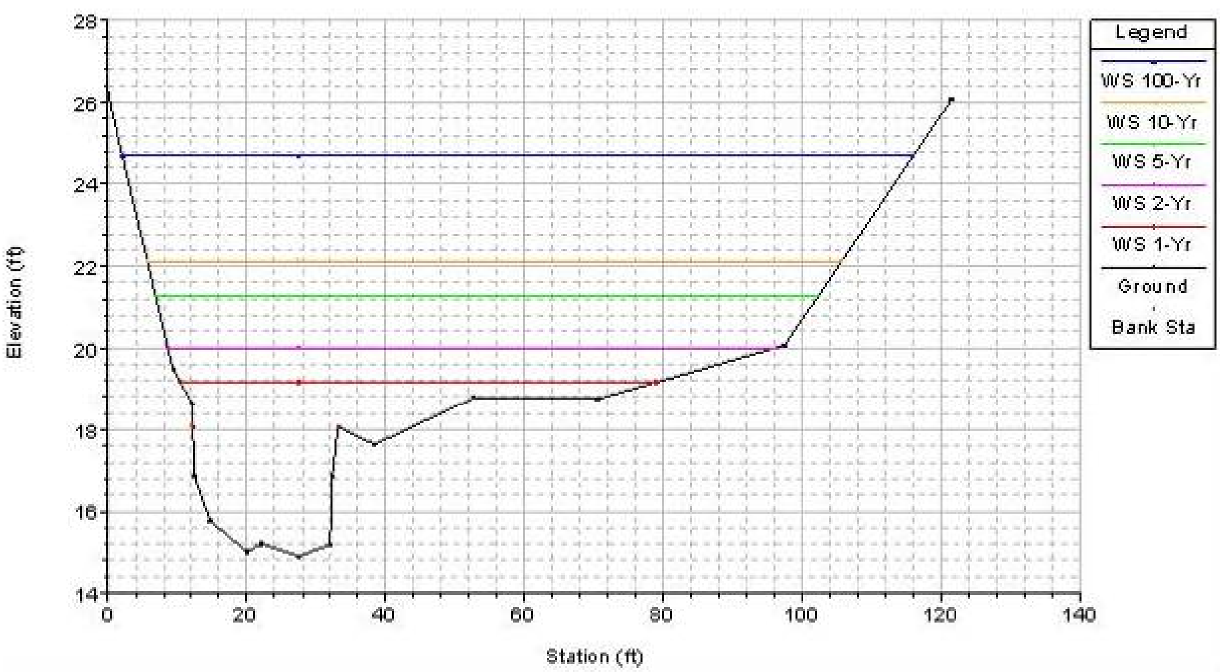


Figure 51. Simulated water surface elevations for the cross-section at Horsetail Creek RS 555 in the highway reach. See Figure 49 for location.

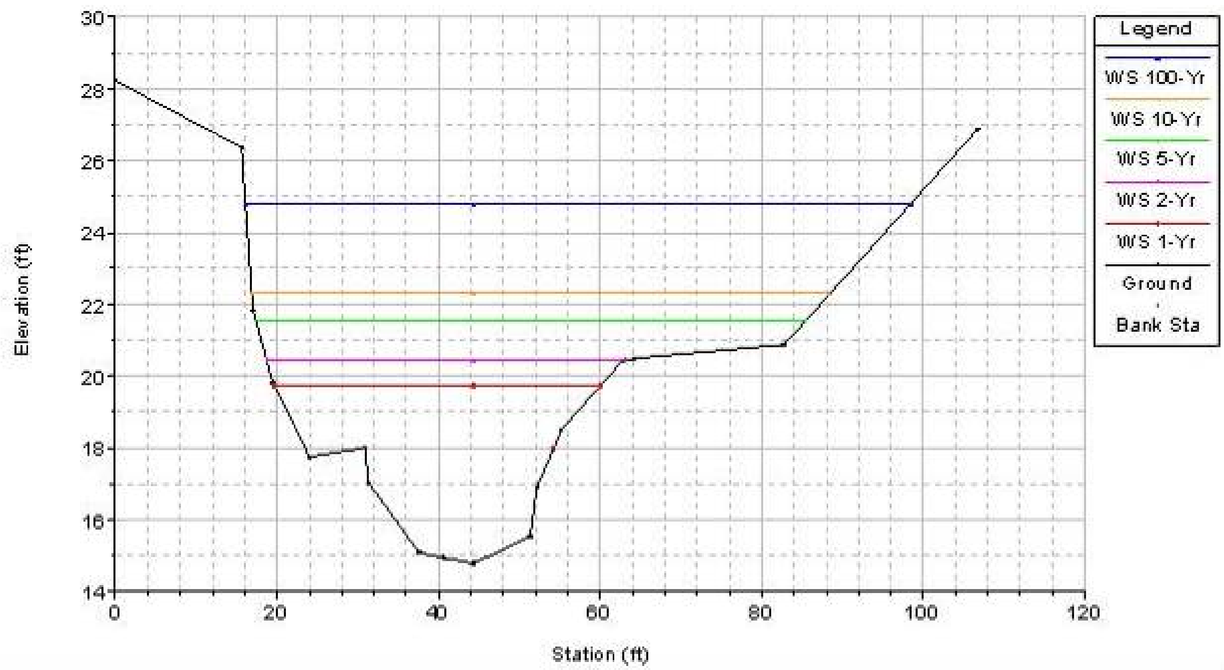


Figure 52. Simulated water surface elevations for the cross-section at Horsetail Creek RS 1171 in the highway reach. See Figure 49 for location.

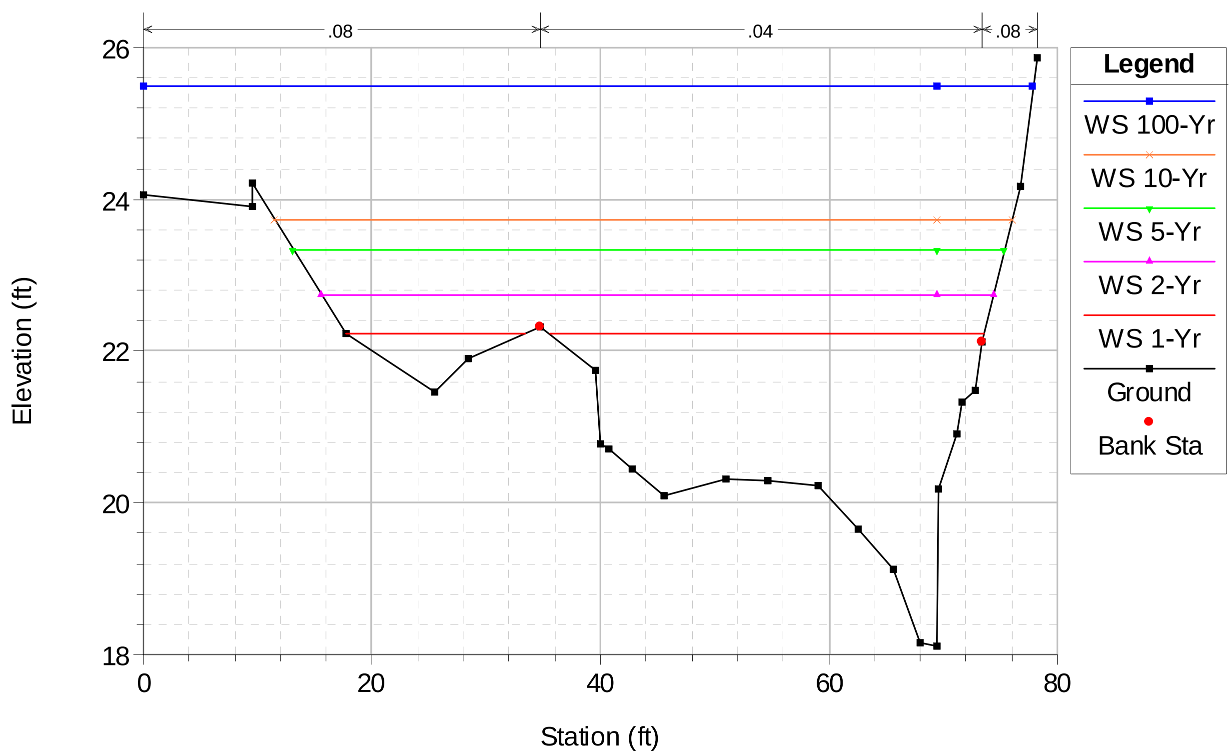


Figure 53. Simulated water surface elevations for the cross-section at Horsetail Creek RS 2184 in the meander reach. See Figure 49 for location.

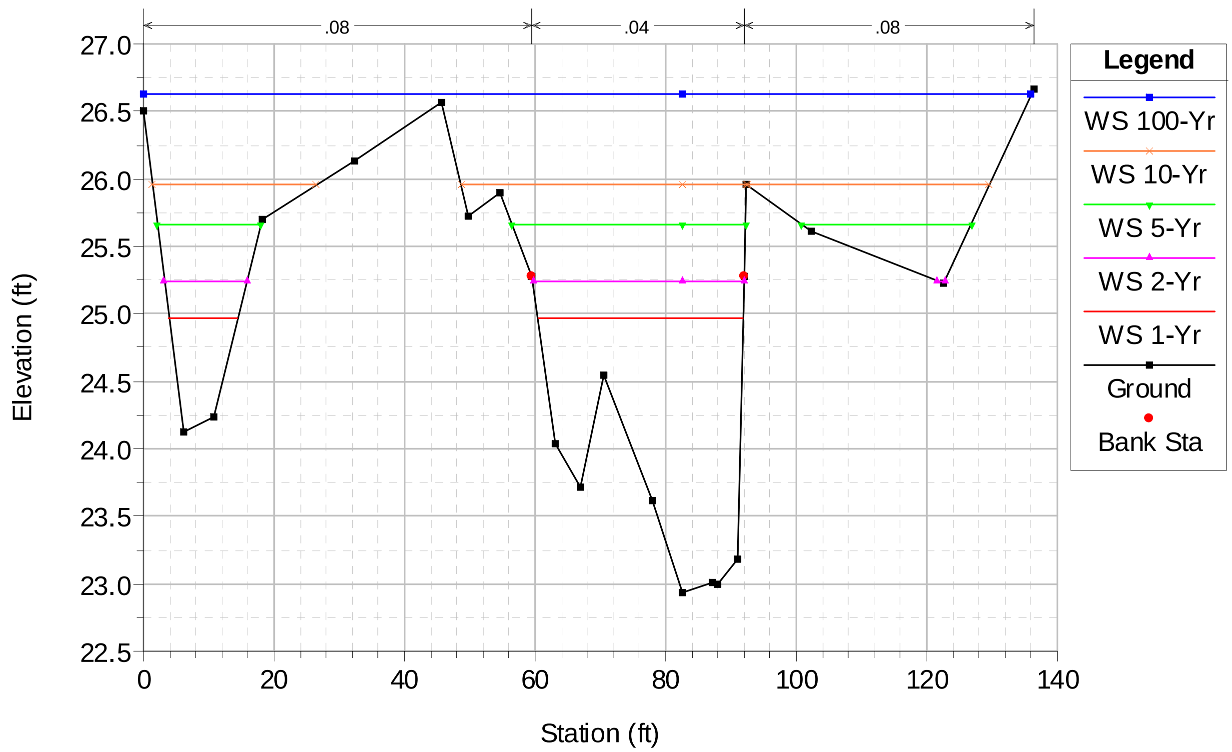


Figure 54. Simulated water surface elevations for the cross-section at Horsetail Creek RS 2499 in the alluvial fan reach. See Figure 49 for location.

The I-84 culvert becomes the controlling hydraulic feature at peak flows between the 2-yr and 5-yr event (Figure 50), which determines the backwater profile that extends upstream through much of the Horsetail Creek highway reach during major floods in the creek. Flows are surcharged above the top of the I-84 culvert at the upstream end of the culvert for all flows greater than the 5-yr event (Figure 50). However, there is over 25' of freeboard between the surcharged 100-year water surface elevation and the I-84 road surface. Capacity of the channel varies along the project reach but generally falls between the 1- and 2-yr return period (Figure 51 - Figure 54). The capacity of the channel decreases between the meander reach and the highway reach, due to the reduction in channel slope and backwater effect from the culvert. This contrasts with the historical trend in channel capacity (discussed in Section 2.6.3), and demonstrates the manner in which channel modifications and highway infrastructure constrain physical processes in the highway reach.

6.2 GRAVEL ROUTING IN HORSETAIL CREEK

To evaluate the general ability of Horsetail Creek to mobilize and convey gravel, channel competence-based calculations were conducted in the study reach (i.e., the size of material that can be transported for a given flow). The Shields (1936) equation was used to predict the median bed surface grain size (D50) mobilized at each cross section for each peak flow based on modeled bed shear stresses. The Shields equation is defined as follows:

$$\tau^*_{c50} = \frac{\tau_c}{(\rho_s - \rho) g D_{50}},$$

where τ^*_{c50} = critical dimensionless shear stress (Shields parameter),
τ_c = critical bed shear stress, N/m^2,
ρ_s = density of water, kg/m^3, and
D_{50} = median grain size, m.

There is inherent uncertainty in selection of a critical Shields parameter (τ^*_{c50}), with values applicable to gravel-bedded rivers cited in the literature ranging from 0.03 to 0.1 (Buffington and Montgomery 1997). Since the objective of this analysis is to demonstrate routing of sediment (that would already be in motion supplied from upstream reaches) through Horsetail Creek, a critical Shields parameter (τ*c50) of 0.047 was utilized in the analysis which is an appropriate value for this application, based on the literature. Figure 55 shows predicted median bed surface grain sizes transported under existing conditions for the range of simulated flows.

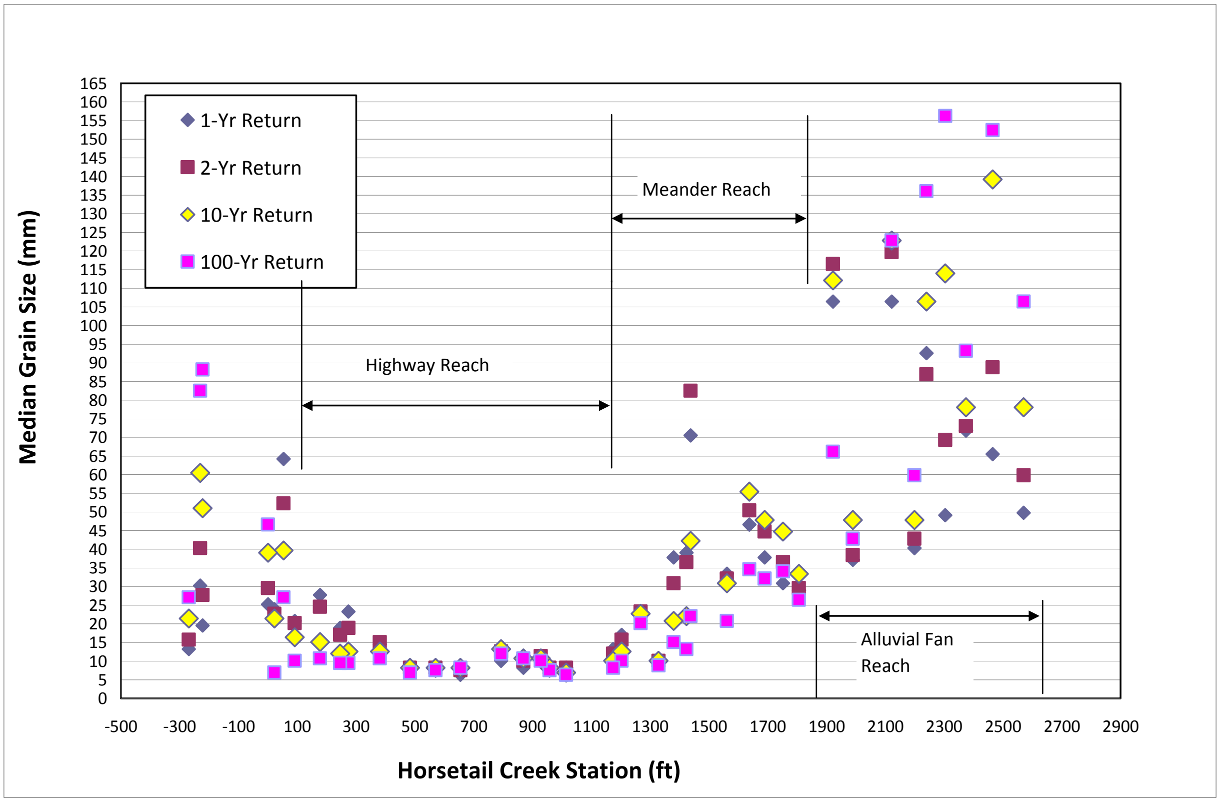


Figure 55. Channel competence results for Horsetail Creek under existing conditions. River Station 0 is at the confluence of Horsetail and Oneonta Creeks in this figure. Add 379 feet to the stationing in the figure to convert to the hydraulic model stationing discussed above, which includes the Oneonta Creek culvert.

Predicted transported grain sizes are greatest at the upstream end of Horsetail Creek where channel slopes are greatest (on the alluvial fan). Predicted transported grain sizes decline dramatically in the downstream direction. This is a result of progressively flatter channel slopes in the downstream direction and the influence of the I-84 culvert over the highway reach for flows greater than the 5-year event. The backwater effect produced by the culvert during floods greater than the 5-year event results in reduced energy gradients with increasing discharge, which reduces the creek's ability to transport sediment even though the discharge and water depths are greater than for the smaller floods. This demonstrates the manner in which the highway infrastructure constrains the movement of sediment through this reach of Horsetail Creek, which in turn constrains aquatic habitat development. In the meandering reach, the channels ability to transport sediment is curtailed in the higher flow events when water inundates the overbank areas.

The size of sediment predicted to be transported increases again at the outlet of the I-84 culvert, especially for the 100-year flood event where the culvert experiences full pipe flow along the entire length of the culvert. The predicted transportable sizes correlate reasonably well with measured streambed substrate characteristics (Figure 22) and field observations.

7 FISH PASSAGE ASSESSMENT

Multiple species and life stages of native fish were identified as currently or potentially using the project site for a portion of their life history (Section 3). The stream crossings located on Oneonta Creek at I-84 and at the railroad/historic highway at the mouth of the Oneonta Gorge were evaluated to assess whether they constrain access to the site by native fish.

7.1 CROSSING DESCRIPTIONS

7.1.1 I-84 Culvert

The combined flows of Oneonta Creek, Horsetail Creek and the eastern sloughs are conveyed through the I-84 road prism through a group of five concrete box culverts 6 feet wide by 6.5 feet tall. The culverts have a compound slope, with nearly flat lower portion and a steeper upper portion. The average slope is 1.5%. Approximately 20 feet upstream of the culverts, a 1 foot tall horseshoe-shaped concrete weir was constructed in front of the eastern four barrels to channel water into the western most barrel during low flow periods (Figure 56). The hydraulic drop over this weir ranges from 0 during periods when the Columbia River is high (Figure 57) to 12 inches during low flow periods (Figure 56). This weir drops onto a concrete slab that runs from the weir to the culvert entrance. During the winter period, flow over this slab is swift and shallow with a hydraulic jump just below the weir (Figure 58).

Figure 56. Inlet to Oneonta Creek culvert at I-84, typical non-backwatered low flow condition.

Figure 57. Inlet to Oneonta Creek culvert at I-84, with upstream weir backwatered by Columbia River stage.

Figure 58. Inlet to Oneonta Creek culvert at I-84 during relatively high flow condition.

The western culvert barrel has a series of 5 baffle weirs spaced at approximately 30 feet to facilitate fish passage (Figure 59). The weirs appear to have deteriorated since they were installed (date unknown). In their present condition, during a period of low flow in August 2010, the two upstream weirs had a hydraulic drop of 14”, the middle weir had drop of 5”, and the downstream two weirs were awash.

Figure 59. Existing fish passage baffle in Oneonta Creek I-84 culvert.

Gravel has aggraded to the top of the concrete weir that is located upstream of the culvert inlet (Figure 56) and into the upstream end of the western barrel, such that the weir is marginally effective at focusing flow into the western barrel during low flow periods. The configuration is also vulnerable to manipulation by recreational users of the area. In summer 2010 during periods of minimum flow (~1-2 cfs), contrary to design, most of the flow was instead going over the weir and flowing as a very shallow sheet over the concrete slab, to be distributed between the 4 eastern barrels (Figure 56 and Figure 60). This condition may be improved marginally by eliminating the diversion of Oneonta Creek flow into the gravel pond.

Figure 60. Inlet to Oneonta Creek culvert at I-84 during summer low flow condition, with berm constructed by recreational users modifying intended flow control.

The outlet of the culvert (elevation 10.9) is backwatered by the Columbia River during portions of the year. Based on the stage duration analysis completed for this study (based on the period 1981-2010), the duration of backwater of the culvert outlet ranges from 23.5% of the time in September, 63% of the time in November and August, to >99% of the time in June (Figure 40). When considering backwater through the culvert to the upstream end, based on the stage duration analysis, the duration of backwater over the concrete weir (elevation 15.4) ranges from <1% of the time in September and October, 35% of the time in July, 42% of the time in March, 56% of the time in April, and 90.5% of the time in May (Figure 40). In this condition, passage is unimpeded for all species. Finally, when considering an elevation 0.5 feet below the weir elevation (i.e., ODFW hydraulic drop criteria for juvenile salmonids and resident trout), these percentages shift to <2% for September and October, 39% for July, 48% for March, 60% for April, and 93% for May (Figure 40).

During periods when the Columbia is low, water level in the culvert outlet is controlled by a riffle in the Oneonta Creek outlet channel located downstream of the culvert outlet, which is at grade with the downstream bed. Because relatively equal volumes of water flow through the 5 culverts over most of the year, upstream migrating fish may be attracted to any of the five barrels. As described above, disparate passage potential is present at the upstream ends of each barrel.

7.1.2 Railroad and Historic Highway Crossings

Three bridges cross Oneonta Creek at the mouth of Oneonta Gorge, including the Union Pacific railroad, the Historic Columbia River Highway, and a pedestrian bridge (listed from downstream to upstream, respectively). The railroad bridge is 21 feet long, and is supported by vertical concrete abutments that result in stream width of 45 feet through the bridge. The streambed beneath the railroad bridge consists of a 45 foot wide, flat concrete slab which expands to 77 feet wide over a 17 foot distance both downstream and upstream of the bridge (Figure 61). A scour pool is located downstream of the concrete slab, with residual depth ranging from 1.5 to 2.5 feet. The streambed grade at the riffle downstream of the scour pool is 2.2 to 2.5 feet below the grade at the edge of the concrete slab. The concrete slab and abutments are in sound condition. Flow across the slab is wide and shallow, with depth of 0.4 feet at the time of the survey (April 2010). Low flow depths were not measured, but are estimated to be less than 0.1 feet.

Figure 61. Downstream view of Union Pacific RR bridge over Oneonta Creek.

During periods of significantly high stage in the Columbia River, the concrete slab (elevation 25.6) may be backwatered by the Columbia River. Based on the stage duration analysis completed for this study (based on the period 1981-2010), the slab would begin to be backwatered (i.e. elevation 25.6) 8.5% of the time in June, 4.5% of the time in May, and 2% of the time in April (Figure 40). Based on the same analysis, these percentages increase approximately 1% for elevation 25.1 which is 0.5 lower than the elevation of the slab (Figure 40;

0.5 feet is the hydraulic drop criteria for juvenile anadromous salmonids and resident trout per ODFW 2004).

The historic highway bridge is located 50 feet upstream of the railroad bridge, and 37 feet upstream from the edge of the concrete slab. The stream bed between the concrete slab and the historic highway bridge consists of rubble and boulders (Figure 62). The historic highway bridge opening is 23 feet long, and the stream width through the bridge is 45 feet.

Figure 62. Downstream view of historic highway bridge over Oneonta Creek.

The pedestrian bridge spans Oneonta Creek 21 feet upstream of the historic highway bridge, is 23 feet long, with stream width of 58 feet beneath the bridge. The bridge is supported by three piers. The flow is focused between the piers by a stone wall which cuts off the opening between the left pier and the abutment.

A continuous concrete slab covers the streambed from the upstream edge of the pedestrian bridge to the downstream edge of the historic highway bridge with a slightly concave profile. The slab is flat through the pedestrian bridge and then slopes down through the downstream edge of the highway bridge. The slab is compromised in several locations, with voids that create hydraulic turbulence in several locations. Three unused cast-in-place pier foundations focus flow through the downstream edge of the highway bridge. Other than at the areas of local turbulence, flow is supercritical over the slab, with swift velocities and shallow depths (Figure 63).

Figure 63. Downstream view of pedestrian bridge over Oneonta Creek.

A scour pool with residual depth of 1 to 2.2 feet is located on the right half of the channel below the edge of the concrete. The grade of the riffle downstream of the scour pool is typically approximately 4 feet below the grade at the downstream edge of the concrete slab, except at the right edge of the channel where a 10’ x 6’ section of the slab has failed and slants down into the channel, with edge that is approximately 1 feet higher than the grade of the downstream riffle (Figure 62). The total drop over the concrete slab is 5.8 feet for an average slope of 8.1%. The total drop between the upstream edge of the slab and the downstream riffle is 7.5 feet, for an average slope of 7.5%. Finally, the total drop between the upstream edge of the pedestrian bridge and the riffle downstream of the railroad bridge is 10.1 feet, for an average slope of 5.4%.

7.2 ANALYSIS METHODS AND CRITERIA

7.2.1 Identification of Species for Assessment

Multiple species and life stages of native fish were identified as currently or potentially using the project site for a portion of their life history (Section 3). The stream crossings located on Oneonta Creek at I-84 and at the railroad/historic highway at the mouth of the Oneonta Gorge were evaluated to assess whether they constrain access to the site by native fish. The species, timing and lifestages considered in the analysis are summarized in Table 20 and Table 21.

Table 20. Species and timing of adult fish migration considered in the fish passage assessment

Species	ESU	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Coho	LCR									S,G	S,G	S,G	S,G
Steelhead	LCR		S,G	S,G	S,G	S,G							
Steelhead	Upriver ESUs												
Chinook	Upriver ESUs												
Sockeye	Upriver ESUs												
Chum	LCR	S										S	S
Cutthroat	LCR	S,G	S,G	S,G	S,G	S,G	S	S	S	S	S	S	S
Pacific Lamprey	LCR		S,G	S,G	S,G	S,G	S,G						

LCR = Lower Columbia River
Upriver ESUs = Any ESUs located above Bonneville Dam.
S = I-84 crossing
G = Railroad and historic highway crossings

Table 21. Species and timing of juvenile fish migration considered in the fish passage assessment

Species	Population	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Coho	LCR	S	S	S	S	S	S	S	S	S	S	S	S
Steelhead	LCR	S	S	S	S	S	S	S	S	S	S	S	S
Steelhead	Upriver ESUs				S	S	S						
Chinook	Upriver ESUs				S	S	S	S	S				
Sockeye	Upriver ESUs					S	S						
Chum	LCR												
Cutthroat	Local	S	S	S	S	S	S	S	S	S	S	S	S
Pacific Lamprey	LCR	S	S	S	S	S	S	S	S	S	S	S	S

LCR = Lower Columbia River
Upriver ESUs = Any ESUs located above Bonneville Dam.
S = I-84 crossing
G = Railroad and historic highway crossings

7.2.2 Fish Passage Assessment by Hydraulic Design Criteria

ODFW published fish passage criteria (2004) that provide guidelines for providing suitable passage conditions at road crossings. These criteria are recommended for retrofit of existing structures, and are required by Oregon Administrative Rules for new structures (ODFW 2006). NMFS (2008) also published hydraulic criteria for upstream passage of anadromous salmonids. The combined ODFW and NMFS hydraulic design criteria were evaluated for use in the fish passage evaluation. In general, the two sets of criteria agree. In cases where there was a difference between the two sets of criteria, the more restrictive criteria were adopted for the evaluation. As these criteria are generally intended as conservative design criteria, their use in fish passage assessment should result in a conservative assessment of fish passage performance. Alternatively, matching published swimming capabilities for fish against hydraulic characteristics results in a less conservative assessment. This approach was also utilized for this study, described in Section 7.2.3. The hydraulic design criteria used in the fish passage assessment are summarized in Table 22 and Table 23. In the following tables, note that velocity criteria become more stringent with increasing length, which explains the difference in velocity criteria between the two sites.

Table 22. Hydraulic Method Criteria for I-84 crossing (200-300 feet in length).

Parameter	Species					
	Adult steelhead	Adult coho	Adult chum	Adult cutthroat	lamprey	Juvenile salmon
Velocity (f/s)	3	3	2	2	2**	1
Depth (in)	12	12	10	8	--	8
Jump height (in)	12	12	12	6	--	6

** 8 ft/s if culvert has smooth, impermeable, uninterrupted surface or simulated streambed

Table 23. Hydraulic Method Criteria for railroad/historic highway crossings (60-100 feet in length).

Parameter	Species					
	Adult steelhead	Adult coho	Adult chum	Adult cutthroat	lamprey	Juvenile salmon
Velocity (f/s)	5	5	4	4	2**	1
Depth (in)	12	12	12	8	--	8
Jump height (in)	12	12	12	6	--	6

** 8 ft/s if culvert has smooth, impermeable, uninterrupted surface or simulated streambed

Note that the velocity requirement for upstream passage of juvenile fish (1 ft/s) is very low. The Washington Department of Fish and Wildlife (2003) suggests that in many cases it is impractical to obtain velocities during high flows that meet the juvenile requirements for the hydraulic method, and suggest that juvenile fish may be able to tolerate some degree of delay during high flow events. They further suggest that if high flow passage requirements for adult trout are met, juvenile passage requirements will likely be met during lesser flows. In this report, we have reported results related to juvenile passage requirements for high and low flow criteria, but suggest that project stakeholders consider the limitation of the hydraulic method with respect to juvenile fish. A further evaluation of the periods of the year when upstream passage for juvenile fish is critical may be appropriate.

Pacific lamprey are a unique species in that they are poor swimmers, but have the capacity to attach to wetted impermeable surfaces through suction when they become fatigued, and proceed with their migration in staged fashion. While the velocity criteria for lamprey listed in the table above is low (2 ft/s), this criteria applies only when the culvert is constructed of non-smooth, non-native, or permeable materials. When the culvert consists of materials that lamprey can adhere to, or a simulated streambed, velocity criteria for lamprey increase to 8 ft/s. (ODFW 2006) Additional passage requirements for lamprey include avoiding surfaces that are overhanging or angled in the upstream direction, to prevent lamprey from becoming trapped by the downstream current (ODFW 2006)

7.2.3 Fish Passage Assessment by Literature-based Swimming Capacities

As described previously, use of hydraulic design criteria results in a conservative fish passage assessment. To provide additional perspective on fish passage characteristics, literature-based swimming capacities were compared to modeled hydraulic characteristics to result in a less- or non-conservative fish passage assessment. To date, literature based criteria have been identified for adult fish only, and in particular with respect to swim velocities. In addition, estimates of potential body depth (calculated using Fish Xing software) were utilized to develop estimates of minimum water depth that may be required for upstream passage. The modified criteria based on literature values are summarized in Table 24 and Table 25.

Table 24. Literature-based Swimming Capacity Criteria for I-84 crossing (200-300 feet in length), using literature values for prolonged swim speeds (up to 30 min duration). Note that velocities in this table are the average/midpoint value if a range was specified in the data source.

Parameter	Species			
	Adult steelhead[1]	Adult coho[2]	Adult chum[3]	Adult cutthroat[1]
Velocity (f/s)	9.7	6.7	5.2	4
Depth (in)	9	9	9	6
Jump height (in)	12	12	12	6

[1]Bell 1991
[2]Hunter and Mayor 1986
[3] Aserude and Orsborne 1985

Table 25. Literature-based Swimming Capacity Criteria for railroad/historic highway crossings (60-100 feet in length), using literature values for burst swim speeds (up to 10 second duration). Note that velocities in this table are the average/midpoint value if a range was specified in the data source.

Parameter	Species			
	Adult steelhead	Adult coho	Adult chum	Adult cutthroat
Velocity (f/s)	20[1]	16[1]	8[2]	10[1]
Depth (in)	9	9	9	6
Jump height (in)	12	12	12	6

[1]Bell 1991
[2] Powers and Orsborne 1985

7.2.4 Assessment Analysis and Scoring

7.2.4.1 I-84 Culvert

The hydraulic characteristics of the I-84 culverts were simulated with the HEC-RAS model (Section 6) for the fish passage flows (Table 7) and compared against the criteria listed above. Because the level of the Columbia River downstream of the culvert directly influences the hydraulics in the culverts and is variable in time, two separate downstream boundary conditions were used in the fish passage assessment to represent a range over which fish passage conditions may be constrained. In the first case, the 50% excedence river stage was assumed for each month, which corresponds with median conditions for that month (Figure 40). In the second case, the 90% excedence river stage was assumed for each month, which corresponds with a relatively low water scenario (Figure 40), and results in a conservative assessment. Thus, for each of the four assessed fish passage flows (Table 7), 2 cases were assessed corresponding to the two separate downstream boundary conditions, resulting in 8 cases calculated for each applicable month and life stage (Table 20 - Table 21). It should be noted that upstream passage is relatively unconstrained during periods when the Columbia River is high (Figure 57), thus a separate set of analyses were not completed for this third downstream boundary condition scenario.

For each case, the criteria listed above (Table 22, Table 24) were scored based on whether or not the criteria were met at upstream and downstream locations at each crossing (a score of 1 was assigned if the criteria was met, 0 if the criteria were not met). The maximum possible score for each case was 6 (3 criteria x 2 zones each), for which all criteria were met and corresponds with an unconstrained passage condition. Scores less than 6 indicate at least one or more criteria were not met, indicating a potential barrier. Lower scores correspond with the likely greatest constraint on upstream passage.

7.2.4.2 Oneonta Gorge Crossings: UPRR, Historic Highway and Pedestrian Crossings

Similar to the I-84 crossing, the hydraulic characteristics of the railroad, historic highway and pedestrian bridges were simulated with a HEC RAS model for the fish passage flows (Table 7) and compared against the criteria listed above (Table 23, Table 25). The railroad bridge was assessed as one independent structure, and the historic highway and pedestrian bridges were considered together as they are joined by a concrete slab between the two. The Oneonta Gorge crossings are rarely affected by backwater, thus only a single downstream boundary condition scenario was assessed at these crossings.

Fish passage scores were calculated similarly as described above for the I-84 crossing. The maximum possible score for each flow was 6, for which all criteria were met and corresponds with an unconstrained passage condition. Scores less than 6 indicate at least one or more criteria were not met, indicating a potential barrier. Lower scores correspond with the likely greatest constraint on upstream passage.

7.3 RESULTS

7.3.1 I-84 Culvert

Table 26 reports the average fish passage scores for the various species and months at the I-84 culvert using hydraulic design and literature-based criteria. Detailed results are included in Appendix D. The assessment suggests that potential for juvenile and adult cutthroat passage is good during periods when the Columbia River is high and the facility is backwatered from downstream (primarily in the months of April to June for average water years), and moderately impaired to poor for the remaining months and for low water years. For adult coho salmon and steelhead, the assessment suggests that passage conditions are moderately impaired to good for the key upstream passage months for both average and low water years, with conditions for steelhead slightly better than for coho. For chum salmon, fish passage potential was assessed to be moderately impaired for both average and low water years. In general, passage constraints in the winter months relate to high flow velocities and the hydraulic drop over the upstream weir, while limited water depths lead to passage constraints in the summer months. The literature-based criteria lead to moderately higher (less constrained) fish passage scores.

Table 26. Average fish passage scores for all species analyzed at I-84 culvert, based on hydraulic design criteria (top) and literature-based swimming capacity criteria (bottom). For downstream boundary condition, median refers to the 50% excedence Columbia River stage for the respective month. Low refers to the 90% excedence Columbia River stage for the respective month. Note that literature-based criteria not available for juvenile salmonids. See Appendix D for detailed results with respect to each flow level analyzed.

Species/ Life Stage	DS Boundary Condition	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Average Scores Using Hydraulic Design Criteria													
Juvenile Salmonid	median	3.5	3.5	3.5	5.5	6	6	3.3	3	3	3.7	3.3	3.8
	low	3.5	3.5	3.5	3.5	5.7	3.3	3	3	3	3	3.3	3.8
Adult Steelhead	median		4.5	4.5	5.5	6							
	low		4.5	4.5	4.8	6							
Adult Coho	median									4	4.3	4.3	4.8
	low									4	4	4.3	4.8
Adult Chum	median	4.5										4.3	4.5
	low	4.5										4.3	4.5
Adult Cutthroat	median	3.5	3.5	3.8	5.5	6							
	low	3.5	3.5	3.8	3.5	6							
Average Scores Using Literature-based Swimming Capacity Criteria													
Adult Steelhead	median		5.5	5.5	6	6							
	low		5.5	5.5	5.3	6							
Adult Coho	median									4	4.7	4.3	5
	low									4	4	4.3	5
Adult Chum	median	5.3										4.8	5.3
	low	5.3										4.8	5.3
Adult Cutthroat	median	4.3	4.3	4.3	5.8	6							
	low	4.3	4.3	4.3	4.5	6							

7.3.2 Railroad, Historic Highway, and Pedestrian Bridge Crossings

Table 27 reports the average fish passage scores for the various species and months at the Oneonta Gorge crossings using hydraulic design and literature-based criteria. Detailed results are included in Appendix D. The assessment suggests that potential for juvenile and adult cutthroat passage is poor over the range of conditions due to hydraulic drops and excessive velocities over the range of flows when considering hydraulic design passage criteria. For adult coho salmon and steelhead, the assessment suggests that passage conditions are moderately impaired to poor for the key upstream passage months when considering hydraulic design passage criteria. When assessed against literature-based swimming capabilities, passage potential at the crossings improves. Adult fish are observed in Oneonta Gorge, which in part demonstrates the conservative nature of the hydraulic design passage criteria. Even though adult fish are observed in Oneonta Gorge, upstream passage through the crossings presents significant challenges.

Table 27. Average fish passage scores for all species analyzed at Oneonta Gorge crossings, based on hydraulic design criteria. UPRR refers to the railroad bridge. HH/Ped refers to the joint Historic Highway and pedestrian crossings. Note that literature-based criteria not available for juvenile salmonids. See Appendix D for detailed results with respect to each flow level analyzed.

Species/ Life Stage	Crossing	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Average Scores Using Hydraulic Design Criteria													
Juvenile Salmonid	UPRR	1.5	1.8	1.8	1.2	1.2	2.5	3	2.5	2.2	2.3	1.4	1.8
	HH/Ped.	2.6	2.6	2.6	2.1	1.9	1.9	1.9	1.9	2	1.9	2.3	2.7
Adult Steelhead	UPRR		2	2	2.5	3							
	HH/Ped.		2.8	2.8	2.3	2.4							
Adult Coho	UPRR									3	3	2	2
	HH/Ped.									1.9	2	2.6	2.6
Adult Chum	UPRR	3										3	3
	HH/Ped.	2.8										2.7	2.7
Adult Cutthroat	UPRR	2.1	2.6	2.6	2.5	3							
	HH/Ped.	3.3	3.3	3.3	2.6	2.5							
Average Scores Using Literature-based Swimming Capacity Criteria													
Adult Steelhead	UPRR		4	4	3	3							
	HH/Ped.		5.2	5.2	4.5	3.9							
Adult Coho	UPRR									3	3	3.6	3.8
	HH/Ped.									3.9	4	4.8	4.9
Adult Chum	UPRR	2.8										2.9	3
	HH/Ped.	3.6										3.4	3.4
Adult Cutthroat	UPRR	3.8	4	4	3.5	3							
	HH/Ped.	4.1	4.1	4.1	4.1	3.8							

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9 APPENDIX A: STREAM SUBSTRATE DATA SHEETS

Location (Stream, Reach, Description)

Sediment Grain Size Analysis

Horsetail	Stream
Horsetail Meander	Reach
20' to 50' above slough	Location
1	Identifier / Unit
Riffle	Longitudinal Description (Pool, Riffle, Bend, Crossing)
Surficial	Sample Type: Armor Layer or Subarmor
0.5	Approximate Depth of Flow at Thalweg (ft)

8/6/2010	Date
M. Burke & C. Collins	Personnel
	Latitude
	Longitude
	Northing
	Easting
27	Waypoint

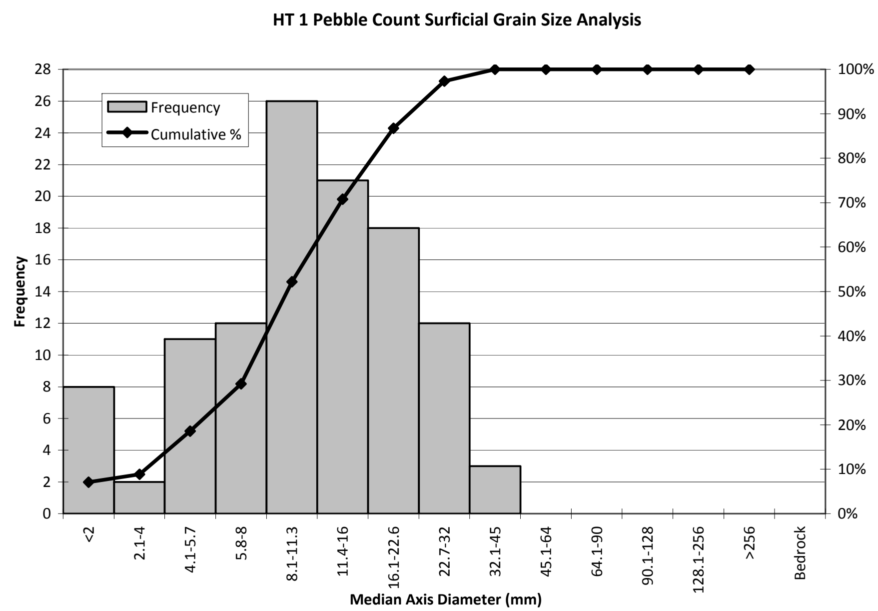
location

subsurface

Notes:
1st riffle US of slough channel confluence
Just DS of berm crossing
backwater fines apparent along channel margins
Slight to moderate armoring
Fine grained banks upper zone, hard pan clay lower zone
Subsurface sizes range from 32 mm to sand

Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Frequency*	*Cumulative %*
Sand	<2	8	7.1%
Very Fine Gravel	2.1-4	2	8.8%
Fine Gravel	4.1-5.7	11	18.6%
Fine Gravel	5.8-8	12	29.2%
Medium Gravel	8.1-11.3	26	52.2%
Medium Gravel	11.4-16	21	70.8%
Coarse Gravel	16.1-22.6	18	86.7%
Coarse Gravel	22.7-32	12	97.3%
Very Coarse Gravel	32.1-45	3	100.0%
Very Coarse Gravel	45.1-64	0	100.0%
Small Cobble	64.1-90	0	100.0%
Small Cobble	90.1-128	0	100.0%
Large Cobble	128.1-256	0	100.0%
Small Boulders	>256	0	100.0%
Bedrock	Bedrock	0	100.0%
	Total	113	

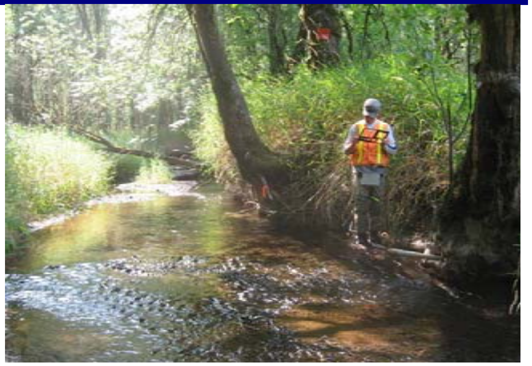


Location (Stream, Reach, Description)

Sediment Grain Size Analysis

Horsetail	Stream
Horsetail Meander	Reach
US pond outlet	Location
2	Identifier / Unit
Riffle	Longitudinal Description (Pool, Riffle, Bend, Crossing)
Surficial	Sample Type: Armor Layer or Subarmor
1	Approximate Depth of Flow at Thalweg (ft)

8/6/2010	Date
M. Burke & C. Collins	Personnel
	Latitude
	Longitude
	Northing
	Easting
28	Waypoint



location

subsurface

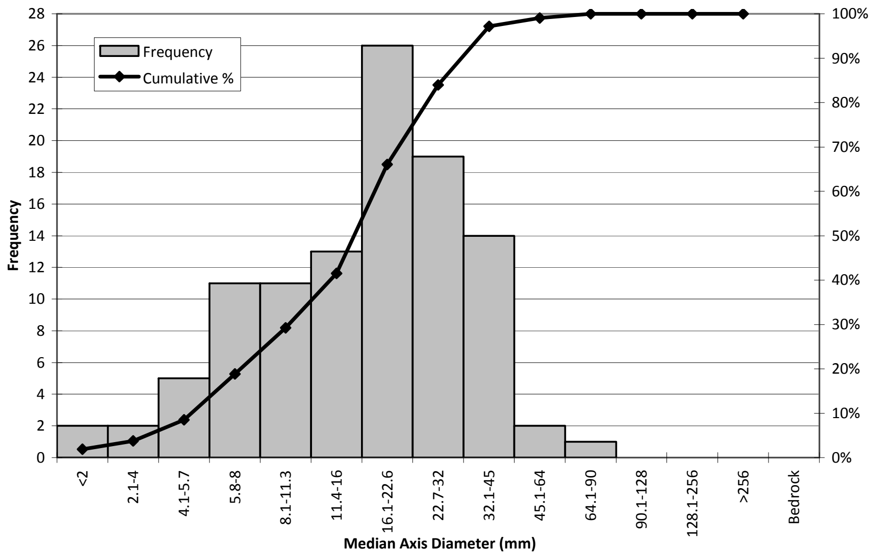
Notes:
1st riffle just US of pond outlet channel confluence
DS of pond outlet channel confluence, gravel lense in lower bank.

Slight to moderate armoring, relatively fresh deposit
Fine grained banks
Subsurface sizes range from 45 mm to sand

Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Frequency*	*Cumulative %*
Sand	<2	2	1.9%
Very Fine Gravel	2.1-4	2	3.8%
Fine Gravel	4.1-5.7	5	8.5%
Fine Gravel	5.8-8	11	18.9%
Medium Gravel	8.1-11.3	11	29.2%
Medium Gravel	11.4-16	13	41.5%
Coarse Gravel	16.1-22.6	26	66.0%
Coarse Gravel	22.7-32	19	84.0%
Very Coarse Gravel	32.1-45	14	97.2%
Very Coarse Gravel	45.1-64	2	99.1%
Small Cobble	64.1-90	1	100.0%
Small Cobble	90.1-128	0	100.0%
Large Cobble	128.1-256	0	100.0%
Small Boulders	>256	0	100.0%
Bedrock	Bedrock	0	100.0%
	Total	106	

HT 2 Pebble Count Surficial Grain Size Analysis



Location (Stream, Reach, Description)

Sediment Grain Size Analysis

Horsetail	Stream
Horsetail Menader	Reach
US first major bend	Location
3	Identifier / Unit
Riffle	Longitudinal Description (Pool, Riffle, Bend, Crossing)
Surficial	Sample Type: Armor Layer or Subarmor
1	Approximate Depth of Flow at Thalweg (ft)

8/6/2010	Date
M. Burke & C. Collins	Personnel
	Latitude
	Longitude
	Northing
	Easting
30	Waypoint

location

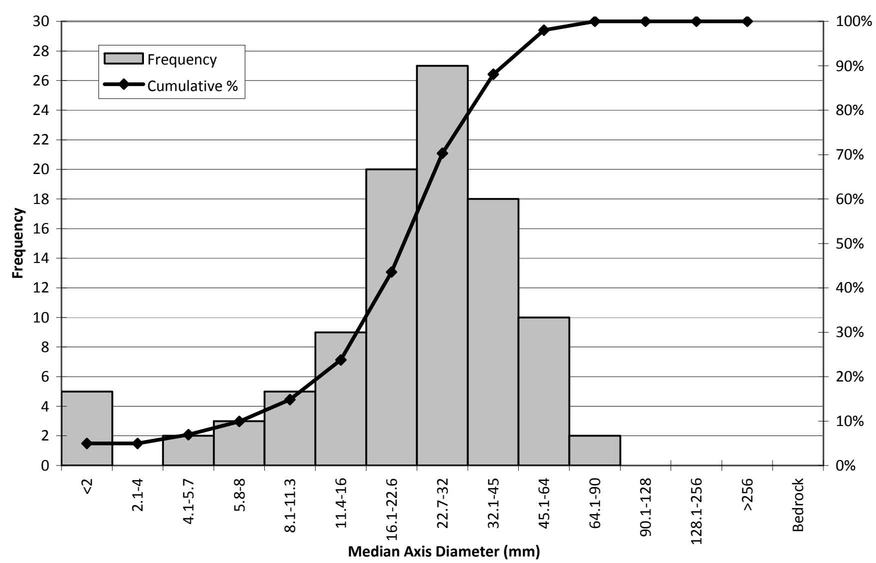
subsurface

Notes:
1st riffle US of 1st major bend above outlet channel confluence
Immed. US of backwater gravel deposit due to LWD DS
Slight incision at ash tree on R bank
Slight to moderate armoring, relatively fresh deposit
Fine grained banks
Subsurface sizes range from 64 mm to sand
Subsurface bulk sample collected at this location

Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Frequency*	*Cumulative %*
Sand	<2	5	5.0%
Very Fine Gravel	2.1-4	0	5.0%
Fine Gravel	4.1-5.7	2	6.9%
Fine Gravel	5.8-8	3	9.9%
Medium Gravel	8.1-11.3	5	14.9%
Medium Gravel	11.4-16	9	23.8%
Coarse Gravel	16.1-22.6	20	43.6%
Coarse Gravel	22.7-32	27	70.3%
Very Coarse Gravel	32.1-45	18	88.1%
Very Coarse Gravel	45.1-64	10	98.0%
Small Cobble	64.1-90	2	100.0%
Small Cobble	90.1-128	0	100.0%
Large Cobble	128.1-256	0	100.0%
Small Boulders	>256	0	100.0%
Bedrock	Bedrock	0	100.0%
	Total	101	

HT 3 Pebble Count Surficial Grain Size Analysis



Location (Stream, Reach, Description)

Sediment Grain Size Analysis

Horsetail	Stream	**8/6/2010**	Date
Horsetail Meander	Reach	M. Burke & C. Collins	Personnel
US first major bend	Location		Latitude
3	Identifier / Unit		Longitude
Riffle	Longitudinal Description (Pool, Riffle, Bend, Crossing)		Northing
Bulk Subsurface	Sample Type: Armor Layer or Subarmor		Easting
1	Approximate Depth of Flow at Thalweg (ft)	30	Waypoint

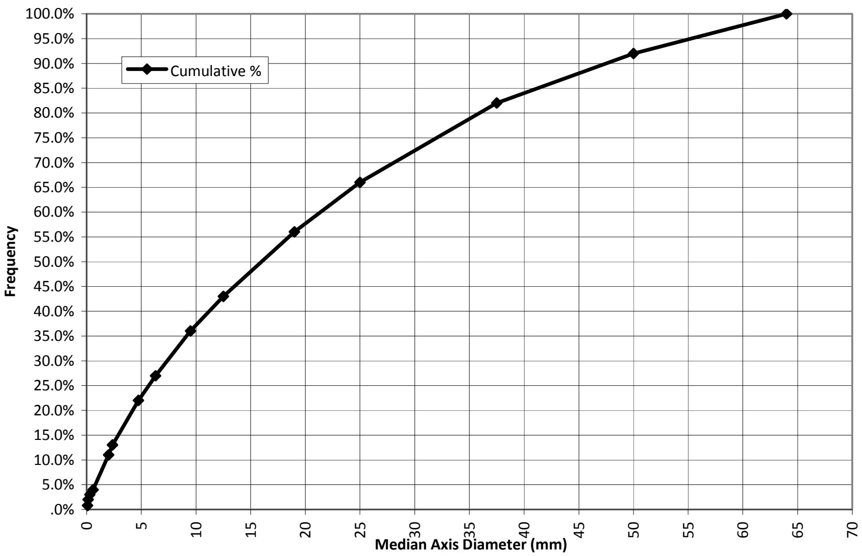
location

Notes:
1st riffle US of 1st major bend above outlet channel confluence
Immed. US of backwater gravel deposit due to LWD DS
Slight incision at ash tree on R bank
Slight to moderate armoring, relatively fresh deposit
Fine grained banks
Subsurface sizes range from 64 mm to sand
Subsurface bulk sample collected at this location

Pebble Count Data

Class (Wentworth)	*Sieve Size mm*	*Cumulative %*
Sand	0.075	.8%
Sand	0.15	2.0%
Sand	0.3	3.0%
Sand	0.6	4.0%
Sand	2	11.0%
Fine Gravel	2.36	13.0%
Fine Gravel	4.75	22.0%
Fine Gravel	6.3	27.0%
Med Gravel	9.5	36.0%
Med Gravel	12.5	43.0%
Coarse Gravel	19	56.0%
Coarse Gravel	25	66.0%
Very Coarse Gravel	37.5	82.0%
Very Coarse Gravel	50	92.0%
Very Coarse Gravel	64	100.0%

HT 3 Subsurface Grain Size Analysis



Location (Stream, Reach, Description)

Sediment Grain Size Analysis

Horsetail	Stream
Horsetail Fan	Reach
US 2nd major bend	Location
4	Identifier / Unit
Riffle	Longitudinal Description (Pool, Riffle, Bend, Crossing)
Surficial	Sample Type: Armor Layer or Subarmor
1	Approximate Depth of Flow at Thalweg (ft)

8/6/2010	Date
M. Burke & C. Collins	Personnel
	Latitude
	Longitude
	Northing
	Easting
31	Waypoint

location

subsurface

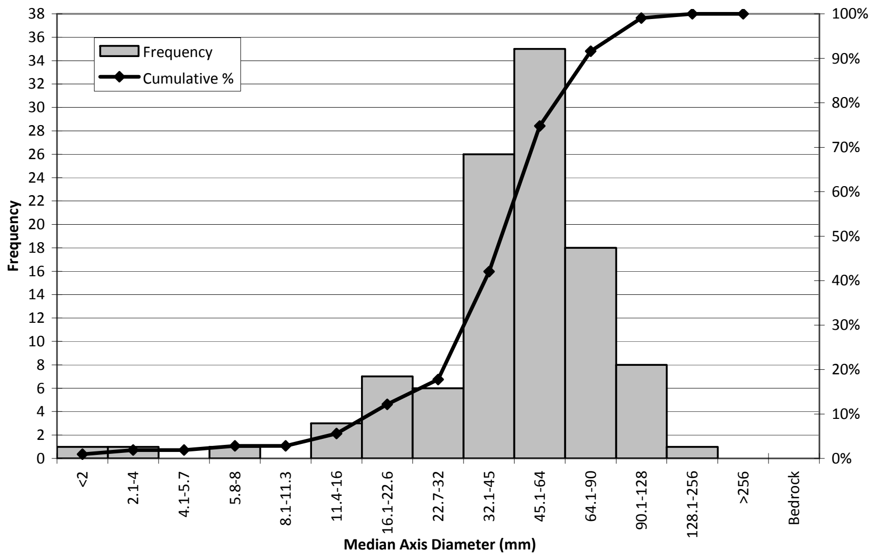
Notes:
2nd riffle US of 2nd major bend above outlet channel confluence
downstream of beaver dam complex
lateral bar with small lag boulders not included in sample
moderate armoring
Fine grained banks over alluvium in lower banks
Subsurface sizes range from 90 mm to sand

presence of lag going into 2nd bend, nose of hist. fan?

Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Frequency*	*Cumulative %*
Sand	<2	1	.9%
Very Fine Gravel	2.1-4	1	1.9%
Fine Gravel	4.1-5.7	0	1.9%
Fine Gravel	5.8-8	1	2.8%
Medium Gravel	8.1-11.3	0	2.8%
Medium Gravel	11.4-16	3	5.6%
Coarse Gravel	16.1-22.6	7	12.1%
Coarse Gravel	22.7-32	6	17.8%
Very Coarse Gravel	32.1-45	26	42.1%
Very Coarse Gravel	45.1-64	35	74.8%
Small Cobble	64.1-90	18	91.6%
Small Cobble	90.1-128	8	99.1%
Large Cobble	128.1-256	1	100.0%
Small Boulders	>256	0	100.0%
Bedrock	Bedrock	0	100.0%
	Total	107	

HT 4 Pebble Count Surficial Grain Size Analysis



Location (Stream, Reach, Description)

inter-fluve, inc.

Sediment Grain Size Analysis

Horsetail	Stream
Horsetail Fan	Reach
Ds of RR	Location
5	Identifier / Unit
Riffle	Longitudinal Description (Pool, Riffle, Bend, Crossing)
Surficial	Sample Type: Armor Layer or Subarmor
1	Approximate Depth of Flow at Thalweg (ft)

8/6/2010	Date
M. Burke & C. Collins	Personnel
	Latitude
	Longitude
	Northing
	Easting
32	Waypoint

location

subsurface

Notes:

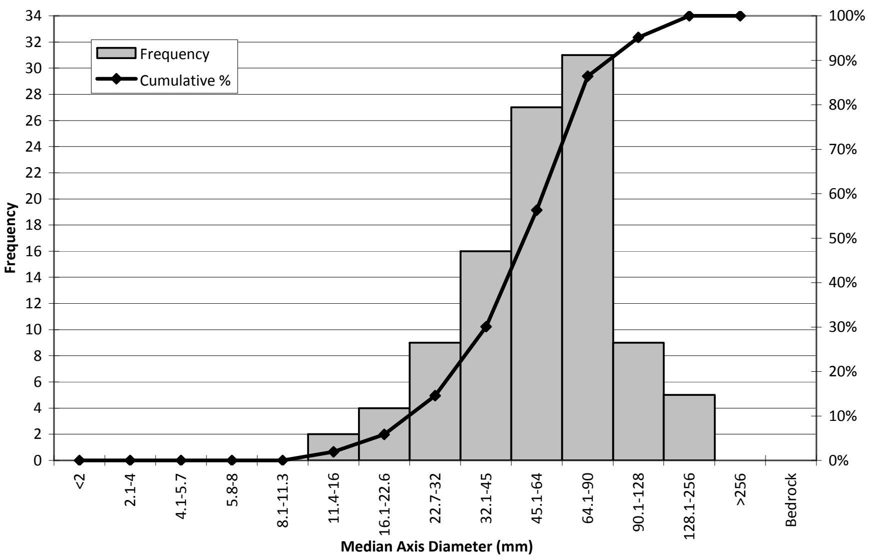
1st big riffle DS of RR

moderate armoring
Fine grained banks over alluvium in lower banks
Subsurface sizes range from 128 mm to sand
Subsurface bulk sample collected at this location

Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Frequency*	*Cumulative %*
Sand	<2	0	.0%
Very Fine Gravel	2.1-4	0	.0%
Fine Gravel	4.1-5.7	0	.0%
Fine Gravel	5.8-8	0	.0%
Medium Gravel	8.1-11.3	0	.0%
Medium Gravel	11.4-16	2	1.9%
Coarse Gravel	16.1-22.6	4	5.8%
Coarse Gravel	22.7-32	9	14.6%
Very Coarse Gravel	32.1-45	16	30.1%
Very Coarse Gravel	45.1-64	27	56.3%
Small Cobble	64.1-90	31	86.4%
Small Cobble	90.1-128	9	95.1%
Large Cobble	128.1-256	5	100.0%
Small Boulders	>256	0	100.0%
Bedrock	Bedrock	0	100.0%
	Total	103	

HT 5 Pebble Count Surficial Grain Size Analysis



Location (Stream, Reach, Description)

Sediment Grain Size Analysis

Horsetail	Stream	**8/6/2010**	Date
Upper Horsetail	Reach	M. Burke & C. Collins	Personnel
Ds of RR	Location		Latitude
5	Identifier / Unit		Longitude
Riffle	Longitudinal Description (Pool, Riffle, Bend, Crossing)		Northing
Bulk Subsurface	Sample Type: Armor Layer or Subarmor		Easting
1	Approximate Depth of Flow at Thalweg (ft)	32	Waypoint

location

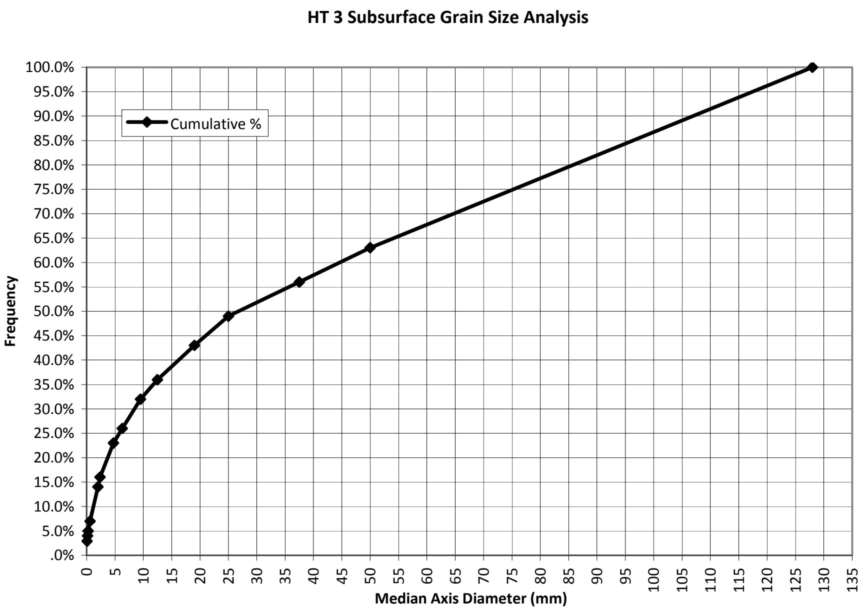
Notes:

1st big riffle DS of RR

moderate armoring
Fine grained banks over alluvium in lower banks
Subsurface sizes range from 128 mm to sand
Subsurface bulk sample collected at this location

Pebble Count Data

Class (Wentworth)	*Sieve Size mm*	*Cumulative %*
Sand	0.075	2.9%
Sand	0.15	4.0%
Sand	0.3	5.0%
Sand	0.6	7.0%
Sand	2	14.0%
Fine Gravel	2.36	16.0%
Fine Gravel	4.75	23.0%
Fine Gravel	6.3	26.0%
Med Gravel	9.5	32.0%
Med Gravel	12.5	36.0%
Coarse Gravel	19	43.0%
Coarse Gravel	25	49.0%
Very Coarse Gravel	37.5	56.0%
Very Coarse Gravel	50	63.0%
Large cobble	128	100.0%



10 APPENDIX B: STAGE DATA WORKSHEETS

Stage data spreadsheet in electronic format available upon request from LCREP. Contact:

Chris Collins
Email: cCollins@lcrep.org
Phone: 503.226.1565 x235

11 APPENDIX C: STREAM TEMPERATURE ANALYSIS SPREADSHEET

Stream temperature analysis spreadsheet in electronic format available upon request from LCREP. Contact:

Chris Collins
Email: cCollins@lcrep.org
Phone: 503.226.1565 x235

12 APPENDIX D: DETAILED FISH PASSAGE ASSESSMENT RESULTS

I-84 Culvert With Hydraulic Design Criteria

Table D1. Fish passage scores for juvenile salmonids at I-84 culvert, based on hydraulic design criteria and 50% excedence stage in Columbia River

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow	3	3	3	5	6	6	3	3	3	5	3	3
ODFW High Flow	4	4	4	5	*	*	*	*	*	*	4	4
50% Excedence Flow	4	4	4	6	6	6	4	3	3	3	3	5
95% Excedence Flow	3	3	3	6	6	6	3	3	3	3	3	3
Average Score	3.5	3.5	3.5	5.5	6	6	3.3	3	3	3.7	3.3	3.8

Table D2. Fish passage scores for juvenile salmonids at I-84 culvert, based on hydraulic design criteria and 90% excedence stage in Columbia River

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow	3	3	3	4	5	3	3	3	3	3	3	3
ODFW High Flow	4	4	4	4	*	*	*	*	*	*	4	4
50% Excedence Flow	4	4	4	3	6	3	3	3	3	3	3	5
95% Excedence Flow	3	3	3	3	6	4	3	3	3	3	3	3
Average Score	3.5	3.5	3.5	3.5	5.7	3.3	3	3	3	3	3.3	3.8

Table D3. Fish passage scores for adult steelhead and coho at I-84 culvert, based on hydraulic design criteria and 50% excedence stage in Columbia River

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow		4	4	5	6				4	5	4	4
ODFW High Flow		5	5	5	*				*	*	5	5
50% Excedence Flow		5	5	6	6				4	4	4	5
95% Excedence Flow		4	4	6	6				4	4	4	5
Average Score		4.5	4.5	5.5	6				4	4.3	4.3	4.8

Table D4. Fish passage scores for adult steelhead and coho at I-84 culvert, based on hydraulic design criteria and 90% excedence stage in Columbia River

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow		4	4	5	6				4	4	4	4
ODFW High Flow		5	5	5	*				*	*	5	5
50% Excedence Flow		5	5	4	6				4	4	4	5
95% Excedence Flow		4	4	5	6				4	4	4	5
Average Score		4.5	4.5	4.8	6				4	4	4.3	4.8

Table D5. Fish passage scores for adult chum at I-84 culvert, based on hydraulic design criteria and 50% excedence stage in Columbia River

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow	4										4	4
ODFW High Flow	5										5	5
50% Excedence Flow	5										4	5
95% Excedence Flow	4										4	4
Average Score	4.5										4.3	4.5

Table D6. Fish passage scores for adult chum at I-84 culvert, based on hydraulic design criteria and 90% excedence stage in Columbia River

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow	4										4	4
ODFW High Flow	5										5	5
50% Excedence Flow	5										4	5
95% Excedence Flow	4										4	4
Average Score	4.5										4.3	4.5

Table D7. Fish passage scores for adult cutthroat at I-84 culvert, based on hydraulic design criteria and 50% excedence stage in Columbia River

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow	3	3	3	5	6							
ODFW High Flow	4	4	4	5	*							
50% Excedence Flow	4	4	5	6	6							
95% Excedence Flow	3	3	3	6	6							
Average Score	3.5	3.5	3.8	5.5	6							

Table D8. Fish passage scores for adult cutthroat at I-84 culvert, based on hydraulic design criteria and 90% excedence stage in Columbia River

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow	3	3	3	4	6							
ODFW High Flow	4	4	4	4	*							
50% Excedence Flow	4	4	5	3	6							
95% Excedence Flow	3	3	3	3	6							
Average Score	3.5	3.5	3.8	3.5	6							

Oneonta Gorge Crossings With Hydraulic Design Criteria

Table D9. Fish passage scores for juvenile salmonids at Union Pacific Railroad, based on hydraulic design criteria.

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow	3	3	3	2	1	2	3	2	1	1	3	3
ODFW High Flow	2	2	2	*	*	*	*	*	*	*	2	2
50% Excedence Flow	1	2	2	1	1	3	3	3	3	3	1	2
95% Excedence Flow	1	1	1	2	3	3	3	3	3	3	1	1
Average Score	1.5	1.8	1.8	1.2	1.2	2.5	3	2.5	2.2	2.3	1.4	1.8

Table D10. Fish passage scores for juvenile salmonids at historic highway/pedestrian bridge, based on hydraulic design criteria.

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow	3	3	3	3	2	2	2	2	2	2	3	3
ODFW High Flow	3	3	3	*	*	*	*	*	*	*	3	3
50% Excedence Flow	3	3	3	2	2	2	2	2	2	2	2	3
95% Excedence Flow	2	2	2	2	2	2	2	2	2	2	2	2
Average Score	2.6	2.6	2.6	2.1	1.9	1.9	1.9	1.9	2	1.9	2.3	2.7

Table D11. Fish passage scores for adult steelhead and coho at railroad, based on hydraulic design criteria.

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow		1	1	2	3				3	3	1	1
ODFW High Flow		2	2	*	*				*	*	2	2
50% Excedence Flow		3	3	3	3				3	3	3	3
95% Excedence Flow		3	3	3	3				3	3	3	3
Average Score		2	2	2.5	3				3	3	2	2

Table D12. Fish passage scores for adult steelhead and coho at historic highway/pedestrian bridge, based on hydraulic design criteria.

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow		3	3	2	3				2	3	3	3
ODFW High Flow		3	3	*	*				*	*	3	3
50% Excedence Flow		3	3	3	2				2	2	3	3
95% Excedence Flow		3	3	2	2				2	2	2	2
Average Score		2.8	2.8	2.3	2.4				1.9	2	2.6	2.6

Table D13. Fish passage scores for adult chum at railroad, based on hydraulic design criteria.

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow	Jan										Nov	Dec
	Score										Score	Score
ODFW High Flow	2										2	2
50% Excedence Flow	0.5										0.5	0.5
95% Excedence Flow	0.5										3	2.5
Average Score	3										3	3

Table D14. Fish passage scores for adult chum at historic highway/pedestrian bridge, based on hydraulic design criteria.

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow	3										3	3
ODFW High Flow	3										3	3
50% Excedence Flow	3										3	3
95% Excedence Flow	3										2	2
Average Score	2.8										2.7	2.7

Table D15. Fish passage scores for adult cutthroat at railroad, based on hydraulic design criteria and.

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow	3	3	3	1.5	3							
ODFW High Flow	1.5	1.5	1.5	*	*							
50% Excedence Flow	1	3	3	3	3							
95% Excedence Flow	3	3	3	3	3							
Average Score	2.1	2.6	2.6	2.5	3							

Table D16. Fish passage scores for adult cutthroat at historic highway/pedestrian bridge, based on hydraulic design criteria

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow	3	3	3	3	3							
ODFW High Flow	4	4	4	*	*							
50% Excedence Flow	4	4	4	3	3							
95% Excedence Flow	3	3	3	2	2							
Average Score	3.3	3.3	3.3	2.6	2.5							

I-84 Culvert With Literature-based Swimming Capacity Criteria

Table D17. Fish passage scores for adult steelhead at I-84 culvert, based on literature-based swimming criteria and 50% excedence stage in Columbia River

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow		5	5	6	6							
ODFW High Flow		6	6	6	*							
50% Excedence Flow		6	6	6	6							
95% Excedence Flow		5	5	6	6							
Average Score		5.5	5.5	6	6							

Table D18. Fish passage scores for adult steelhead at I-84 culvert, based on literature-based swimming criteria and 90% excedence stage in Columbia River

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow		5	5	6	6							
ODFW High Flow		6	6	6	*							
50% Excedence Flow		6	6	4	6							
95% Excedence Flow		5	5	5	6							
Average Score		5.5	5.5	5.3	6							

Table D19. Fish passage scores for adult coho at I-84 culvert, based on literature-based swimming criteria and 50% excedence stage in Columbia River

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow									4	6	4	4
ODFW High Flow									*	*	*	*
50% Excedence Flow									4	4	4	6
95% Excedence Flow									4	4	5	5
Average Score									4	4.7	4.3	5

Table D20. Fish passage scores for adult coho at I-84 culvert, based on literature-based swimming criteria and 90% excedence stage in Columbia River

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow									4	4	4	4
ODFW High Flow									*	*	*	*
50% Excedence Flow									4	4	4	6
95% Excedence Flow									4	4	5	5
Average Score									4	4	4.3	5

Table D21. Fish passage scores for adult chum at I-84 culvert, based on literature-based swimming criteria and 50% excedence stage in Columbia River

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow	4										4	4
ODFW High Flow	6										6	6
50% Excedence Flow	6										4	6
95% Excedence Flow	5										5	5
Average Score	5.3										4.8	5.3

Table D22. Fish passage scores for adult chum at I-84 culvert, based on literature-based swimming criteria and 90% excedence stage in Columbia River

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow	4										4	4
ODFW High Flow	6										6	6
50% Excedence Flow	6										4	6
95% Excedence Flow	5										5	5
Average Score	5.3										4.8	5.3

Table D23. Fish passage scores for adult cutthroat at I-84 culvert, based on literature-based swimming criteria and 50% excedence stage in Columbia River

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow	3	3	3	5	6							
ODFW High Flow	5	5	5	6	*							
50% Excedence Flow	5	5	5	6	6							
95% Excedence Flow	4	4	4	6	6							
Average Score	4.3	4.3	4.3	5.8	6							

Table D24. Fish passage scores for adult cutthroat at I-84 culvert, based on literature-based swimming criteria and 90% excedence stage in Columbia River

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow	3	3	3	5	6							
ODFW High Flow	5	5	5	5	*							
50% Excedence Flow	5	5	5	4	6							
95% Excedence Flow	4	4	4	4	6							
Average Score	4.3	4.3	4.3	4.5	6							

Oneonta Gorge Crossings With Literature-based Swimming Capacity Criteria

Table D25. Fish passage scores for adult steelhead at Railroad Bridge, based on literature-based swimming criteria

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow		5.5	5.5	3	3							
ODFW High Flow		3	3	*	*							
50% Excedence Flow		4.5	4.5	3	3							
95% Excedence Flow		3	3	3	3							
Average Score		4	4	3	3							

Table D26. Fish passage scores for adult steelhead at Historic Highway/Pedestrian Bridges, based on literature-based swimming criteria

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow		6	6	6	4							
ODFW High Flow		6	6	*	*							
50% Excedence Flow		5	5	4	4							
95% Excedence Flow		4	4	4	4							
Average Score		5.2	5.2	4.5	3.9							

Table D27. Fish passage scores for adult coho at Railroad Bridge, based on literature-based swimming criteria

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow									3	3	6	6
ODFW High Flow									*	*	3	3
50% Excedence Flow									3	3	3	4
95% Excedence Flow									3	3	3	3
Average Score									3	3	3.6	3.8

Table D28. Fish passage scores for adult coho at Historic Highway/Pedestrian Bridges, based on literature-based swimming criteria

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow									4	5	6	5
ODFW High Flow									*	*	6	6
50% Excedence Flow									4	4	4	5
95% Excedence Flow									4	4	4	4
Average Score									3.9	4	4.8	4.9

Table D29. Fish passage scores for adult chum at Railroad Bridge, based on literature-based swimming criteria

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow	3										3	3
ODFW High Flow	3										3	3
50% Excedence Flow	3										3	4
95% Excedence Flow	3										3	3
Average Score	2.8										2.9	3

Table D30. Fish passage scores for adult chum at Historic Highway/Pedestrian Bridges, based on literature-based swimming criteria

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow	3										3	3
ODFW High Flow	4										4	4
50% Excedence Flow	4										3	3
95% Excedence Flow	3										3	3
Average Score	3.6										3.4	3.4

Table D31. Fish passage scores for adult cutthroat at Railroad Bridge, based on literature-based swimming criteria

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow	3	3	3	5	3							
ODFW High Flow	5	5	5	*	*							
50% Excedence Flow	5	6	6	3	3							
95% Excedence Flow	3	3	3	3	3							
Average Score	3.8	4	4	3.5	3							

Table D32. Fish passage scores for adult cutthroat at Historic Highway/Pedestrian Bridges, based on literature-based swimming criteria

Flow	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
High Flow	3	3	3	5	4							
ODFW High Flow	5	5	5	*	*							
50% Excedence Flow	5	5	5	4	4							
95% Excedence Flow	4	4	4	4	3							
Average Score	4.1	4.1	4.1	4.1	3.8							