Technical Report

Multnomah & Wahkeena Creek Restoration Project
Feasibility and Alternatives Analysis

Prepared by
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U.S. Forest Service
Henderson Land Services

Funded by
East Multnomah Soil and Water Conservation District

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Table of Contents

1 INTRODUCTION

The Lower Columbia River Estuary Partnership (Estuary Partnership) is working with a group of stakeholders to develop enhancement and restoration actions on Wahkeena and Multnomah Creeks, two small tributaries to the Columbia River located in the Columbia River Gorge National Scenic Area (CRGNSA). Evaluation of site conditions suggests that landscape alterations and resource management practices continue to shape ecological conditions within riparian, fluvial, and lacustrine systems. Key physical processes have been altered, which has led to complex, system-wide responses. Due to these factors, habitat favorable for sustaining populations of native species, including ESA-listed salmonids, has been reduced. In some cases, conditions appear to be on a continued downward trend, placing incremental stress on native populations and producing conditions that favor non-native, invasive species. Without intervention, impacts to ESA-listed salmonids, water quality, and biological diversity are expected to continue, if not worsen.

1.1 PURPOSE & OBJECTIVE

The overall objective of this project is to address environmental conditions on lower Multnomah and Wahkeena Creeks by developing management actions that balance ecological enhancement with recreational, tourism, transportation, and other uses in this critically important portion of the CRGNSA. There are a diverse set of natural resource management goals within the project site, and the secondary purpose of this project is to facilitate development of a cohesive management plan.

As the first step toward restoring the site, the Estuary Partnership and other project stakeholders are 1) identifying to what extent physical processes have been altered and how these processes shape landscape and fluvial responses and biotic communities; 2) identifying limiting factors; 3) developing site specific goals and objectives to address limiting factors; 4) identifying and assessing alternatives that improve ecological conditions; and 5) developing conceptual designs for the preferred alternative(s).

To address the above objectives this technical memo includes three major components:

- Baseline Site Investigations – Collection and analysis of baseline data required to inform alternatives analysis and design;
- Feasibility and Alternatives Analyses – Development and analysis of enhancement alternatives for each subreach; and,
- Concept Designs – Development of conceptual level designs for each subreach’s preferred alternative.

1.2 STAKEHOLDER INVOLVEMENT

The Estuary Partnership is working in partnership with the following organizations to develop this project:

- East Multnomah Soil and Water Conservation District – grantor
- United States Forest Service (USFS) – landowner
- Oregon Parks and Recreation Department (OPRD) – landowner
- Oregon Department of Fish and Wildlife (ODFW) – landowner, water rights holder
- Oregon Department of Transportation (ODOT) – easement holder
- Friends of the Columbia Gorge (FOCG) – partner

As evident from the stakeholder list, this project represents a combined effort amongst federal, state, and non-profit entities. The diversity of stakeholders reflects the site's complexity, which is due primarily to a diverse set of natural resource, tourism, and recreational management goals.

In recognition of the complexity of the project site, the Estuary Partnership met with stakeholders over the course of nine months. Stakeholder participation including expert opinions, data collection and review, development of alternatives, and final review of concept designs has been critical in development of this document.

2 BASELINE CONDITIONS

2.1 SITE OVERVIEW & HISTORY

The project site is located on approximately 60 acres of historic Columbia River floodplain at River Mile (RM) 136, ten miles downstream from Bonneville Dam (Figure 1). The site contains two perennial streams (Wahkeena and Multnomah Creeks), one unnamed intermittent stream, two man-made lakes (Benson Lake and Hartman Pond), and small wetland areas fringing the lake and pond (Figure 2). The site is bounded to the north by I-84 and to the south by the Union Pacific railroad (UPRR). It extends east to Multnomah Falls and west to the western boundary of Hartman Pond.

Prior to settlement, the Government Land Office surveyed the site in 1859 and again in 1906 (Christy 2010). The surveyors characterized the site as riparian forest dominated by ash, maple and Douglas fir with two areas of willow flats (Figure 3). Much of the watersheds along the Gorge bluffs were described as burned timber. Wahkeena Creek meandered through the site crossing one of the surveyor's section lines several times and entered the Columbia River along the center line of present day Benson Lake. The unnamed creek draining Mist Falls flowed along the west end of the site, and Multnomah Creek flowed due north from its falls entering the river at the present location of the visitor parking area. There is no mention of ponds or lakes in the surveyor's notes; however, the surveyor did note that the site likely flooded annually during the Columbia River's spring freshet. (Christy 2010)

The Oregon Railway and Navigation Company constructed the rail grade along the southern margin of the site in 1882. The construction of the rail grade fixed the locations at which the site's three streams enter the floodplain, which reduces the migration of the creeks over their alluvial fans. The Columbia River Highway was constructed at the southern extent of the site between 1912 and 1914. Bridges constructed for the historic highway further fixed the locations of the stream crossings and constricted the creek channels. Aerial photographs from 1935 and 1939 (Figure 4) show this infrastructure. The 1935 aerial photo shows channel alignments for the three streams that generally match those identified in the GLO survey notes. A prominent alluvial fan is present in the 1935 aerial photo where Multnomah Creek enters the Columbia River. The western end of the site is shown as forested. Although still moderately forested, the eastern end of the site shows clearing for agricultural development and construction of a road network. The 1939 aerial photo presumably was taken during elevated flows in the Columbia River as the outlets of all three creeks and the approximate footprint of present day Benson Lake are all inundated. The 1939 aerial photo also shows several buildings (reportedly a Civilian Conservation Corps camp) at the current location of the Benson State Recreation Area parking lot.

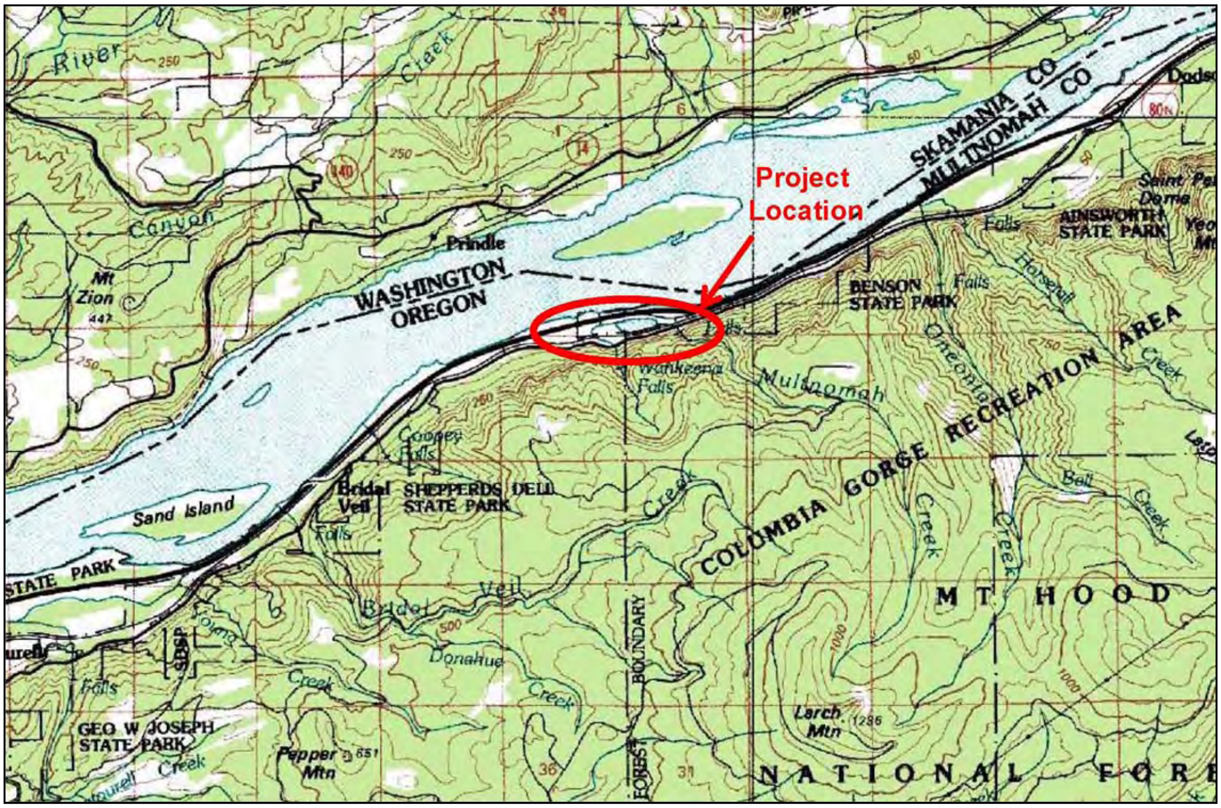

Figure 1: Project Location Map

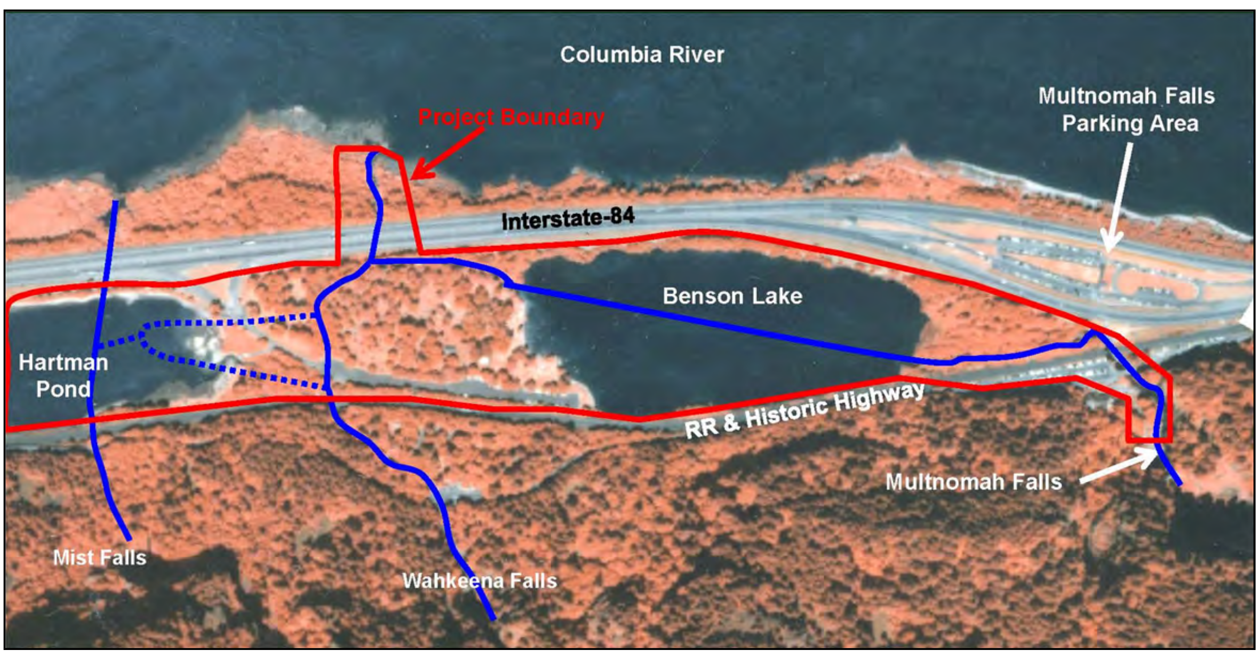

Figure 2: Site Map. Note: the dotted line represents the diversion from Wahkeena Creek into Hartman Pond. Hartman Pond discharges to the Columbia River as well as back into Wahkeena Creek.

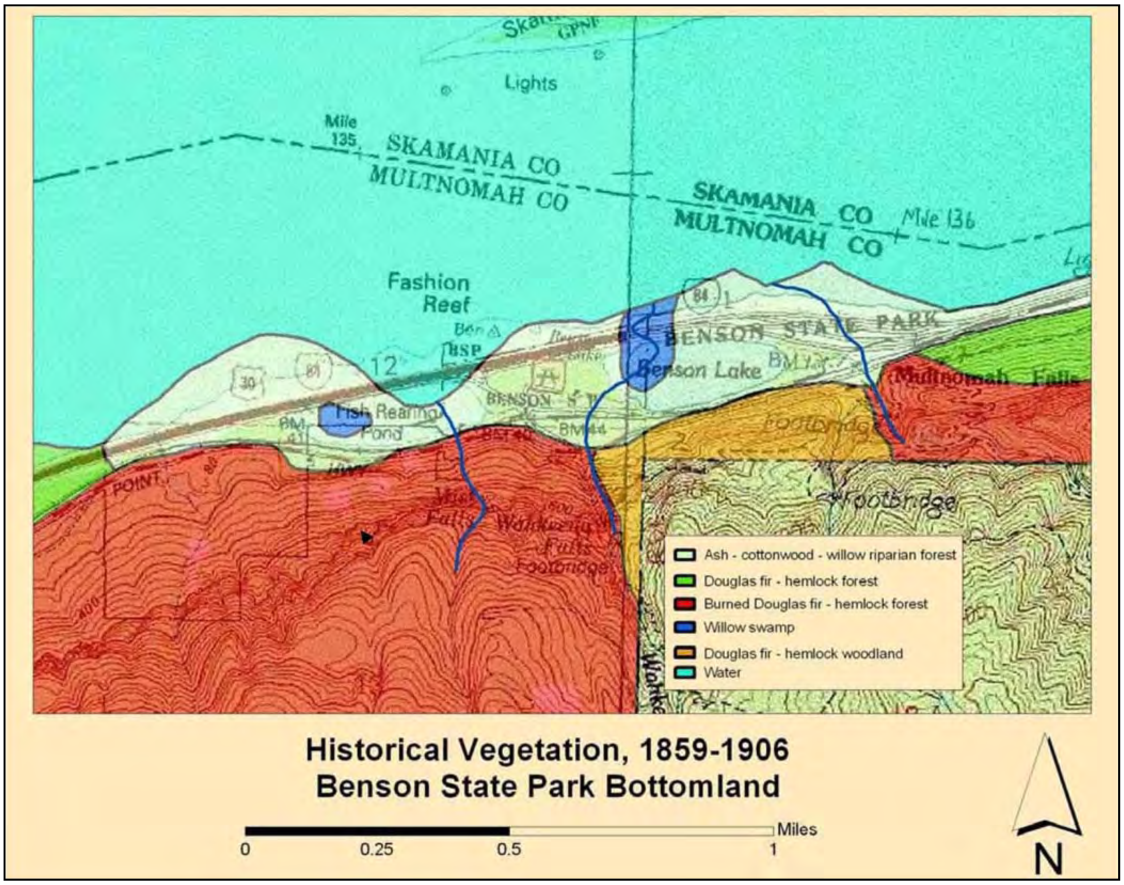

Figure 3: 1859 and 1906 historical survey data.

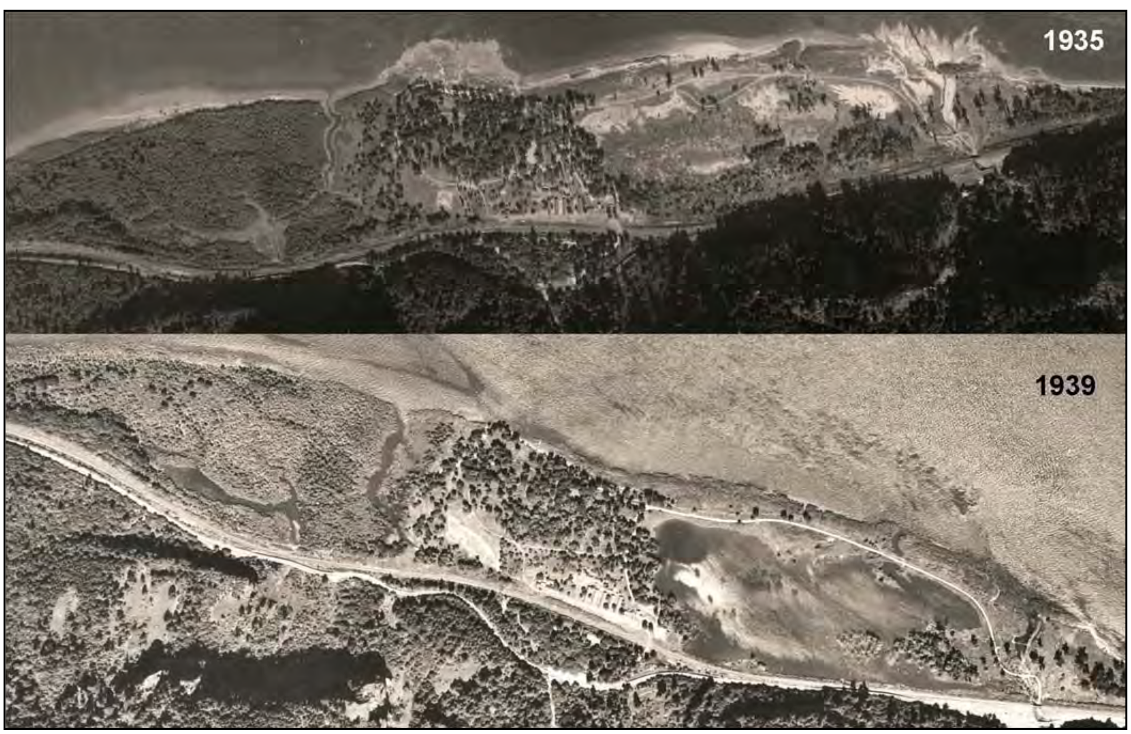

Figure 4: 1935 and 1939 aerial photos.

The primary disturbance to the site occurred through the 1940s to 1960s – the period during which I-84 was built and subsequently widened. A 1948 aerial image shows the recently constructed I-84 (Figure 5). At this point, both Wahkeena and Multnomah Creeks have been diverted and Benson Lake (through which Multnomah Creek is flowing) has been excavated, likely for fill material to construct the I-84 road prism. The western portion of the site is relatively intact. i.e., the rearing pond (now Hartman Pond) has not been constructed. A 1956 aerial image shows similar conditions (Figure 5). 1971 and 1995 aerial images show the newly constructed Hartman Pond, which was excavated for fill material during widening of I-84 (Figure 6). A certificate of water right granted to the State of Oregon in 1960 permits diversion of up to 30.0 cubic feet per second from Wahkeena Creek to Wahkeena Rearing Lake (today called Hartman Pond).

As shown in Figure 7, which contrasts channel alignments in 1935 and 2004, the end result of I-84 construction and widening through the 1940s and 50s is that all three of the site's streams were rerouted, two large lakes were excavated to provide fill material, and a significant portion of Wahkeena Creek's flow was diverted. Multnomah Creek now flows through Benson Lake joining Wahkeena Creek for a common outlet to the Columbia River. Mist Falls' unnamed stream is routed through present day Hartman Pond, which also is fed by a Wahkeena Creek diversion and another small, intermittent drainage to the west of Mist Falls. Hartman Pond appears to have two outlets (one to the Columbia River and one to Wahkeena Creek). Table 1 summarizes alterations to the site.

Table 1. Summary of historical alterations at the site.

Date	Event	Activity
1882	Railroad	Rail grade constructed along southern margin of site
1912-1915	Historic Highway and Visitor Area	Columbia River Highway constructed between the railroad and the valley slopes; Multnomah Falls Visitor Area constructed
1940s	I-84 Construction	Interstate Highway 84 constructed along northern margin of site; Multnomah and Wahkeena Creeks diverted; Benson Lake excavated
1940s	Benson State Recreation Area Developed	OPRD purchased Benson State Recreation Area and developed the site for day use activities, e.g., fishing and boating.
1950s-1960s	I-84 Expansion	Interstate Highway 84 widened; Hartman Pond excavated; portion of Wahkeena Creek diverted to Hartman Pond

Figure 5: 1948 and 1956 aerial photos.

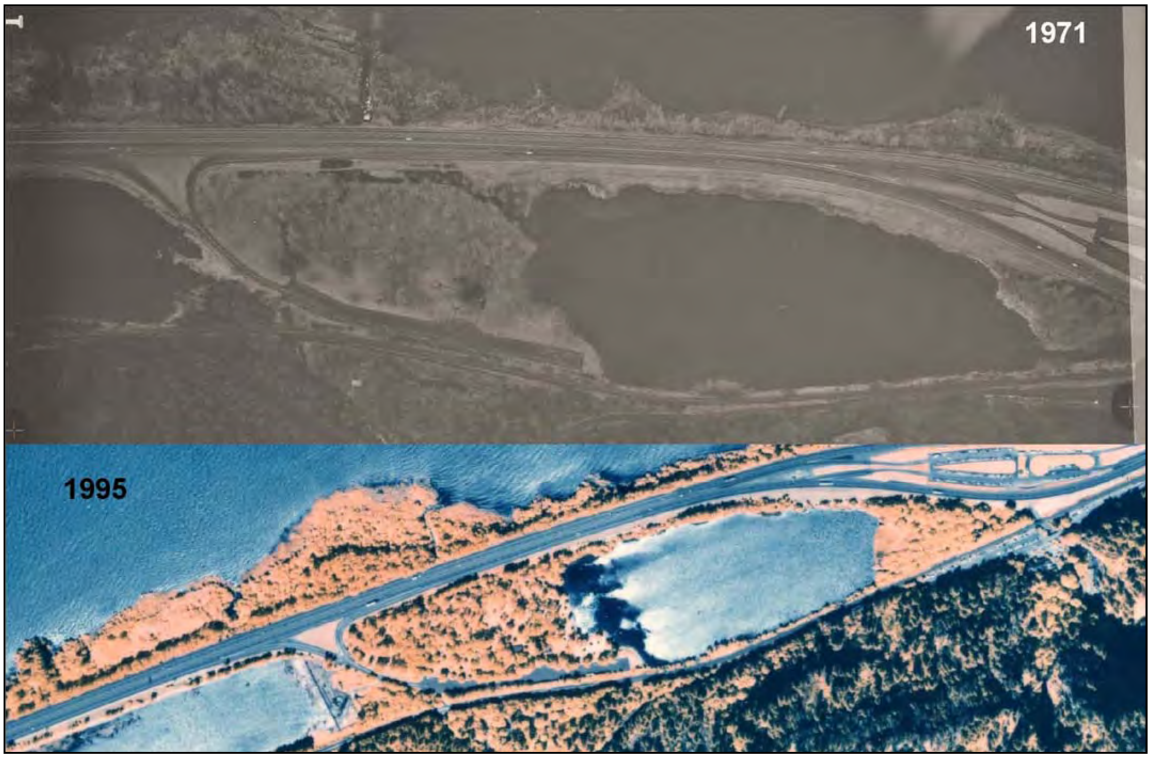

Figure 6: 1971 and 1995 aerial photos.

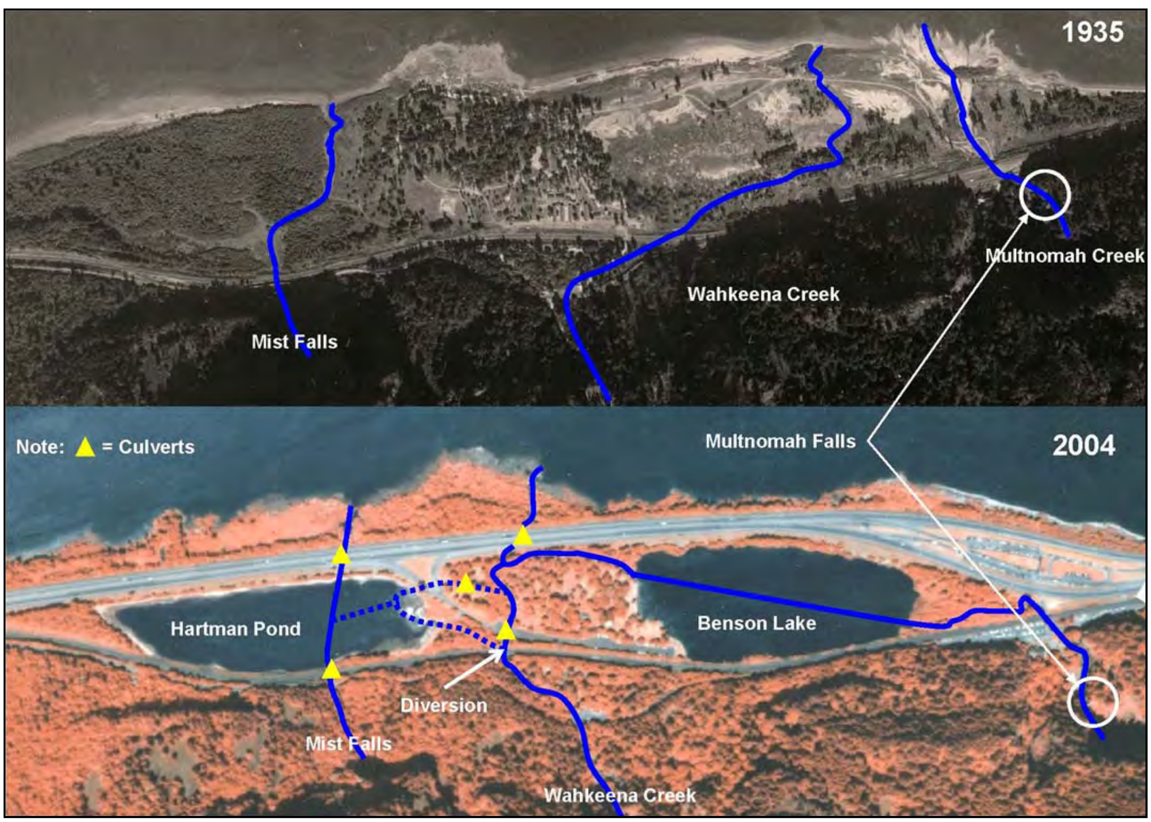

Figure 7: 1935 and 2004 channel alignments.

2.2 BASELINE PHYSICAL CONDITIONS

The Multnomah and Wahkeena Creek watersheds are located adjacent to each other approximately 30 miles to the east of Portland, Oregon (Figure 8). The watershed areas are approximately 5.5- mi^2 (Multnomah Creek) and 0.8-m^2 (Wahkeena Creek). The entirety of the two basins are located in the CRGNSA, and 95% of the total watershed area is located on publicly owned land. Elevations range from a maximum of approximately 4,000 feet and 1,200 feet at the headwaters of Multnomah and Wahkeena Creeks respectively down to 30 feet at their confluence with the Columbia River. Both Multnomah and Wahkeena Creeks plummet off of the Gorge wall into alluvial bottomlands, which are part of the Columbia River floodplain. Overall, both drainages are heavily forested in the upper basin; the Multnomah watershed has pockets of old-growth conifer (primarily noble fir). Both basins were historically logged and forest fires are an integral part of the ecosystem within these two drainages.

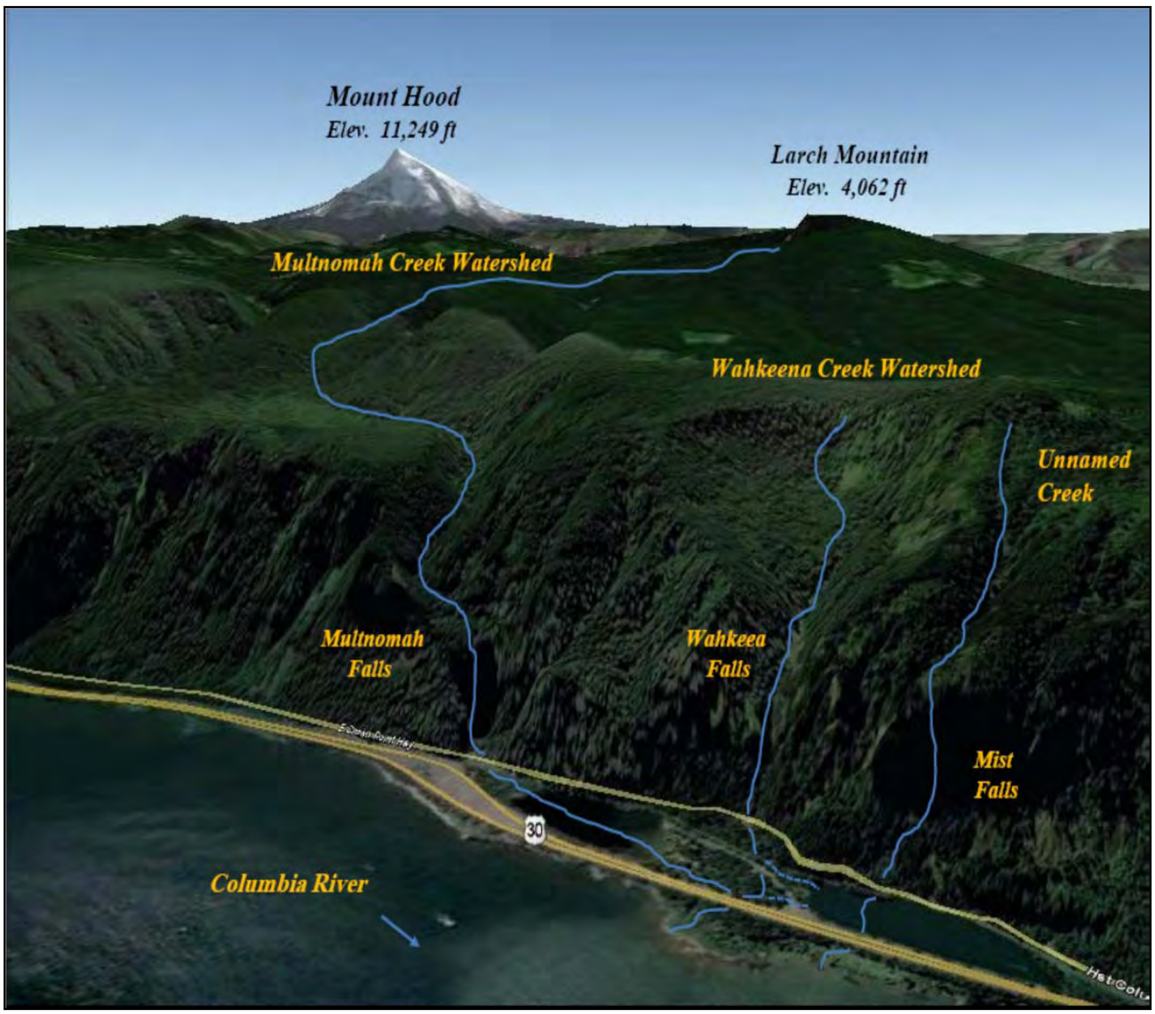

Figure 8: Multnomah, Wahkeena, and adjacent unnamed watersheds Google, 2010).

Precipitation falls primarily as rain throughout both watersheds. Mean annual precipitation varies considerably from an estimated 70 inches at the Columbia River to approximately 100 inches along upper elevations of Multnomah Creek. The two-year 24-hour maximum precipitation intensity is estimated to be approximately 3-4 inches. Although neither basin is gaged, hydrographs in adjacent basins show peak flows during January- March and low flows during August-October. Winter rain events and rain-on-snow events produce the largest peak flows. Wahkeena Creek is characterized by its small, steep watershed, which makes the creek “flashy” in terms of responding to hydrologic events.

Within the project area, the gradient on Multnomah Creek varies from 2% above Benson Lake to 0.1% below the lake. Gradient along Wahkeena Creek varies from approximately 7% above the Benson State Recreation Area parking lot to 0.1% immediately above the I-84 culvert.

Benson Lake has a surface area of approximately 22 acres and is fed by Multnomah Creek. As noted above, ODOT excavated the lake as a source of fill material to construct the I-84 highway prism. Benson Lake has an average depth of approximately 6 feet with a maximum depth of 9 feet. The lake has extensive shallow areas that average 1-2 feet depth, including a large delta at the mouth of Multnomah Creek.

2.3 Quaternary Geology & Geomorphology

Between their respective sources to the confluence of the Columbia River, Multnomah and Wahkeena Creeks have been formed through tectonic subduction of the Juan de Fuca plate. Rapid uplift of this region over the last two million years forced the Columbia River to incise leaving relict streams plunging off the Gorge walls, including Multnomah and Wahkeena Creeks. The stratigraphy of these watersheds, including the gorge wall, are almost entirely composed of Columbia River Basalt Group (CRBG) formed during the Miocene period from 17- 6 million years ago and spanning over 300 separate flow events (Norman and Roloff, 2004). Most of Multnomah Creek flows through the resistant layers of the CRBG, with the Troutdale formation contributing an abundant supply of gravels in the upper basin, and alluvium deposits occurring along the lowest bounds of the watersheds. The CRBG group overall is resistant to erosion and where softer interflow from basalt flows occurs erosion is accelerated and impacts the rate of retreat of the falls (Norman and Roloff, 2004). Below the falls, the creeks transition from bedrock and colluvial deposits to alluvial deposits within the historic boundaries of the Columbia River floodplain.

Several processes have been important in shaping modern day morphology prior to development in the lower portion of the creeks. Quaternary deposits and morphology of these basins were the result of the Pleistocene era Missoula Floods between 12,700 and 15,300 years ago, the largest known floods to have occurred over the last two million years (WDNR, 1991). The retreat of the Cordilleran ice sheet led to failed ice dams and enormous floods greater than 1,000 feet deep roared down the Columbia River, changing the river by significantly widening its active floodplain and depositing large amounts of silt, sand, and clay within modern day bottomlands (O’Conner et al, 2003).

Mainstem flooding along Wahkeena and Multnomah Creeks has historically affected channel morphology. Notable floods on record include the 1996 and 2003 flood events. The 1996 flood transported a large amount of material in both basins, aiding in the (re)development of an alluvial fan immediately above Wahkeena Creek’s railroad bridge. This event also deposited a significant amount of material within the Multnomah Falls Visitor Area and initiated development of the existing sediment management plan. Overall, bed elevations on both creeks changed significantly with an estimated 3-5 feet of deposition within the channels. Periodic dredging of both channels is required to maintain adequate capacity.

2.4 Species Use

2.4.1 Salmonids

The project site is known to support salmonids listed under the Endangered Species Act (ESA) as well as other native aquatic and terrestrial species. This section details known and presumed use of the site by both local stocks (Lower Columbia River [LCR] Evolutionarily Significant Units [ESUs]) and up-river stocks (those spawned above Bonneville Dam).

2.4.1.1 Lower columbia ESUs

Myers et al. (2003) reports that historically, LCR coho (*Oncorhynchus kisutch*), Chinook (*O. tshawytscha*), and chum (*O. keta*) salmon and steelhead (*O. mykiss*) spawned and reared in both Multnomah and Wahkeena Creeks. Based on StreamNet (2011), unpublished ODFW spawning survey data (ODFW 2009), and observations by Estuary Partnership and USFS scientists, the project site currently supports spawning and rearing of LCR coho salmon and steelhead (Figure 9). LCR Chinook salmon also use the site to some degree for spawning and rearing (StreamNet, 2011; ODFW 2009); however, very few spawning adults are observed annually and passage conditions at the I-84 culvert typically are not suitable for Chinook during August and September when adults would be attempting to enter the site (USFS 2003). LCR cutthroat trout (*O. clarki*) also may use the site for spawning and/or rearing. Passage conditions at the I-84 culvert prevent chum salmon from accessing the site at all flows (USFS 2003). Although not found on-site, chum salmon spawning is documented at the historic outlet of Multnomah Creek in the mainstem of the Columbia River (Arntzen 2008). This remnant alluvial fan presumably has sufficient upwelling to support chum salmon spawning, an assumption supported by discharge data taken by the USFS in Multnomah Creek, which indicates subsurface flow through the historical channel (USFS 2010).

Figure 9: Adult coho salmon spawning in Multnomah Creek, October 2010.

Table 2 summarizes the timing of use by the key salmonid species and life stages found at the project site. In Wahkeena Creek, spawning and incubation likely are limited to the reach located downstream of the park entrance road. In Multnomah Creek, spawning and incubation occurs upstream of Benson Lake only (Reaches 1 and 2). Rearing likely occurs site-wide, except within areas that are temperature limited during low-flow periods (see Section 4.4 for detail regarding the site's thermal regime).

Table 2. Timing of Use Among Key Salmonids in Wahkeena and Multnomah Creeks

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Species/Life Stage												
Spawning												
Chinook Salmon								Gray	Gray	Gray	Gray	
Coho Salmon										Black	Black	Black
Chum Salmon												
Steelhead	Gray	Gray	Black	Black	Black	Gray						
Incubation												
Chinook Salmon	Gray	Gray	Gray	Gray						Gray	Gray	Gray
Coho Salmon	Black	Black	Black	Gray						Gray	Gray	Black
Chum Salmon												
Steelhead	Gray	Gray	Black	Black	Black	Black	Gray					
Rearing												
Chinook Salmon	Gray	Gray	Gray	Gray	Gray	Gray	Gray	Gray	Gray	Gray	Gray	Gray
Coho Salmon	Black	Black	Black	Black	Black	Black	Black	Black	Black	Black	Black	Black
Chum Salmon												
Steelhead	Black	Black	Black	Black	Black	Black	Black	Black	Black	Black	Black	Black

- (White) Species/Life Stage Not Present
- (Gray) Species/Life Stage May Be Present
- (Black) Species/Life Stage Greatest Chance of Presence

2.4.1.2 UP-RIVER ESUs

As evident in the 1939 aerial photograph (Figure 4), the site historically functioned as an active part of the Columbia River floodplain that was inundated annually during the spring freshet. Based on knowledge of Columbia River salmon life histories, salmon use floodplain habitats such as these extensively during their outmigration through the Columbia River estuary (Bottom et al., 2005; Fresh et al., 2005). Although no data detailing historical fish use at the site are available; it is likely that a variety of ESUs used the site not only for spawning and rearing, but also as off-channel habitat. As detailed in a number of studies (Jones et al., 2008; Bottom 2010; Sol et al., 2008; Sol et al., 2009), a variety of Columbia River salmon ESUs (including federally listed Columba River chum salmon and fall-run Snake River Chinook salmon) still use floodplain habitats in the Columbia River Gorge as they outmigrate through the estuary. However, due to intensive management of Columbia River hydrology via the Federal Columbia River Power System (FCRPS), the project site currently is inundated only during the very highest flood flows, e.g., the 1996 floods. Because the site is not inundated routinely and because the I-84 culvert is not passable for juvenile salmonids, it is unlikely that salmonids other than those spawned on-site utilize the majority of its habitat. However, numerous ESUs likely still use the portion of Multnomah Creek (along with its floodplain) located north (downstream) of I-84.

2.4.2 Other Aquatic Species

Benson Lake and Harman Pond historically have been managed as warm-water fisheries, although ODFW stocks both lakes annually with hatchery rainbow trout (*O. mykiss*). A similar array of species found in the Columbia River likely are also found in both lakes. The project team has observed the following non-salmonid aquatic species at the site:

- threespine stickleback *(Gasterosteus aculeatus)*
- sculpin (*Cottus* spp.)
- crayfish (unknown)
- common carp *(Cyprinus carpio)*
- largemouth bass *(Micropterus salmoides)*
- pumpkinseed *(Lepomis gibbosus)*

Other non-salmonid aquatic species also may occur on-site.

2.4.3 Other Species

Other species observed on-site by the project team include the following:

- Bald eagle (*Haliaeetus leucocephalus*)
- Great blue heron *(Ardea herodias)*
- American beaver (*Castor canadensis*)
- Tundra swan (Cygnus columbianus)
- Canada goose *(Branta canadensis)*
- American bittern *(Botaurus lentiginosus)*
- Red-tailed hawk *(Buteo jamaicensis*)

A variety of other species likely also use the site.

3 METHODS

For assessment purposes, the project team began by dividing the site into specific reaches based on landscape and structural features. Within project reaches additional sites were defined based on physical characteristics, location, and anticipated restoration objectives. Project reaches are listed below and shown in Figure 10. Photographs that show reach characteristics are provided in Section 4.2.

- Reach 1: Multnomah Creek Visitor Area
- Reach 2: Upper Multnomah Creek – extends from terminus of visitor area downstream to inlet of Benson Lake
- Reach 3: Benson Lake
- Reach 4: Lower Multnomah Creek – extends from Benson Lake outlet to inlet of I-84 culvert
- Reach 5: I-84 Culvert and N. Multnomah Creek – extends from inlet of I-84 culvert downstream to confluence with Columbia River
- Reach 6: Wahkeena Creek – extends from RR crossing downstream to inlet of I-84 culvert; includes Hartman Pond diversion channel
- Reach 7: Parking lots – Benson SP and Multnomah Falls parking areas

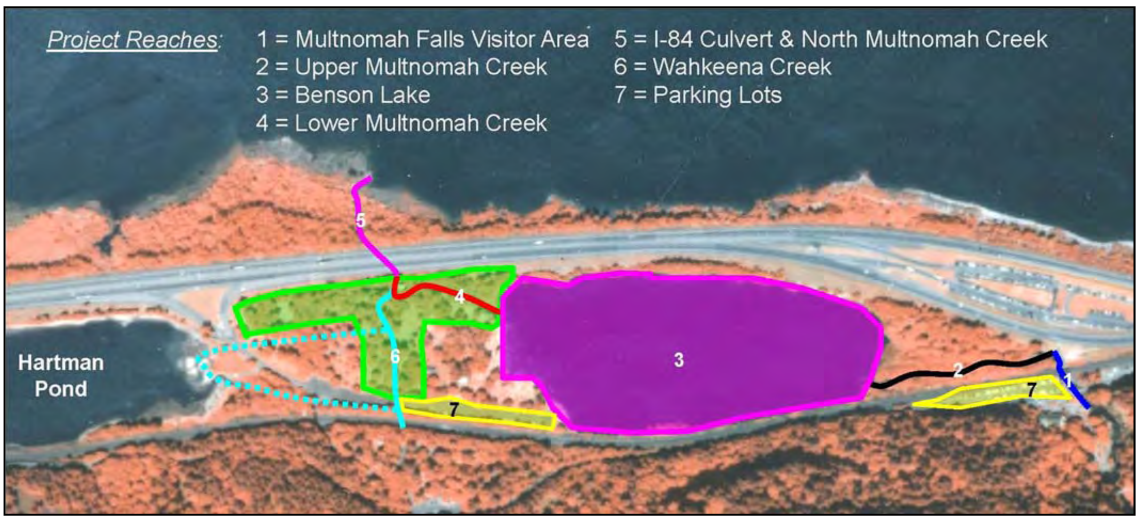

Figure 10: Project reaches.

3.1 FIELD OBSERVATIONS AND MEASUREMENTS

The project team conducted observations and stream surveys on both Wahkeena and Multnomah Creeks below their respective falls. Throughout Wahkeena Creek and on Multnomah Creek below Benson Lake, we surveyed topography at identified cross sections and along longitudinal profiles, conducted pebble counts, took discharge measurements, noted stage elevations, evaluated and characterized channel morphology, and evaluated instream and riparian habitat conditions. We developed a photo-log of specific cross sections and overall project reach characteristics. We also used data loggers to monitor stream temperatures in both streams throughout the site.

On Benson Lake, we conducted temperature profiles and a detailed bathymetry survey. We also evaluated storm water discharge from all parking lots by visual inspection and topographic evaluation.

In summary, the following field data were collected using either numeric (n) and/or qualitative (q) measurements:

- Channel type, geometry and stability (n, q)
- Discharge and water surface elevations (n)
- Topography & bathymetry (n)
- Availability of spawning habitat and in-channel habitat complexity (q)
- Geomorphic conditions (n,q)
- Riparian conditions (q)
- LWD size and distribution (n)
- Thermal profiles (n)
- Stormwater (q)
- Photo-log (q)

3.2 HYDROLOGY EVALUATION

During September 2010, the project team measured base flow discharge on Multnomah and Wahkeena Creeks (cross-sections 9 and 4 respectively; Figure 11) and on the Hartman Pond diversion. Table 3 summarizes the results.

The project team surveyed a total of nine cross-sections at the site (Figure 11). Using channel survey data, measured flow, and observed water surface elevations, a spreadsheet approach (Wilcock 2008) was developed to model discharge at base flows. The modeled discharge for base flows was calibrated to a discharge of 5 cfs for both creeks. Analytic and field methods were used to validate stage and discharge relationships and to estimate peak flows.

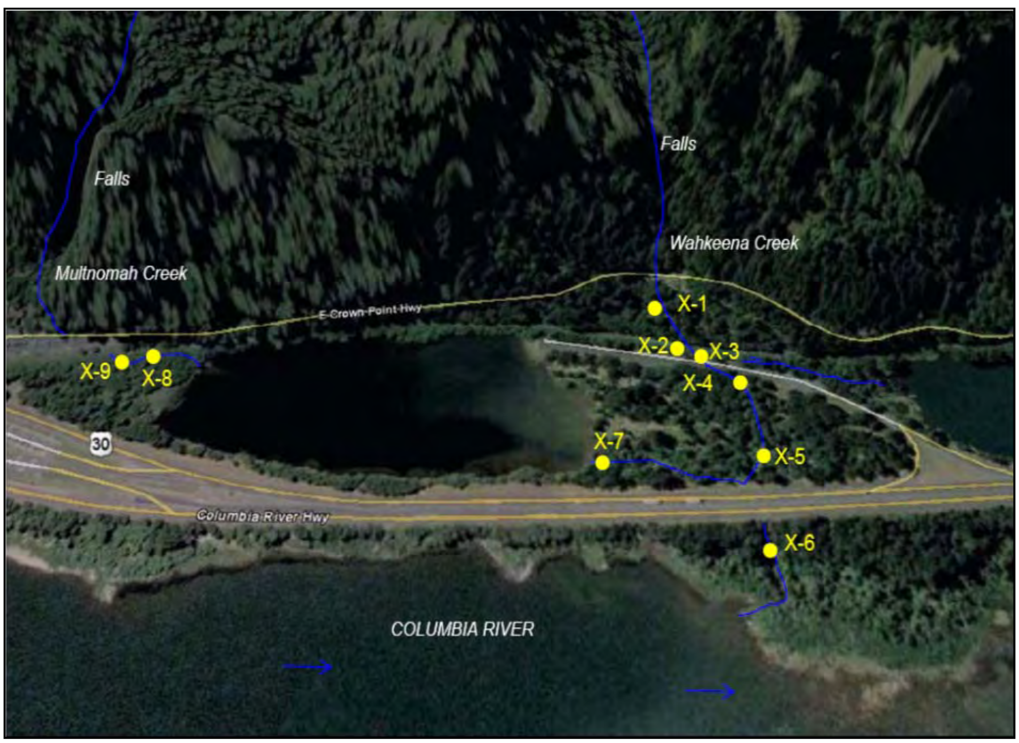

Figure 11. Cross-section locations.

Table 3. Base Flow Discharge Measurements- September 15, 2010.

Location	Discharge (cfs)
Multnomah – d/s of Visitor Area	3.7[a]
Wahkeena Creek – d/s of diversion	2.6
Hartman Pond Diversion Channel	1.8
Wahkeena Creek – u/s of diversion	4.4[b]

[a] The USFS has also taken discharge measurements in Multnomah Creek both u/s and d/s of the visitor area. They have noted decreased flow through this area, indicating that some flow goes subsurface, likely through the historical channel to the Columbia River.
[b] Calculated based on discharge measurements taken u/s and d/s of the Hartman Pond diversion.

We determined the appropriate peak flows to be modeled using USGS StreamStats software (StreamStats 2008). StreamStats was used to predict peak flood flows that occur (on average) every two years (Q_2) to every hundred years (Q_{100}). StreamStats uses regional regression equations, which are a function of area (A), slope (S), and the 2-year 24- hour precipitation intensity ($I24\text{-}2^x$). For this location, StreamStats prediction equations use the following criteria:

- ungaged watersheds in Region 2B, and,
- western interior with mean elevations less than 3,000 feet.

The following are the equations for calculating peak flow from StreamStats over the Q_2-Q_{100} flood flows:

$$Q_2 = 9.136\ Area^{0.9004}\ Slope^{0.4695}\ I24 - 2^{0.8481} \quad (1)$$
$$Q_5 = 14.54\ Area^{0.9042}\ Slope^{0.4695}\ I24 - 2.^{07355} \quad (2)$$
$$Q_{10} = 18.49\ Area^{0.9064}\ Slope^{0.4688}\ I24 - 2^{0.6937} \quad (3)$$
$$Q_{25} = 23.72\ Area^{0.9086}\ Slope^{0.4615}\ I24 - 2^{0.6578} \quad (4)$$
$$Q_{50} = 27.75\ Area^{0.9101} Slope^{0.4595}\ I24 - 2^{0.6390} \quad (5)$$
$$Q_{100} = 31.85\ Area^{0.9114} Slope^{0.4501}\ I24 - 2^{0.6252} \quad (6)$$

Although modeling and average prediction error are developed in the StreamStats program they were not utilized for this level of analysis.

Benson Lake residence time during low flow conditions was estimated by dividing lake volume by calculated inflow into the lake from discharge measurements. Note that this calculation assumes complete mixing, no evaporation, and that the average change in storage is zero.

$$T_R = \frac{S}{m_Q} = \frac{S}{m_I} \quad (7)$$

Where T_R is residence time, S is the volume of water and m_I is inflow and m_Q is outflow; when $m_Q = m_I$ then change in storage is zero.

3.3 HYDRAULICS EVALUATION

Hydraulics were predicted using the spreadsheet approach developed earlier. Predicted hydraulics assume steady-state conditions and are a simplification of actual conditions. Channel surveys were conducted to determine elevations, slope, surface roughness (D_{50}), grain sizes, and surface water elevations to derive spreadsheet inputs and generate hydraulic geometry. Based on survey data, hydraulic geometry relationships, and assumed roughness (n) values, discharge (Q) was determined by combining the continuity equation and Manning's equation to produce

$$Q = \frac{\sqrt{S}}{n} AR^{2/3} \qquad (8)$$

where S is slope, A is channel area, R is hydraulic radius and n is a specified roughness value.

As indicated above base flows were used to calibrate the spreadsheet model approach. Peak flows determined using regression approach over the $Q_2 – Q_{100}$ flows were then input into the spreadsheet, to predict hydraulic conditions. A sediment transport relationship based on streambed shear stress was calculated using an incipient motion approach. Where calculated shear stress (τ) exceeds the critical value of shear stress (τ_c) $\tau > \tau_c$ movement of bed-surface grains begins. Shear stress is calculated by:

$$\tau = \gamma S R \qquad (9)$$

where γ is the specific weight of water, S is slope and R is hydraulic radius.

The critical value of shear stress is determined by:

$$\tau_c = (s\text{-}1)\,\rho g D\,\tau^*_c \qquad (10)$$

Where s is the relative density of quartz, ρ is the fluid mass density, g is acceleration due to gravity, D is the D_{50} particle diameter, and τ^*_c is a specified critical Shields Number (.045 was used) (Shields 1936).

Estimates of hydraulic and sediment transport conditions including stage, depth of flow, velocities, critical shear stress, shear stress, and incipient motion are reported.

In general, at Q_{base} particle and bed roughness (n) exert strong influence on discharge. As flow depth increases the effect of particle and bed roughness tends to decrease. As a result, n values were increased during Q_{base} flows and in areas where particle diameters (D_{50}) exert a greater flow resistance, e.g., step-pool morphology.

3.4 INSTREAM AND LAKE TEMPERATURE ASSESSMENT

3.4.1 DATA COLLECTION

The project team selected five locations to monitor surface water temperature. On August 20, 2010 the project team also collected thermal profiles of Benson Lake at four locations. The network of monitoring locations was chosen to provide a comprehensive assessment of the site's thermal profile, including the effect of Benson Lake, different channel types, and riparian conditions. Table 4 outlines the locations of the five monitoring stations, along with their location titles and probe identification numbers. Figure 12 provides an aerial photograph with probe locations as well as the locations of the Benson Lake thermal profiles. At the fixed monitoring locations, the project team deployed Hobo U20 temperature probes, which were set to record temperatures at 1/2-hour intervals. The project team used a YSI temperature probe to collect the lake's thermal profiles, measuring temperature at 1-foot depth intervals.

Data collected by the Estuary Partnership were supplemented by 2006 temperature monitoring data provided by the USFS (also shown on Figure 12). Methods used to collect these data were very similar and therefore provide a valuable comparison (see Flick 2007 for details re: USFS methods).

Table 4. Monitoring Station Titles, Locations, Probe ID Numbers, and Sample Dates

Monitoring Station	Location	Probe ID	Date Deployed	Date Retrieved
	Multnomah Creek			
Multnomah – Visitor Area	~50 yards d/s of pedestrian area	9724286	7/16/10	9/29/10
Multnomah – Benson Lake Inlet	~30 yards u/s of Benson Lake inlet	9724287	7/16/10	9/29/10
Multnomah – Benson Lake Outlet	~20 yards d/s of Benson Lake outlet	9724288	7/16/10	9/29/10
Multnomah – I-84	~20 yards u/s of I-84 culvert	9724289	7/16/10	9/29/10
	Wahkeena Creek			
Wahkeena – I-84	~20 yards u/s of I-84 culvert	9724290	7/16/10	9/29/10

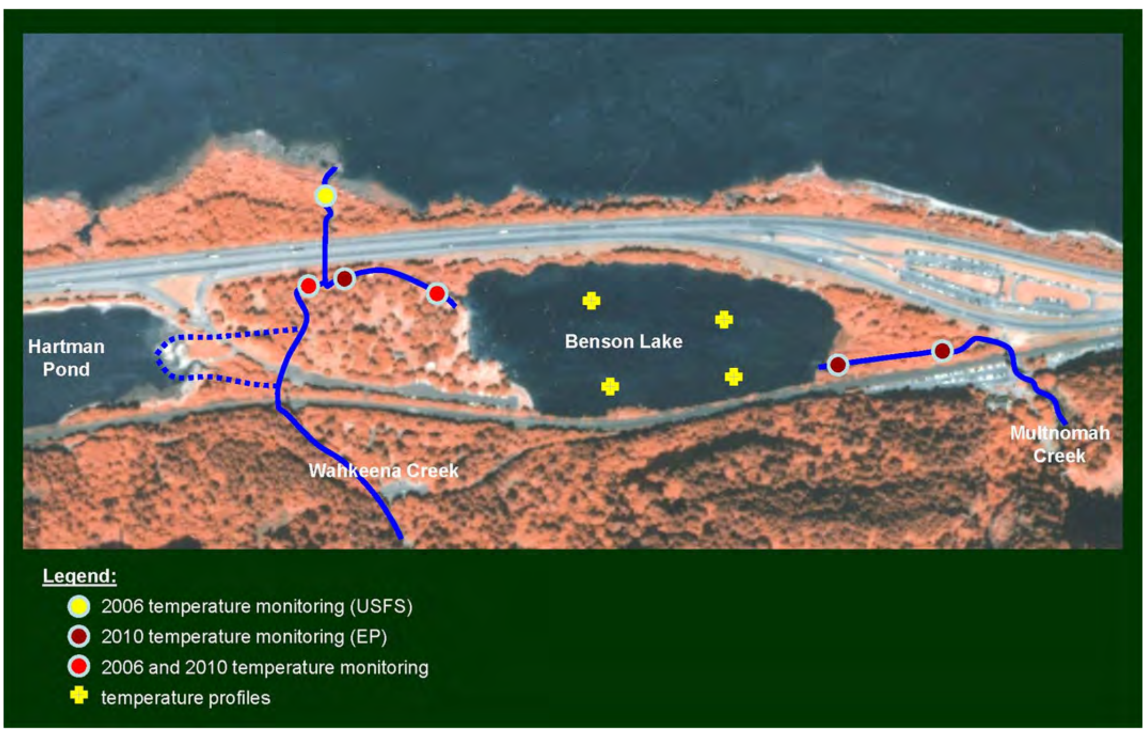

Figure 12: Temperature probe and profile locations.

3.4.2 DATA ANALYSIS – JUVENILE SALMONIDS

As shown in Table 2, rearing is the only salmonid life history stage that occurs on-site during summer months when temperatures potentially are limiting. Consequently, our temperature 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. This 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 Biological Opinion for off-channel habitat mitigation.
- Oregon Department of Environmental Quality (DEQ) 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 5 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 5. Temperature Based Habitat Classification for Juvenile Salmonids

Classification	Definition
Ideal Rearing Habitat	Stream reaches where the highest 7-day average maximum temperature is between 10°C and 14°C.
Functional Rearing Habitat	Stream reaches where the highest 7-day average maximum temperature is between 14°C and 18°C.
Poor Rearing Habitat	Stream reaches where the highest 7-day average maximum temperature is between 18°C and 23°C.
Unusable (Lethal) Rearing Habitat	Stream reaches where the highest 7-day average maximum daily temperature exceeds 23°C.

Note: The 7-day average maximum temperature metric is DEQ's regulatory standard and is therefore used in this analysis.

3.4.3 DATA ANALYSIS – 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 lower portion of the Columbia River Gorge that are most tolerant of cool-water temperatures;
- Largemouth bass have been observed on-site, 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 6 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 6. Temperature Based Habitat Classification for Smallmouth Bass

Classification	Definition
Poor Smallmouth Habitat	Stream reaches where the highest 7-day average maximum temperature does not exceed 19°C.
Functional Smallmouth Habitat	Stream reaches where the highest 7-day average maximum temperature is between 19°C and 21°C.
Ideal Smallmouth Habitat	Stream reaches where the highest 7-day average maximum temperature is between 21°C and 31°C.

3.4.4 Climate Analysis

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 Multnomah and Wahkeena 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 9 miles northeast of the site; and,
- Troutdale Airport (Station ID #358634) – located along the Columbia River approximately 15 miles west of the site.

3.5 Archival Evaluation

We reviewed historical data and reports that influenced the two basins including channel alignment, channel dimensions and hydrology. The USFS also provided geomorphology and hydrology monitoring data for Multnomah Creek (reaches 1 and 2) 2002-2010.

4 RESULTS & DISCUSSION

4.1 HYDROLOGY & HYDRAULICS

As detailed in Section 3.2, the StreamStats program developed by USGS was used to estimate peak flows and determine hydraulic conditions within Multnomah and Wahkeena Creeks. Results from field surveys were used to generate spreadsheet model inputs. Discharge was measured during low flow months (August-September) to generate base flows (Q_{base}), which were used to calibrate the spreadsheet approach. Higher peak flows were estimated using regression equations embedded in StreamStats (USGS 1993). Table 7 presents the results from these evaluations.

Table 7. Results from measured (Q_{base}), spreadsheet (Q_{base}), and StreamStats predicted (Q_2 - Q_{100}).

	Hydrologic Reach		
Discharge	Multnomah Creek	Wahkeena Creek (below park road)	Confluence
Q_{base} (measured)	4	4	8
Q_{base}	6	4	10
Q_2	456	76	532
Q_5	633	107	740
Q_{10}	753	128	881
Q_{25}	904	154	1,058
Q_{50}	1,020	173	1,193
Q_{100}	1,130	192	1,322

Note: All values are provided in cubic feet per second (cfs).

At the Q_{base} flows (4-6 cfs), predictions for surface water elevations, on both Multnomah and Wahkeena Creeks, compared favorably to measured water surface elevations along the eight cross sections (see Figure 11 for cross-section locations). Additionally, to further evaluate model predictive capabilities, the estimated Q_2 peak flow value was compared against field indicators, e.g., breaks in slope and changes in vegetation and bed material, and by plotting against the channel cross-section (Dunne & Leopold, 1978). The Q_2 peak flow is often used to represent bankfull discharge, a surrogate for representing the dominant discharge. Dominant discharge can be thought of as the flow that performs the most work in terms of sediment transport and determines river channel physical characteristics, including the formation of floodplains (Knighton, 1998).

Figure 13 shows the predicted Q_2 at cross section 9 (X-9). At the estimated Q_2 flow of 456 cfs there is an observed break in slope (bench) that is forming on the right bank. Overall, this appears to offer some support to the predictive capacity of the spreadsheet model at the Q_2 flow, i.e., the bench is the type of feature that would be anticipated to occur at the Q_2 elevation. Only X-9 offered adequate comparison of predicted peak flows against field/survey data; limits in survey data at other cross-sections do not allow for a comparison of peak flows due to expansion of flow out onto the floodplain. Additionally, there is no available gage data to compare higher flow values. For these reasons, the predicted peak flow estimates presented here should be evaluated further due to uncertainty related to confidence in StreamStats and limits of using bankfull predictors in unstable streams.

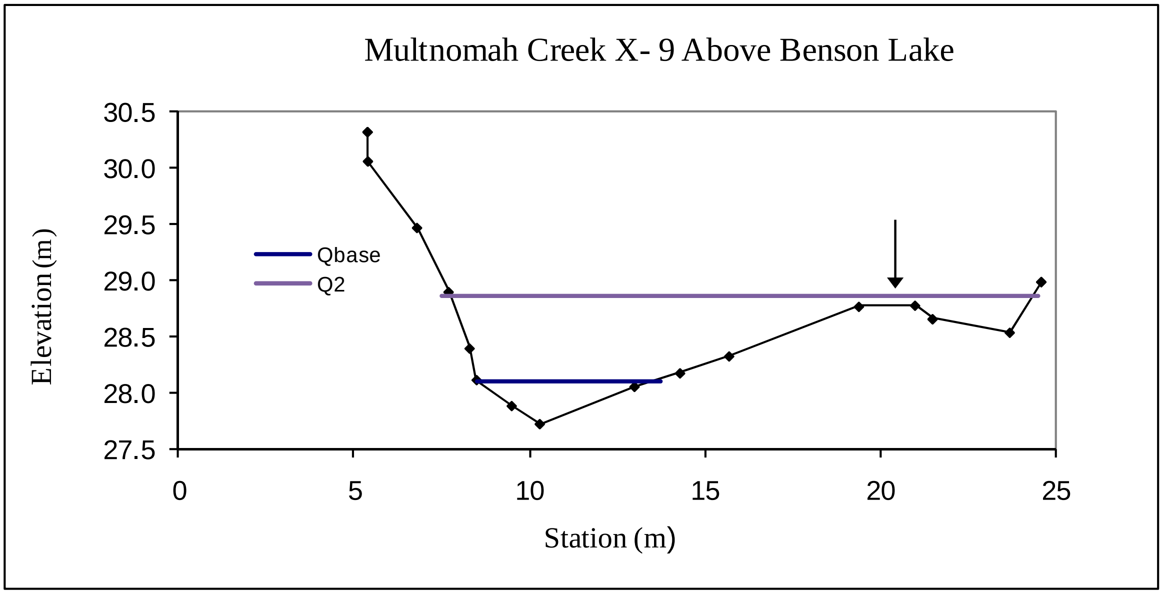

Figure 13. Reach 2 cross section, measured flow (Q_{base}) and spreadsheet predicted flow for the two-year peakflow (Q_2). Arrow points to a bench forming within the channel which supports estimates of the Q_2 flow. Viewing direction is downstream. Elevations on the y-axis are relative and do not reflect actual site elevations.

Discharge estimates from StreamStats and stream survey cross section data were used to predict average hydraulic conditions at surveyed cross sections. The Q_2 peak flows were utilized for both Wahkeena Creek and Multnomah Creek cross sections to generate hydraulic and hydrologic conditions. Estimating hydraulic and hydrologic conditions for the Q_{100} peak flow was possible only on Wahkeena Creek due to the stream's unique cross section geometry, i.e., the channel is highly incised therefore Q_{100} elevations are within the channel and could be surveyed in the field. On Multnomah Creek, Q_{100} elevations are on the floodplain (well outside of the stream channel) and therefore are not practical to survey in the field. Without survey data, hydrologic and hydraulic estimates for the Q_{100} peak flow could not be generated. StreamStats discharge values reported below represent the recommended model values; model uncertainty was not incorporated into this level of evaluation. Future evaluations, and any design efforts, on Wahkeena and Multnomah Creeks should incorporate model uncertainty and collect data to verify model predictions. Tables 8 and 9 present the results.

Table 8. Predicted hydraulic conditions for Wahkeena Creek at Q_2 and Q_{100} flows.

	Project Reach 6 - Wahkeena Creek X Sections									
Parameter	X-1	X-2	X-3	X-4	X-5	X-1	X-2	X-3	X-4	X-5
Q_2 discharge (cfs)	76	76	76	76	76					
Q_{100} discharge (cfs)						192	192	192	192	192
Qav.depth (ft)	1	0.6	0.7	0.7	1	1.3	1.2	1.2	1.1	1.5
Q max.depth (ft)	1.2	1	1.1	1.2	2.7	2	1.8	1.8	2	3.8
velocity (μ) ft^2	3.8	3.3	4.2	5.7	4.4	6.7	4.8	6.1	7.6	5.7
critical shear stress (τ_c) pds/ft	73	51	50	43	29	72	51	51	43	29
shear stress (τ) pds/ft	69	25	21	49	61	103	45	60	74	90

Table 9. Predicted hydraulic conditions for Multnomah Creek at the Q_2 flow.

Parameter	Project Reach 1 & 3- Multnomah Creek	
	X-7	X-9
Q_2 discharge (cfs)	456	456
$Q_{average}$ depth (ft)	3.3	1.5
$Q_{maximum}$ depth (ft)	3.7	3.8
velocity (μ) ft^2	2.3	5
critical shear stress (τc) pds/ft	8.1	18.2
shear stress (τ) pds/ft	5.5	42
D_{50} (in)	0.8	1

4.1.1 CULVERTS

Two culverts, two UPRR bridges, and one pedestrian bridge exist within the project study area. Although the UPRR and pedestrian bridge located in Reach 1 constrict the channel, based on a qualitative assessment, they do not have hydraulic capacity or fish passage issues. Similarly, although the I-84 culvert is perched and its roughened chute presents fish passage constraints, the culvert itself has sufficient capacity to pass flood flows and is not a concern for fish passage. This is largely due to flat stream gradient and an overall lack of sediment inputs due to sediment trapping at Wahkeena Creek's culvert and UPRR bridge and the presence of Benson Lake, which removes sediment contributions from Multnomah Creek.

Wahkeena Creek's parking lot culvert (located in Reach 6) is a two barrel culvert, which over time has lost 50% or more of its capacity due to sedimentation (Figure 42). This trend can also be seen at the upstream railroad bridge where almost all of the capacity under the bridge has been lost due to sedimentation and continued growth of the alluvial fan (Figure 41). Using the spreadsheet approach, the parking lot culvert is estimated to overtop at the Q_{50}- Q_{100} flood flows. The spreadsheet approach uses the upstream cross section (X-2) to predict water levels; however, due to the fact that the culvert is already partially plugged, these estimates should be adjusted down to the Q_{25} - Q_{50} event.

4.2 MORPHOLOGY & HABITAT CONSIDERATIONS

Channel morphology exerts an important control on reach and site specific conditions. In light of this, it is important to understand baseline conditions and evaluate stressors. Although an in depth-analysis of historic geomorphic conditions is not within the scope of this report, current channel responses (using field observations) have been included.

Due to disturbances within project reaches, fluvial processes have been fundamentally altered. Geomorphic responses have been complex including changes in channel planform, longitudinal profile, sediment supply and transport, streambed grain size (D_{50}), and streambank and channel geometry, e.g., width, depth, and slope. Compared to pre-disturbance conditions, project reaches have narrowed, sediment supply has been reduced, and stream channels have incised.

At the flows specified in Wahkeena Creek (Table 8), shear stress values for Q_2 flows do not exceed critical shear stress values at X-1, X-2, and X-3 and therefore are not able to effectively move the D_{50} particle. Only at the Q_{100} flow is incipient motion predicted. This suggests that there should be sedimentation at these cross sections; field observations confirm that these portions of the channel are aggrading. There are additional signs of sedimentation above the railroad bridge and the Benson State Park parking lot culvert, e.g., both sites have filled with approximately four feet of sediment. Lower Multnomah Creek shows a similar sediment trend at X-7 with the Q_2 flow unable to move the D_{50} particle suggesting that reach also is transport limited.

4.2.1 CHANNEL RESPONSES

Geomorphic conditions were determined using a combination of field and desk-top approaches. In general, project reaches on both creeks occur within a transitional zone where the energy gradient changes from very high just above the project sites, to low just above the I-84 culvert, and back to moderate below the I-84 culvert. There have been very few disturbances in the upper portions of the watersheds (above the historic highway) over the last 50-100 years, therefore it is assumed that changes in project reaches have occurred due to fundamental alterations within or immediately upstream of the reaches themselves. Table 10 provides a summary of reach conditions. The following sections provide a more complete representation of reach level conditions.

Table 10. Geomorphic conditions along project reaches.

	Multnomah Creek			**Confluence***	**Wahkeena Creek****
Parameter	*Reach 1*	*Reach 2*	*Reach 4*	*Reach 5*	*Reach 6*
Channel type[1]	step-pool	pool-riffle (LWD forced)	entrenched	pool-riffle	entrenched/pool-riffle
Base flow channel width (ft) [2]	30	36	32		15
Gradient (ft/ft) [2]	0.025	0.01	0.0001	0.03	0.03
D_{50} (in) [2]	2.5	0.9	0.3ᵻ		2.7ᵻ
Sinuosity [3]	1.1	1.5	1.1	1.4	1.3
Stability rating [4]	V/VI	V/VI	III	III	III/IV

* Below roughened chute.
** Below parking lot culvert but above headcut and low gradient section.
ᵻ D_{50} estimated using 5-10 clasts.
1 After Montgomery & Buffington (1993) and Rosgen (1994).
2 Field surveys (USFS & LCREP).
3 Estimated using GIS (LCREP).
4 Simon (1989): III) vertical degradation, IV) vertical degradation & widening, V) aggradation & widening, VI) stable.

Project Reach 1- Multnomah Creek above the Visitor Center

Project Reach 1 encompasses the area between Multnomah Falls and the downstream extent of the visitor area. The upper portion of this reach is bedrock controlled, while the lower portion has been manipulated with instream rock structures to contain the flow and divert the channel out of its historical alignment to the west (Figure 7). As a result of this diversion, the gradient decreases and sediment deposits within the channel. There is limited channel response due to overall channelization, and due to the location, elevation, and use of infrastructure, ODOT periodically harvests sediment from this reach to protect infrastructure, maintain channel capacity, and reduce the risk of overbank flooding.

Figure 14: Habitat conditions in the upper (left photo) and lower (right photo) portions of Reach 1.

Project Reach 2 – Multnomah Creek below the Visitor Center

As noted above, prior to construction of I-84, Multnomah Creek flowed due north terminating into a large alluvial fan at the mouth of the Columbia River (Figure 7). Multnomah Creek's current channel alignment has created conditions that require sediment harvest immediately above this project reach. However, recent sediment management practices appear to be changing with less instream gravel removal occurring during recent years. Broad evidence exists that the reduction in sediment harvest has placed this reach on a positive trajectory, i.e., widening, forming new side-channels, and accumulating sediment. Figure 16 shows an increase in Reach 2 streambed elevation, including greater pool depths and increased bed slope in certain areas. The main channel appears to have sufficient access to the floodplain along river right (looking downstream) and is actively creating side channels. There was evidence of LWD within the channel creating localized topographic changes and forcing pool-riffle morphology. Numerous pool-riffle sequences were observed, and pool depth averaged 1-2 ft. The project team observed a channel slope of 1% and a D_{50} of approximately 1 inch. Overall, this reach contained the greatest habitat complexity in the project area.

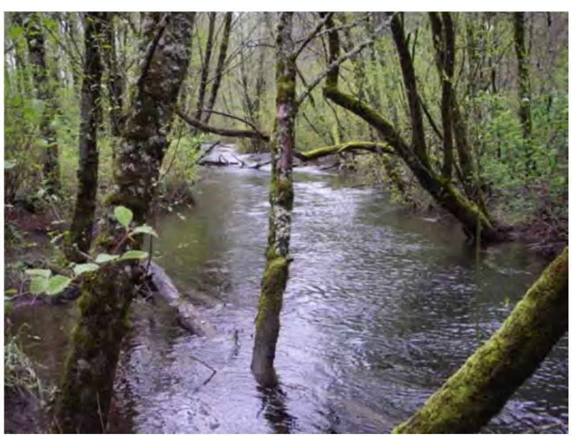

Figure 15: Habitat conditions in Reach 2.

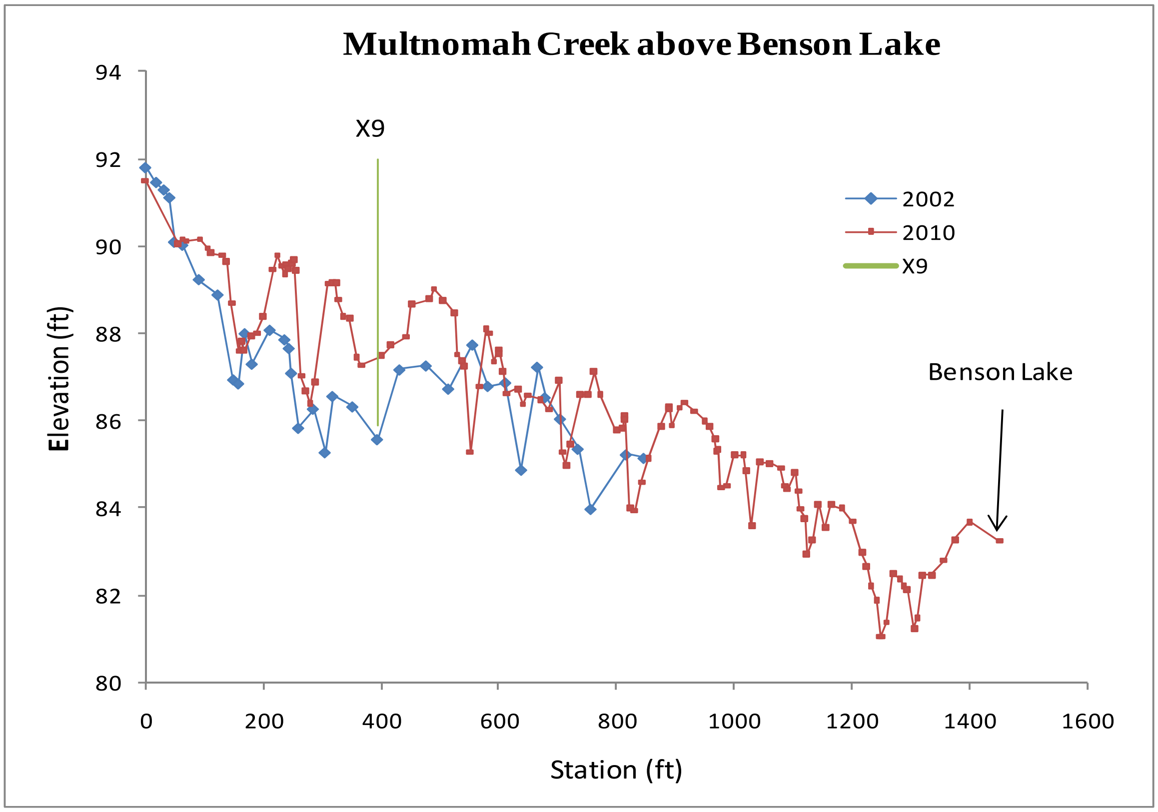

Figure 16. Reach 2 Longitudinal profile from 2002-2010 on Multnomah Creek . Data provided by USFS. Elevations on the y-axis are relative and do not reflect actual site elevations.

At the basin scale, investigations of surficial geology reveal adequate supplies of cobbles and gravels within the Multnomah Creek basin. If current sediment harvesting practices continue, there should be an adequate supply of gravel, and this reach should continue to actively adjust to the increased sediment supply through widening. This should allow greater access to floodplain habitat for aquatic species.

Project Reach 3 – Benson Lake

Sediment deposition and accumulation continues at the inlet of Benson Lake where a large delta (approximately ¾-acre) has formed. As the delta continues to expand both vertically and horizontally, vegetation may soon begin to colonize portions of it. The lake will continue to function as a sediment trap until, eventually, it fills with sediment.

Figure 17: Habitat Conditions in Benson Lake (Reach 3)

Project Reach 4 – Lower Multnomah Creek

Benson Lake attenuates flows and changes sediment dynamics such that the magnitude, frequency and duration of flows in this reach have been significantly altered and the delivery of sediment effectively has been eliminated. Overall, within this project reach, the channel is entrenched with a rectangular shape and very limited instream morphological diversity (Figures 18 and 19). This section is sediment starved and exhibits similar traits to watersheds found downstream of dams where there is an increase in available energy in the system. The result has been channel downcutting with very limited available cobbles and gravels – the D_{50} is estimated to be approximately 0.3 inches. The channel is isolated from its floodplain, and the banks are nearly vertical. Streambanks along river right (facing downstream) are more than 5 feet in height and are mostly cohesive in nature. This reach is nearly straight with an estimated sinuosity of 1.1 and a gradient of 0.0001ft/ft (0.01%) (Figures 18 and 20).

Figure 18: Habitat Conditions in Reach 4

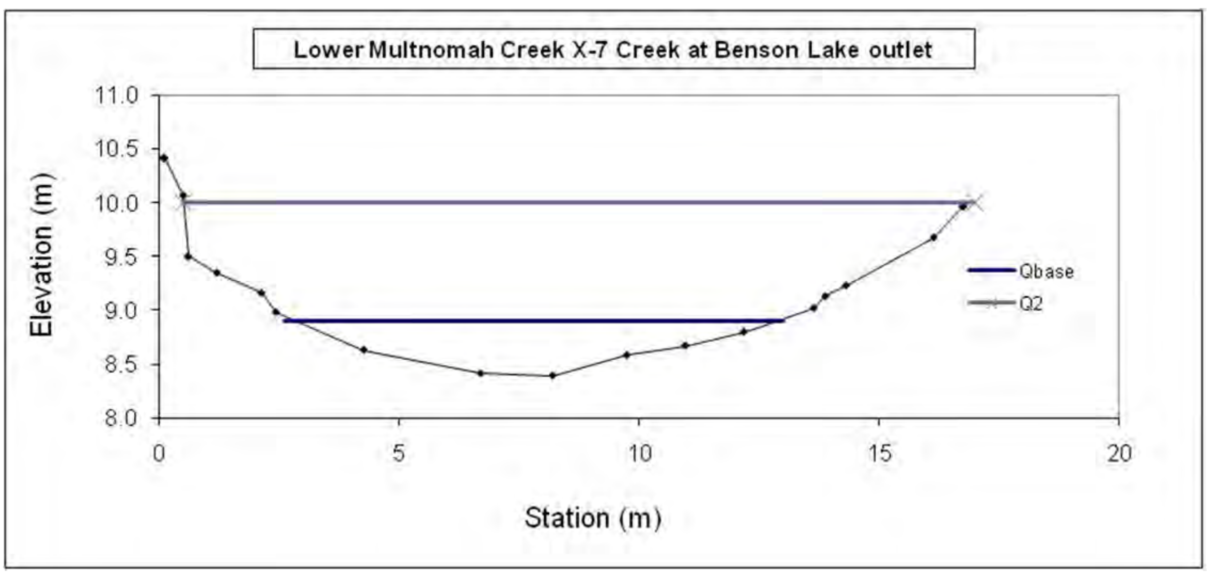

Figure 19: Reach 4 cross-section. Spreadsheet model predicted values for Q_{base} and for the two- year peakflow (Q_2) are shown. View is looking upstream. Elevations on the y-axis are relative and do not reflect actual site elevations.

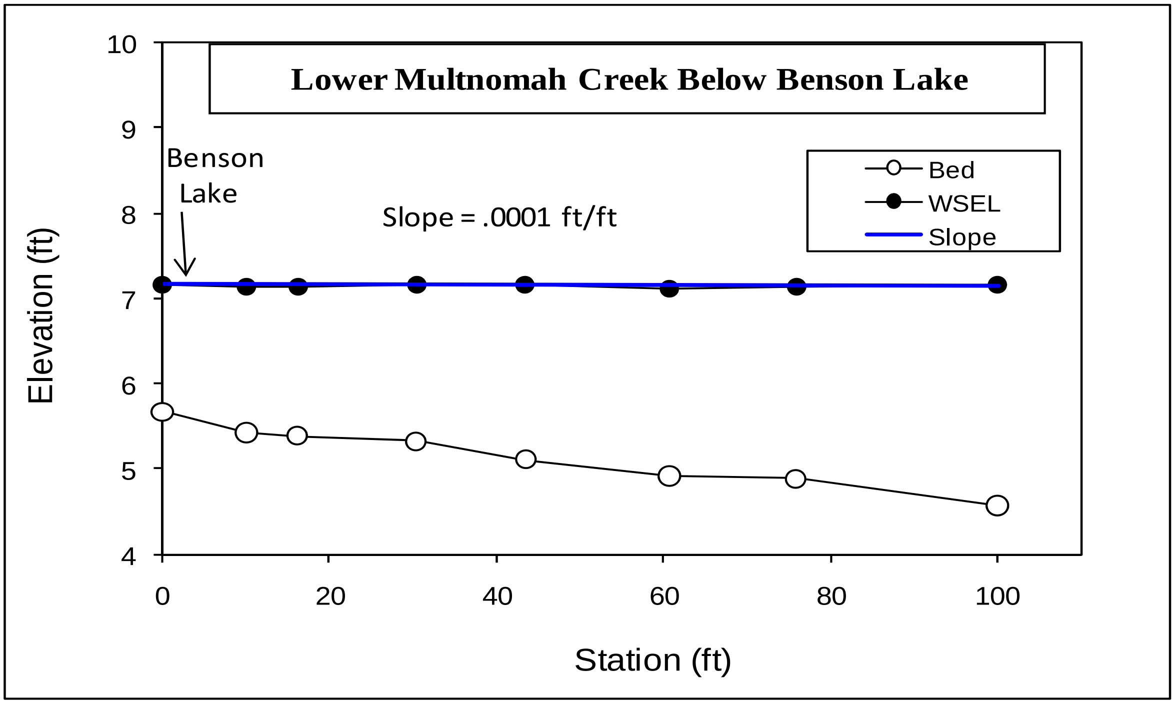

Figure 20. Reach 4 longitudinal profile. Slope indicated in percent is 0.01%. Elevations on the y-axis are relative and do not reflect actual site elevations.

Project Reach 5 – I-84 Culvert & Confluence Reach

The upstream extent of this project reach is a very high energy system marked by an extremely steep gradient (14%) (Figures 21 and 22). This area was initially designed to be a roughened chute providing access to the inlet of the I-84 culvert, but due to the energy gradient, any available gravel and cobble are quickly transported through this section. Within this chute, there are two channels that have formed, with the left channel (looking downstream) slightly perched above the steeper right channel. At the base of the chute, an island has formed and continued the flow separation. Below the island, the channel is active and there is evidence of widening, braiding and vertical degradation. This section of the creek has vertically hit a clay lens and any future changes to the channel in the vertical dimension appear limited. Past this section the creek transitions to a pool-riffle sequence with adjacent off-channel pond/wetland features that provide excellent habitat conditions. The bank separating these ponds is degrading and the ponds are close to being activated by the stream. Overall habitat quality in this reach is good, although passage conditions are extremely poor.

Figure 21. Passage and habitat conditions in Reach 5. View is looking upstream. Photo on the left is located below I-84 culvert and on the right is approximately 100ft above confluence with Columbia River.

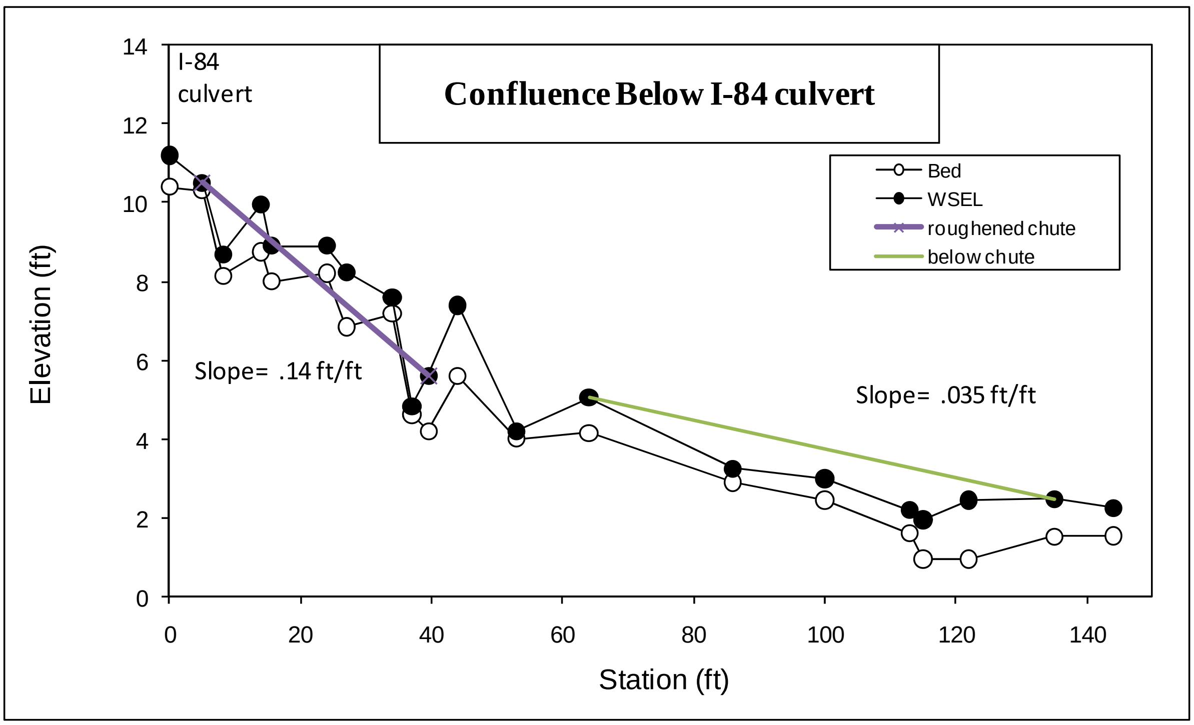

Figure 22: Longitudinal profile below I-84 culvert. Slope indicated in percent is 14 % immediately below roughened chute and 3.5% further downstream. Elevations on the y-axis are relative and do not reflect actual site elevations.

Project Reach 6 – Wahkeena Creek

Channel location, planform, hydrology, and sediment regime have been altered on Wahkeena Creek, and the creek is demonstrating a complex response to these changes. Along the creek immediately upstream of the UPPR bridge, this area is thought to historically have been an active alluvial fan with multiple threads. It remains active with evidence that the channel is moving to the east, threatening

USFS infrastructure. The existing berm at the upstream extent of the fan was constructed in an attempt to keep Wahkeena Creek within a single channel. However, fluvial processes, and an adequate supply of sediment, cause this area to deposit large amounts of material through which the creek is actively migrating. The result has been significant channel widening, loss of the adjacent walking path, and loss of capacity at the railroad bridge. Less than 1 foot of freeboard remains across the majority of the UPRR bridge's span.

Between the railroad bridge and the upstream extent of the parking lot culvert there is a general trend of aggradation (as noted previously, the bridge and culvert function as sediment traps), while downstream of the culvert, sediment supply has been greatly reduced and there is evidence of vertical degradation (Figures 23-27). A headcut is present further downstream, perhaps the result of the base level control exerted by the I-84 culvert (Figure 28). Further horizontal degradation of the channel is prevented by the cohesive nature of the streambanks and lack of sediment available for transport. There is some evidence of debris within the creek channel increasing pool habitat.

In summary, the area upstream of the railroad bridge is very unstable and can be expected to continue to actively braid and form an alluvial fan. X-2 and X-3 (the area between the UPRR bridge and park road culvert) marks a depositional area where shear stress values at the Q_2 flood do not effectively move sediments (only the Q_{100} is predicted to begin moving sediments). Even with limited sediment supplies (due to trapping at the railroad bridge) this portion of the channel is unable to accommodate its sediment load. This stands in stark contrast to the area downstream of the park road culvert (X-4 and X-5) where existing shear stress exceeds critical levels necessary for sediment movement at Q_2 flood and there is an excess of energy due to reduced sediment supply.

Figure 23: Habitat conditions in Reach 6 above (left photo) and below (right photo) the park road. Photo on the left is looking downstream (north) and photo on the right is looking upstream (south).

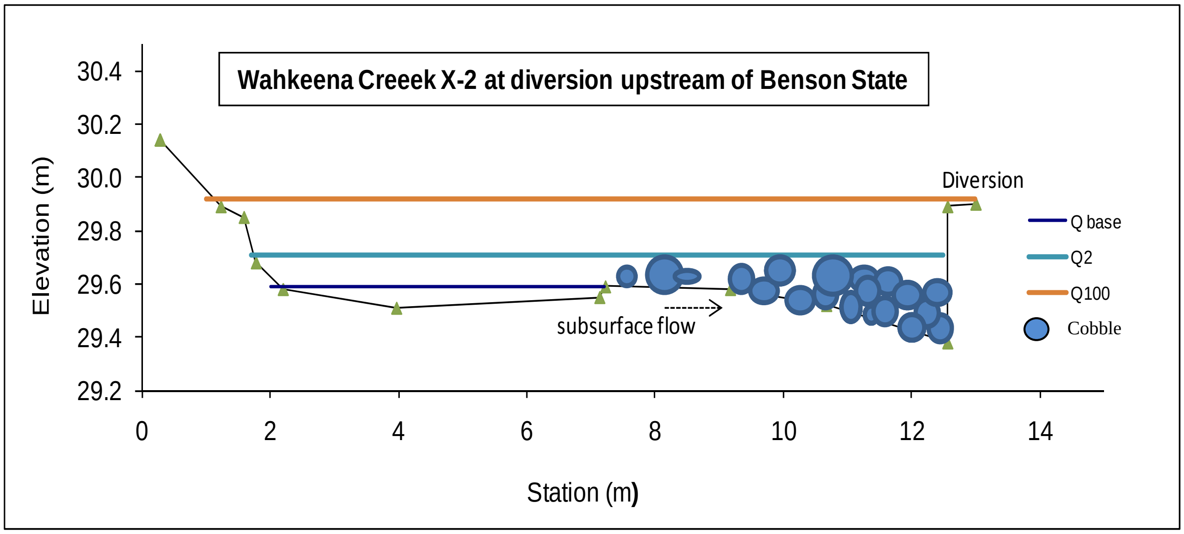

Figure 24: Reach 6 cross-section between UPRR bridge and Benson State Park parking lot. Measured flow (Q_{base}) and spreadsheet predictions for the two-year peak flow (Q_2) and one-hundred year peak flow (Q_{100}) are shown. There is subsurface flow at the base of the diversion structure. View is looking upstream. Elevations on the y-axis are relative and do not reflect actual site elevations.

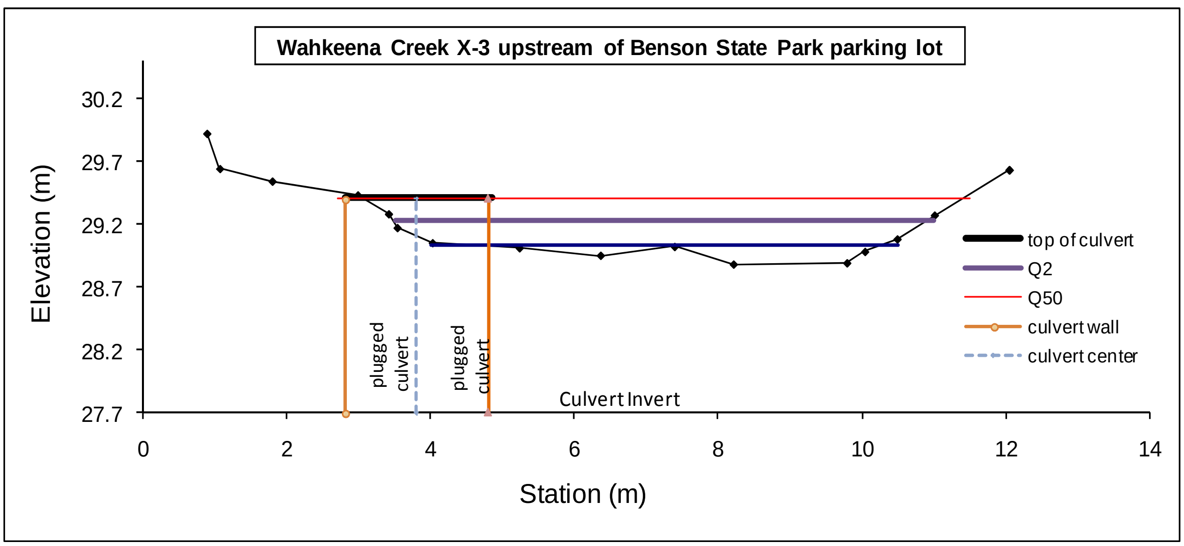

Figure 25: Reach 6 cross-section (immediately above Benson State Park parking lot culvert). Model predictions for the two-year peak flow (Q_2) and fifty-year peak flow (Q_{50}) are shown along with culvert dimensions. View is looking upstream. Elevations on the y-axis are relative and do not reflect actual site elevations.

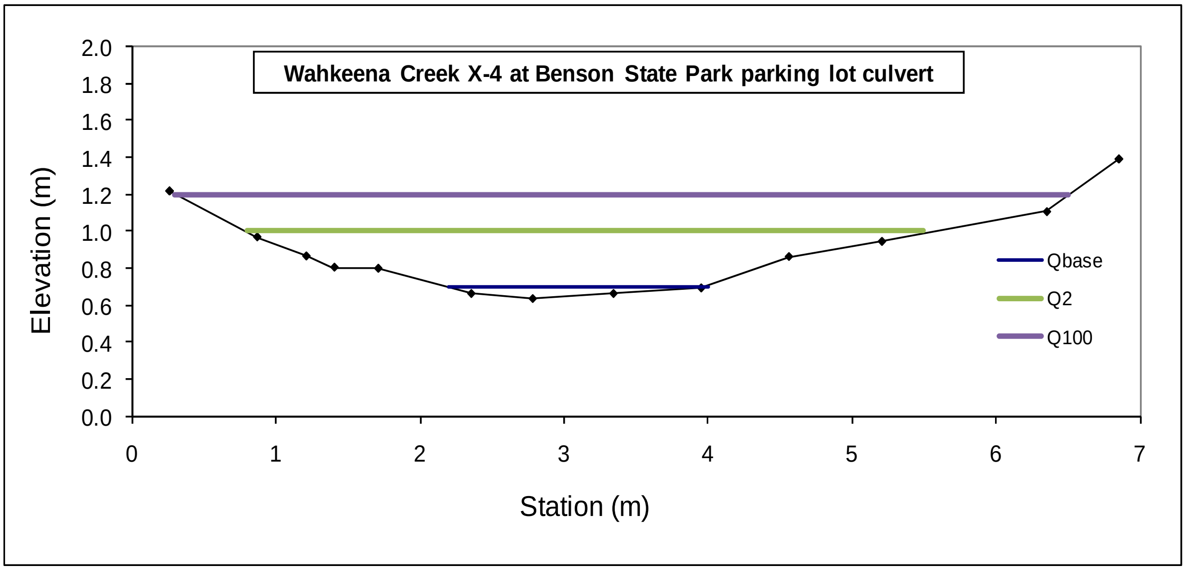

Figure 26: Reach 6 cross-section taken immediately below Benson State Park parking lot culvert. Measured flow (Q_{base}) and spreadsheet predictions for the two-year peak flow (Q_2) and one-hundred year peak flow (Q_{100}) are shown. View is looking downstream. Elevations on the y-axis are relative and do not reflect actual site elevations.

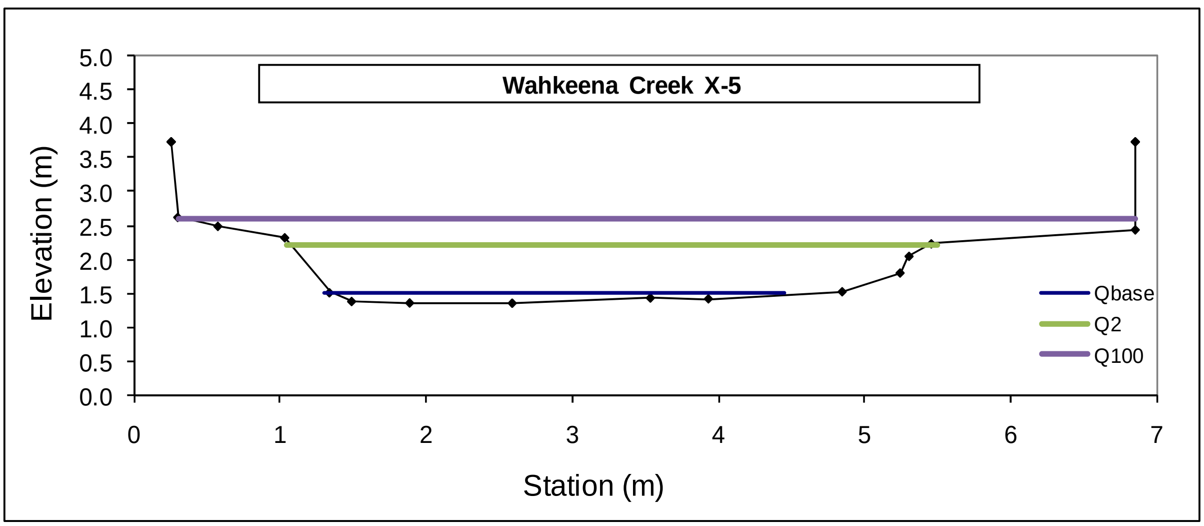

Figure 27: Reach 6 cross-section taken approximately 50 yards upstream of the I-84 culvert. View is looking downstream. Measured flow (Q_{base}) and spreadsheet predictions for the two-year peak flow (Q_2) and one-hundred year peak flow (Q_{100}) are shown. Elevations on the y-axis are relative and do not reflect actual site elevations.

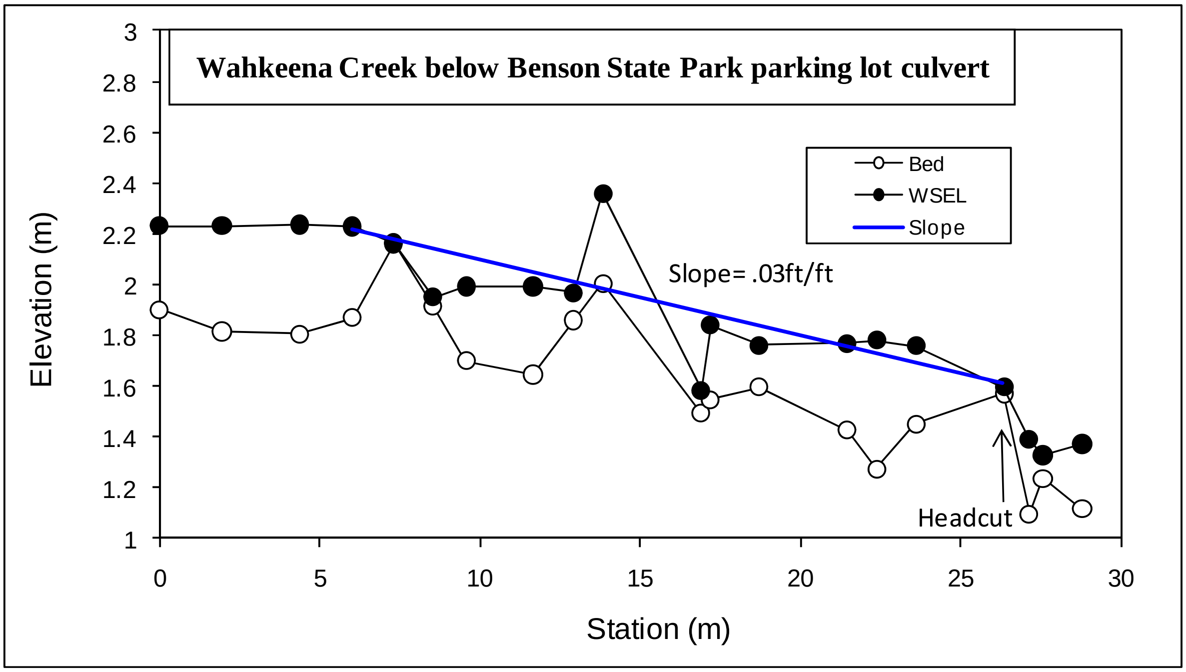

Figure 28: Longitudinal profile below Benson State Park parking lot culvert. Slope indicated equals 3%. Elevations on the y-axis are relative and do not reflect actual site elevations.

4.2.2 MORPHOLOGIC COMPLEXITY & HABITAT

Morphologic complexity is the primary driver of habitat conditions. At the reach scale, morphologic complexity is a function of broader scale processes and site specific conditions such as energy gradient, bed form, plan form, instream structures, e.g., LWD, changes in topography, disturbances, and sediment dynamics. These site-scale parameters also control discrete hydrogeomorphic conditions and further shape downstream processes. We characterized morphological complexity including pools, riffles, glides, and LWD to evaluate habitat potential. Each attribute was recorded along with its unit length. Results are reported in Figure 29.

The primary observations from the morphological assessment are as follows:

- Site-wide: Site disturbances, e.g., culverts and sediment harvest, are controlling reach level geomorphic responses to which habitat complexity is closely tied.
- Reach 2: Has sustained morphologic diversity with greater spacing of units and the highest rate of LWD and floodplain access.
- Reach 4: Morphology is homogenous. Very little LWD and pool habitat; no riffles; negligible access to floodplain.
- Reach 5: Appears to suggest multiple habitat potentials. Spacing of units is compressed. This is a dynamic and evolving area.
- Reach 6: Morphological complexity is limited to 150 feet below parking lot culvert, at which point there is an abrupt change in habitat. Negligible floodplain access in lower portion of reach.

Results reveal a range of morphological conditions with each reach displaying signature characteristics. In reaches 4 and 6, morphological complexity is limited and reflects lower bed slopes, vertical changes in channel geometry, and limited inputs of sediment and woody debris. Reaches 2 and 5 showed the greatest complexity, although only Reach 2 showed sustained habitats longer than 10-20 feet.

With the exception of Reach 2, LWD quantity and riparian buffer width were poor for all project reaches, with little-to-no floodplain access from the main channel and an overall lack of available sediment. The riparian buffer appears to be relatively healthy within Reach 2 with adequate width to the north, access to the floodplain, and native plant species present.

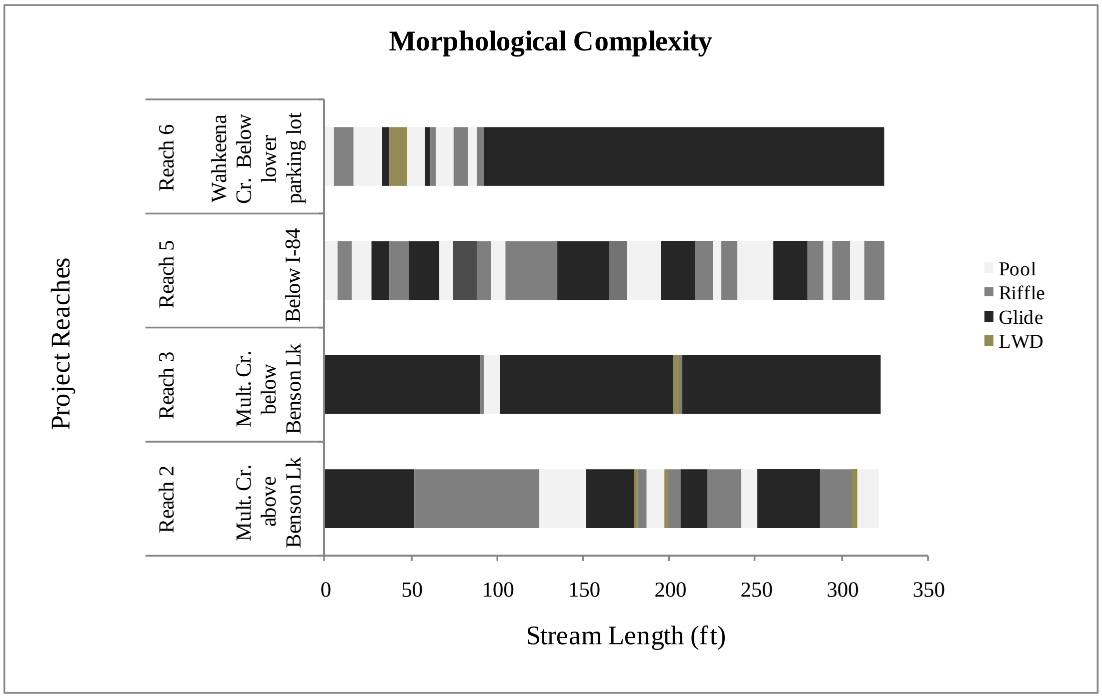

Figure 29: Morphological Complexity by Project Reach.

Causal factors were identified to develop an understanding of preliminary limiting factors that impact habitat conditions (Table 11). A properly functioning alluvial creek has specific attributes that support ecological functions. In highly disturbed systems fluvial processes have been impacted such that local physical dynamics and ecological communities have been altered. Attributes of a properly functioning alluvial system are reported in Section 6 in order to quantify reach scale conditions.

Table 11. Preliminary Limiting Factors.

	Multnomah Creek/ Benson Lk.				Confluence	Wahkeena Creek
Parameter	*Reach 1*	*Reach 2*	*Reach 3*	*Reach 4*	*Reach 5*	*Reach 6*
LWD quantity[1]	poor	poor/fair		poor	poor	poor
Channel migration[2]	none	low-moderate		none	none	none
Sediment deposition[3]	moderate-high	moderate		none	little	little
Riffle embeddeness[4]	low	low		moderate-high	low	low
Riparian functioning[5]	fair	fair	poor	poor	poor	poor

[1] Fox & Bolton (2007)
[2] Schumm (1985)
[3] Professional judgment
[4] Sytle (2002)
[5] Beechie et al. (2003)

4.3 FISH PASSAGE

Presently, fish passage at the site is impaired by both physical and thermal barriers. The primary physical barrier is the I-84 culvert, the site's only outlet to the Columbia River. Due to recent passage upgrades, conditions within the culvert appear to be suitable for all salmonid species and life stages at all flow regimes. These upgrades include baffles to provide hydraulic roughness and a "lip" at the outlet to backwater the culvert providing sufficient depths for passage. Despite these improvements, the steep grade (approximately 14%) of the constructed roughened chute below the culvert prohibits access to the site by juvenile salmonids of all species. Adult chum salmon also are unable to successfully navigate this barrier, while passage conditions for adult Chinook salmon also are limiting. Based on ODFW spawning survey data and observations by the project team, the roughened chute does not appear to be a barrier to adult coho salmon and steelhead (ODFW 2009). The undersized park culvert and UPRR bridge also likely inhibit passage in Wahkeena Creek.

Water temperatures within much of the site, including the channel below the I-84 culvert, also inhibit passage (or at least make conditions less attractive than surrounding habitats). For example, Flick (2007) reports a maximum seven-day average maximum temperature of 18.9°C below the I-84 culvert (Reach 5). This temperature exceeds regulatory standards and likely discourages adult and juvenile salmon migrating through the Columbia River from using this habitat during summer months. Similarly, temperatures in Reach 4 regularly exceed 20°C (maximum seven-day average maximums of 23°C and 24°C are reported in Section 4.4 for the two monitoring stations in Reach 4). These temperatures, which are in the lethal range for salmonids (see Section 3.4.2), likely prevent juveniles from migrating between relatively high quality rearing habitats in Wahkeena Creek and upper Multnomah Creek during summer months.

4.4 TEMPERATURE EVALUATION

As detailed in Section 2.4.1, Multnomah and Wahkeena Creeks are 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, the project team identified surface water temperatures as a potential limiting factor. The project team monitored temperatures during spring and summer 2010 and used the resulting data 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 Multnomah Creek, Wahkeena Creek, and Benson Lake;
- 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.

Surface water temperatures typically are warmest during July and August, therefore temperature data collected at the site were analyzed during the period July 17 – August 31. Tables 12 and 13 and Figure 30 summarize the temperature monitoring results. Figures 31 and 32 provide summary graphs for each monitoring station.

Table 12. Summary of 2010 Temperature Monitoring Data (July 17 – August 31, 2010).

Station	Max. 7-day Avg. Max. Temp.	Avg. Daily Low Temp.	Avg. Daily High Temp.	Avg. Diurnal Fluctuation	Avg. Hrs. <14ºC	Avg. Hrs. >18ºC
Multnomah Creek						
Visitor Area	17.7	12.9	16.0	3.1	11.2	1.0
Lake Inlet	17.8	13.1	16.0	2.9	10.4	1.0
Lake Outlet	24.1	16.5	19.1	2.6	3.7	11.0
I-84	23.5	14.8	18.0	3.2	8.7	8.0
Wahkeena Creek						
I-84	11.4	9.7	10.5	0.8	24.0	0.0

Table 13. Summary of 2010 Benson Lake Temperature Profiles (August 20, 2010)

Station	Low Temp. (°C)	High Temp. (°C)	Temp. Range (°C)
Benson Lake – NW	20.0	20.6	0.6
Benson Lake – NE	19.6	20.6	1.0
Benson Lake – SE	16.1	20.7	4.6
Benson Lake – SW	17.8	20.7	2.9

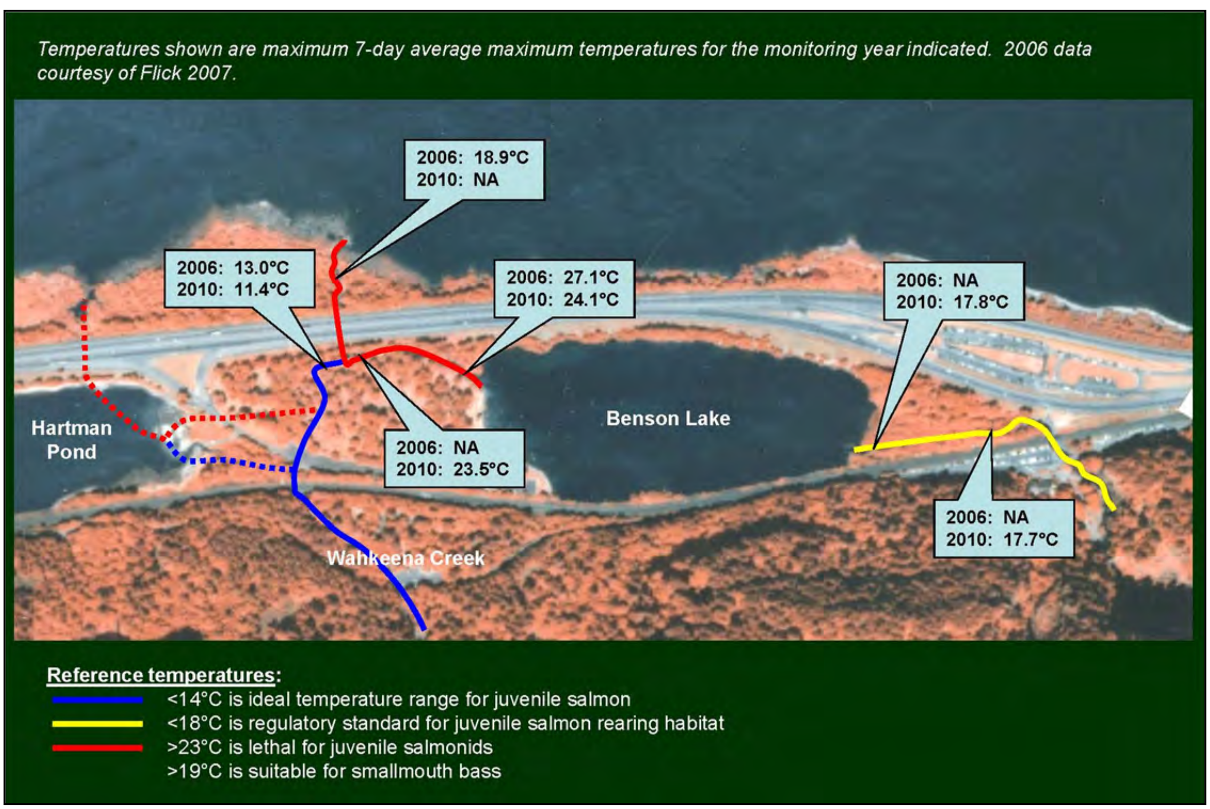

Figure 30. Summary of 2010 temperature monitoring.

4.4.1 High And Low Temperatures

Average daily high temperatures at the site ranged from 10.5°C at the Wahkeena – I-84 monitoring station to 19.1°C at the Multnomah – Benson Lake Outlet station. Average daily low temperatures ranged from 9.7°C to 16.5°C. The project team also assessed 7-day average maximum temperatures at each station as that is the metric utilized by ODEQ to assess thermal suitability of juvenile salmon habitat. The highest 7-day average maximum temperature for each station ranged from 11.4°C in Wahkeena Creek to 24.1°C at the Multnomah Creek – Benson Lake Outlet station, exceeding the state criteria of 18°C at the two Multnomah Creek monitoring stations located below Benson Lake. These can be compared to 2006 maximum 7-day average maximum temperatures reported by the USFS ranging from 13.0°C in Wahkeena Creek to 18.9°C and 27.1°C above and below Benson Lake (Flick 2007) (Figure 30).

In general, temperatures were lowest in Wahkeena Creek and upstream of Benson Lake in Multnomah Creek. Temperatures in Wahkeena Creek never exceeded 12°C. In Multnomah Creek, the highest seven day average maximum temperatures increased only 0.1°C between the two stations upstream of the lake (from 17.7°C to 17.8°C); however, they increased 6.3°C between the inlet and outlet monitoring stations. This increase (from 17.8°C to 24.1°C) caused lower Multnomah Creek to exceed ODEQ's regulatory standard of 18.0°C for juvenile salmonid rearing habitat.

In Benson Lake, surface temperatures were remarkably consistent ranging from 20.5°C to 20.7°C. At the SE and SW monitoring stations, temperatures were much lower (as low as 16.1°C at the SE monitoring station) at and below 5 feet depth. At the NE and NW monitoring stations, temperatures varied less than 1.0°C throughout the profile.

4.4.2 Average Diurnal Fluctuations

Average diurnal fluctuations are defined as the difference between the average daily minimum and maximum temperatures at each monitoring station. Diurnal fluctuations were relatively constant throughout Multnomah Creek, ranging from 2.6°C to 3.2°C. Diurnal fluctuations in Wahkeena Creek averaged 0.8°C.

These results are somewhat surprising in that reaches with significant surface area and relatively long detention times (such as Benson Lake) typically are susceptible to rapid daytime warming and night-time cooling. However, as compared to reaches upstream of Benson Lake, the monitoring stations located downstream of the lake did not have significantly higher diurnal fluctuations. Wahkeena Creek's average diurnal fluctuation of 0.8°C is not surprising in that the stream is spring-fed, nearly 100% forested, and has a relatively small watershed (and therefore a shorter channel with less time for exposure to ambient temperatures).

4.4.3 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 while only Wahkeena Creek is consistently below 14°C, temperatures typically fall below 14°C throughout the entirety of the site for a portion of the 24 hour period. Additionally, even the portion of Multnomah

Creek located above the lake (one of the higher quality rearing habitats on-site) has temperatures in exceedance of 14°C for an average of greater than 12 hours daily.

4.4.4 Hours Per Day With Temperatures Above 18°C

As noted above, 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, i.e., sites with the highest average temperatures exceeded 18°C for the greatest duration. Results were encouraging in that Wahkeena Creek never exceeded 18°C, and above Benson Lake, Multnomah Creek exceeded the 18°C criteria an average of only one hour per day. Although the thermal regime in many portions of the site (particularly within and below Benson Lake) is not ideal, night-time temperatures below 18°C theoretically allows juvenile salmon to move throughout the site on a daily basis.

4.4.5 Thermal Profiles and Habitat Suitability of Waterbodies

This section presents a summary of the thermal profiles of Benson Lake and the site's two streams, 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 Tables 5 and 6) for both juvenile salmonids and smallmouth bass.

4.4.5.1 Multnomah Creek

Figure 31 shows the thermal profiles at all Multnomah Creek monitoring stations for July 17 – September 15, 2010.

Development within the project area has resulted in dramatic alterations to Multnomah Creek. Among other factors, these alterations have affected the creek's thermal regime. As detailed below, a combination of site-wide temperature monitoring results, targeted discharge measurements, and lake bathymetry helped to identify Benson Lake as the primary source of thermal loading to the creek.

Figure 31: Thermal profiles for Multnomah Creek monitoring stations

During summer 2010 monitoring, Multnomah Creek's average daily high temperature increased from 16.0°C to 18.0°C between the Multnomah Falls visitor center and the I-84 culvert; however, the highest 7-day average maximum values (a better indicator of extremes faced by juvenile salmonids) increased 5.8°C (from 17.7°C to 23.5°C) between these two stations. The highest 7-day average maximum temperatures remained essentially stable (increase of 0.1 ºC) as the creek passed from the visitor center downstream to the inlet of Benson Lake (a distance of 1,050 feet). Due to lack of thermal inputs and relatively intact habitat conditions, this reach provides a valuable reference. Multnomah Creek's highest 7-day average maximum temperature warmed 6.3°C between the inlet and outlet monitoring stations. This suggests that Benson Lake is a significant source of thermal loading. The estimated low-flow detention time in the lake of 16 days and 2006 temperature monitoring (Flick 2007) (which shows similar results) help confirm that the lake is the primary source of thermal loading to lower Multnomah Creek. It should be noted that the thermal profiles of the two monitoring stations downstream of the lake are unusual. Because they do not match the upper creek's profiles, it appears that lake processes contribute significantly to the thermal character of the lower portion of the creek.

Multnomah Creek's highest 7-day average maximum temperature decreases 0.6°C between the outlet of the lake and the I-84 culvert. The reason for this decrease is unclear, although this portion of the stream is relatively well shaded.

The project team did not place a temperature probe downstream of the I-84 culvert, therefore 2010 temperature data are not available for this reach. The highest 7-day average maximum temperature reported for this reach by the USFS in 2006 monitoring was 18.9°C (Flick 2007).

Table 13 summarizes habitat classification for salmon and non-native predators based on the site's thermal regime.

Table 13. Habitat Classification Based on Thermal Regime

Monitoring Station	Highest 7-day Average Maximum Temperature	Salmon Habitat Classification	Smallmouth Habitat Classification
Multnomah Creek			
Visitor Center	17.7	Functional	Poor
Benson Lake Inlet	17.8	Functional	Poor
Benson Lake Outlet	24.1	Lethal	Ideal
I-84	23.5	Lethal	Ideal
Wahkeena Creek			
I-84	11.4	Ideal	Poor
Benson Lake			
Lake-wide	NA	Poor	Ideal

4.4.5.2 Wahkeena Creek

Figure 32 shows the thermal profile for the Wahkeena Creek monitoring station for July 17 – September 15, 2010.

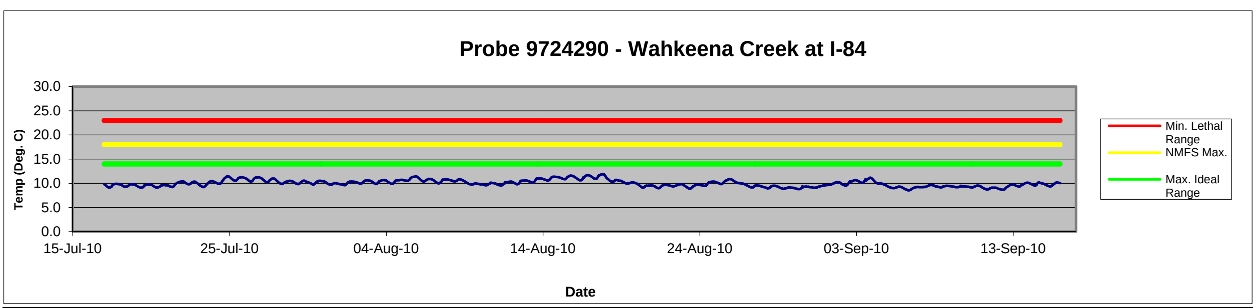

Figure 32: Thermal profile for the Wahkeena Creek monitoring station

Although it has a smaller watershed than Multnomah Creek ($0.8mi^2$ vs. $5.5mi^2$), discharge in Wahkeena Creek was slightly higher than that in Multnomah Creek during the September 2010 flow monitoring event (Table 14). Given its smaller watershed, greater baseflow, steeper channel gradient, and spring-fed headwaters, it is not surprising that baseline temperatures are lower in Wahkeena Creek than Multnomah Creek.

Once on-site, Wahkeena Creek flows a short distance (approximately 400 feet) before passing through the I-84 culvert and entering the Columbia River. The primary factor of interest in regards to Wahkeena Creek's thermal regime is that a significant portion of the creek's flow (approximately 40% based on September 15, 2010 discharge measurements) is diverted into Hartman Pond. Hartman Pond has two discharge locations – one to the Columbia River and one back into Wahkeena Creek approximately 100 feet upstream of the I-84 culvert. The project team did not locate the Wahkeena Creek discharge until late in the season, therefore, probes were not located upstream and downstream of this feature to assess its effect (if any) on the creek's thermal regime. Sampling during the summer of 2011 will target this potential loading source.

Based on its thermal profile, Wahkeena Creek was classified as "ideal" rearing habitat for juvenile salmonids and "poor" habitat for smallmouth bass.

4.4.5.3 BENSON LAKE

Long-term temperature monitoring data are not available for Benson Lake; however, the project team took four thermal profiles of the lake on August 20, 2010 (Figure 33). Profiles were taken in the lake's deeper portions (minimum depth of 7 feet) to determine if water temperatures changed with depth, i.e., whether the lake was thermally stratified. Results indicated that the northern portion of the lake was not stratified, with temperatures varying 1°C or less throughout the depth profile. In contrast, the southern portion of the lake was thermally stratified, with temperatures varying up to 4.6°C throughout the profile (from 20.7°C at the surface to 16.1°C below 5 feet). In both of the southern profiles, a rapid change in temperature occurred between the 4 and 5 foot depths. Within this one foot zone (known as the thermocline), temperatures decreased by an average of 3.1°C at the two sites. Stratification at these sites may be due to a number of factors including Multnomah Creek water being diverted through the southern portion of the lake, shade provided by Gorge walls, groundwater seeps feeding the southern portion of the lake, and/or natural lake stratification processes.

Temperatures at Multnomah Creek's Benson Lake Outlet monitoring station provide an indication of the thermal profile of the lake over the course of the monitoring period. The creek's thermal profile at this location is unusual, with large spikes in temperature and periods of stability that do not match climate conditions, i.e., precipitation and temperature patterns, or the thermal profile of the upper portion of the creek. The thermal profile at Multnomah Creek's I-84 culvert monitoring station exhibits a very similar pattern. Although no quantitative assessment of these variances was completed and sufficient data are not available to thoroughly assess lake conditions, it can be surmised that the lake has a negative impact on Multnomah Creek's thermal regime. Additionally, during low-flow conditions, thermal conditions (as defined in Tables 5 and 6) in the entirety of the lake's surface waters (less than approximately 4 feet depth) and much of its deeper areas (greater than 4 feet depth) are "poor" for salmonids and "ideal" for smallmouth bass.

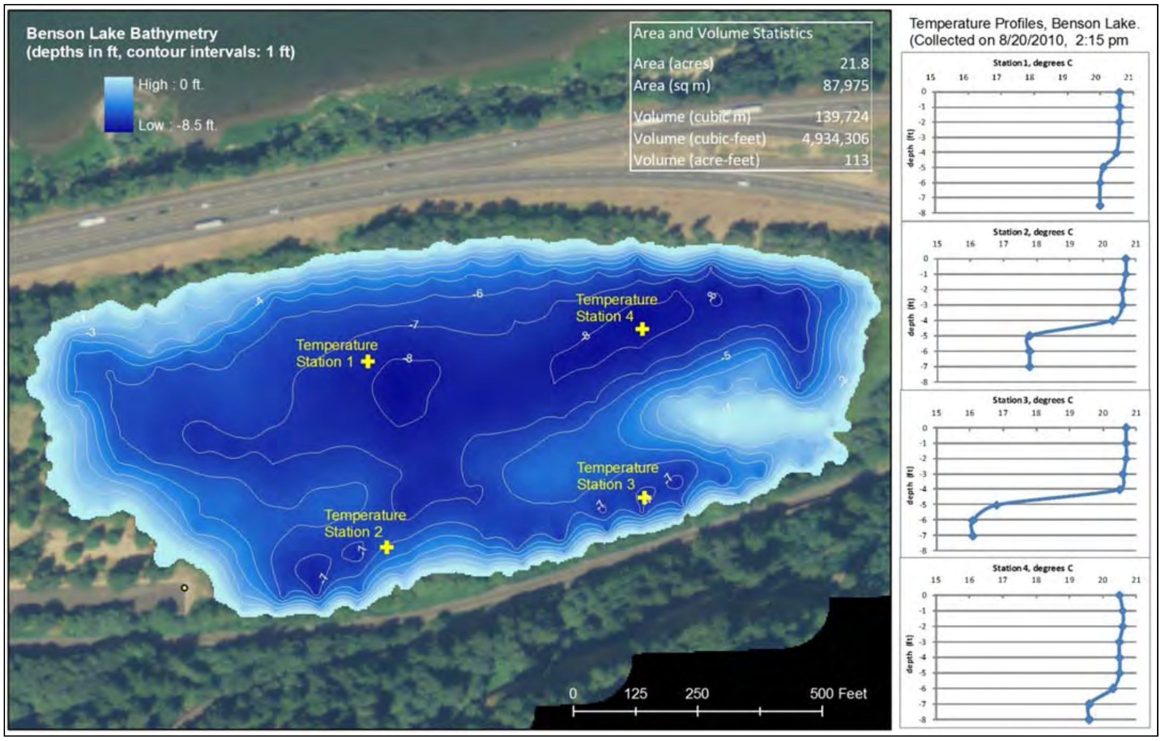

Figure 33. Benson Lake temperature and bathymetry survey results.

4.4.6 CLIMATE & PRECIPITATION DATA

This analysis 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. The goal is to provide a general indication of how surface water temperatures at the site during the 2010 monitoring period may have varied from average conditions.

4.4.6.1 PRECIPITATION

In the month leading up to and during the 2010 monitoring period, total precipitation at the Bonneville Dam and Troutdale weather stations was 173% and 165% of normal levels respectively (Table 14). However, total precipitation for the entire monitoring period masks monthly deviations from normal. During the month of June, precipitation was nearly three times the historic average at both stations, while during July and August, precipitation was 26% and 17% of normal levels at the Bonneville Dam and Troutdale weather stations respectively.

In summary, precipitation was well above average during the month before the monitoring period (June), but was below average during the monitoring period (July and August). 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 14. 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
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 (June 1 – August 31)	4.98	8.62	3.64	3.75	6.19	2.44

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. Three days of data for this month were not collected.

4.4.6.2 AMBIENT AIR TEMPERATURES

Data from the Bonneville Dam and Troutdale weather stations (Table 15) indicate that during the 2010 study period, ambient air temperatures were cooler than historic averages. Overall, the average high temperature from July 1, 2010 through August 31, 2010 at the Troutdale Airport was 1.7°C (6%) below average, while the average high temperature at the Bonneville Dam station during the same period was 0.4°C (2%) below average. These deviations from historic averages were greater in July than August.

Table 15. Historic and 2010 Average Maximum Air Temperature Data from Bonneville Dam and Troutdale Airport Weather Stations

Date	Bonneville Dam[1] (ºC)			Troutdale Airport[2] (ºC)		
	Historic	2010	Δ	Historic	2010	Δ
July	26.1	25.6[4]	-0.5	27.6	25.3	-2.3
August	26.1	25.8	-0.3	27.3	26.2	-1.1
Average (July 1 – August 31)	26.1	25.7	-0.4	27.5	25.8	-1.7

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. One day of data for this month was not collected.

4.4.6.3 CLIMATE SUMMARY

Based on available data, air temperatures in the vicinity of the project site appear to have been 2-6% below average during the 2010 study period. Monthly precipitation totals varied considerably, but overall were nearly 300% of the historic average the month prior to the monitoring period, but only 17-26% of average during the monitoring period. Based on these data, it is not readily obvious how climate conditions (lower temperatures but also lower flows) may have affected surface water temperatures during the 2010 monitoring period.

4.4.7 SUMMARY OF RESULTS

Table 16 summarizes impacts to each project reach based on information presented in the above sections.

Table 16. Summary of impacts to project reaches.

	Project Reaches						
Characteristics	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7
Channel instability				√	√	√	
Fish passage			√	√	√		
Thermal regime			√	√	√		
Instream habitat diversity & functioning	√			√		√	
Riparian habitat diversity & functioning	√		√	√		√	
Hydrologic regime					√	√	√
Sediment regime		√		√	√	√	

Note: Areas shaded grey indicate the characteristic is not applicable to that reach.

5 PROJECT GOALS AND OBJECTIVES

As a result of the baseline site assessment, the project team identified the following factors as limiting the ecological function of the site and its support of multiple life stages of native species.

- Habitat connectivity is impacted by physical and thermal passage barriers and lack of floodplain connection.
- Stream temperature is impaired by direct loading from Benson Lake and Hartman Pond, dispersed loading from impacted riparian cover, and altered hydrologic conditions.
- Sediment supply and transport capacity is severely limited in many reaches due to undersized infrastructure, altered channel alignments, construction of Benson Lake, and stream diversions.
- Riparian forest is on a declining trajectory due to lack of recruitment resulting from impaired mainstem hydrology, competition from invasive species, prior agricultural disturbance, and current recreational and tourism uses.
- Habitat quality and diversity is impaired throughout much of the site, particularly in channelized/sediment poor reaches and in Benson Lake.
- Food web production and cycling is likely impaired due to homogenization of riparian vegetation and lack of instream habitat structure to retain organic inputs to the stream channels.

Following completion of the baseline assessment and identification of the limiting factors detailed above, the project team convened a stakeholder meeting on November 29, 2010 to present results of the baseline assessment, review limiting factors, and develop restoration/enhancement objectives for the site. Meeting participants included the USFS (Robin Dobson and Mark Kreiter), OPRD (Andrea Berkley and Mark Stevenson), Estuary Partnership (Chris Collins and Paul Kolp), and Henderson Land Services (Matt Koozer). The project team summarized the meeting discussion via meeting notes as well as the following set of enhancement objectives, which subsequently were approved by the USFS and OPRD.

<u>Project Goals and Objectives</u>:

1. Improve fish passage
    a. Adult salmonid passage into the site, particularly chum and Chinook salmon
    b. Juvenile salmonid passage into site (all species)
    c. Thermal barriers impeding juvenile and adult fish passage during summer and fall
2. Improve hydrologic and geomorphic processes
    a. Re-establish Multnomah Creek's historic connection to Columbia River
    b. Restore pre-development hydrology in Wahkeena Creek, i.e., reduce or eliminate Hartman Pond diversion
3. Improve thermal regime
    a. Reduce summer rearing temperatures
    b. Provide cool-water refugia in mainstem for late outmigrants and returning adults
4. Improve water quality
5. Improve riparian/floodplain connectivity and processes
6. Improve instream habitat diversity and function
    a. Over-wintering habitat (LCR coho and steelhead)
    b. Summer rearing capacity (LCR coho and steelhead)
    c. Spawning habitat (LCR coho and steelhead; potentially chum and Chinook)
    d. Organic matter retention and food web production

6 FEASIBILITY AND ALTERNATIVES ANALYSES

The primary goal of this report is to use a science-based approach to identify and assess the feasibility and benefits of a variety of enhancement alternatives at the site. After assessing site conditions and using those data to identify limiting factors and establish project goals, the project team next identified potential constraints in order to provide guidance for the development and evaluation of restoration alternatives. The following constraints were identified based on site observations, data collection and analysis, and discussions with project stakeholders.

- Existing transportation corridors (I-84, UPRR, and Historic Columbia River Highway) and attendant infrastructure (culverts and bridges);
- Existing recreational and tourism uses and infrastructure, including Benson State Recreational Area, Hartman Pond, and the Multnomah Falls Visitor Area;
- High level of public interest;
- Preservation requirements for historically significant infrastructure including the Historic Columbia River Highway and Multnomah Falls Visitor Area infrastructure;
- Reduced natural disturbance regime due to the regulation of Columbia River hydrology and lack of upstream sediment contributions;
- Non-native flora and fauna introductions and their impact on biotic communities and local ecological processes; and,
- Lack of funding/capacity for long-term maintenance and monitoring of enhancement features.

The project team recognizes that the site is not only ecologically important but also is of critical importance to tourism and recreation in the CRGNSA. Consequently, proposed alterations that affect these uses will justifiably receive high levels of scrutiny. Additionally, due to existing infrastructure and the logistics of working in areas with high levels of public use, some enhancement actions may require extensive planning, may be disruptive to existing uses, and may be expensive to implement. Consequently, when developing enhancement alternatives, the project team subdivided the alternatives into two categories:

1. Short-term: Alternatives whose construction would have little to no impact on existing site uses and would be relatively inexpensive to implement; and,
2. Long-term: Alternatives whose construction would have moderate to high levels of temporary impact on existing site uses and would be relatively expensive to implement.

By subdividing enhancement alternatives into two categories, the project team hopes to move forward in the near future with actions that will measurably improve site function but will involve limited investment and disturbance to existing site uses. Concurrently, the project team will continue working with stakeholders to move long-term enhancement actions forward towards implementation.

As a first step in developing site alternatives, the project team assessed and compiled a suite of reference conditions. These reference conditions are intended to provide guidance as to what a healthy, moderate to highly functioning system would look like. Reference conditions for each resource component are detailed below.

- *Large Woody Debris*: Fox and Bolton (2007) assessed natural wood loading rates in Washington streams, which InterFluve (2010) reviewed, summarized, and reported as being applicable to a similar project site in the CRGNSA. For streams with similar size and climatic region as Multnomah and Wahkeena Creeks, Fox and Bolton (2007) found median LWD densities of 52 pieces per 100 meters (29 pieces and 63 pieces per 100 meters for 25th and 75th percentiles, respectively). These densities are based on WDFW's LWD criteria of diameter > 10cm and length > 2m.

- *Riparian Conditions*: Reference vegetation conditions that apply to the subject site are described in Christy's 2004 "Native Freshwater Wetland Plant Associations of Northwestern Oregon." Associations that are applicable indicate that *Fraxinus latifolia* would be a primary tree with lesser amounts of *Populus balsamifera* ssp. *trichocarpa, Frangula purshiana, Abies grandis,* and *Alnus rubra.* The shrub layer would be diverse, averaging less than 10 percent cover, with occasionally high cover of *Rubus ursinus, Symphoricarpos albus, Cornus sericea*, and *Acer circinatum* (also including: *Rosa nutkana, Spiraea douglasii, Physocarpus capitatus* and *Corylus cornuta). Carex obnupta* would likely dominate the herb layer with many other herbaceous species present to a lesser degree. This corresponds to Christy's *Fraxinus latifolia / Carex obnupta* association, but it should be noted that Christy's Shrubland Associations with *Salix lasiandra* are also applicable in portions of the site.
- *Stream Temperature*: As detailed in Section 3, Bjornn and Reiser (1991) report 14°C as the upper limit of ideal temperatures for rearing salmon. 18°C is used by DEQ as the regulatory threshold for streams that support juvenile salmonid rearing. The portions of the Multnomah and Wahkeena Creek watersheds located above the Historic Columbia River Highway are in relatively pristine condition; consequently, during 2011, the project team will collect data in this area to provide reference thermal conditions specific to each stream.
- *Alluvial Rivers:* Alluvial rivers are dynamic in nature and species have evolved to colonize within natural disturbance regimes that result from fluvial processes. Hydrogeomorphic conditions bring with it reach scale complexity in the vertical, horizontal and longitudinal directions. Although there are no regional reference or properly functioning conditions, we have incorporated elements from McBain (2008) that outline attributes of river integrity including:
    - Balanced fine and coarse sediment budget
    - Spatially complex channel morphology
    - Frequently mobilized channel morphology
    - Functional floodplain
    - Self-sustaining riparian plant communities
    - Flows and water quality are predictably variable

6.1 Development and Assessment of Proposed Alternatives

It should be noted that as used within this document, the term 'alternative' is not meant to define a broad scale alternative such as would be proposed in NEPA documentation, but finer-scale pre-screening alternatives used to assess the technical feasibility and relative order-of-magnitude costs associated with various applied enhancement approaches. The full suite of enhancement alternatives analyzed is detailed in the following sections. For reference, Figure 10 provides a map of project reaches. Appendix A presents concept designs for all short-term enhancement alternatives.

Reach 1 – Multnomah Falls Visitor Area

Existing Conditions: Reach 1 extends approximately 650 feet from the lower falls downstream to the end of the visitor area (the terminus of the historical rock wall). The Multnomah Falls visitor area is developed as a tourist facility and is visited by approximately 2 million people per year (USFS 2003). The upper portions of this reach have natural stream banks and narrow riparian areas; however, the lower portion of the reach has hardened stream banks and riparian areas that have been paved for walking paths and other facilities (Figure 34). Three bridges cross the stream within this reach.

Additionally, this reach is the location of the Multnomah Creek diversion, which realigned the stream channel to the west through Benson Lake. To accomplish this diversion, the stream channel, which historically flowed due north to the river, was turned 90 degrees to the west. Since this diversion was constructed, substrate accumulates at this bend during flood events necessitating routine (approximately once every two to three years) dredging to maintain channel capacity (Figure 34) (USFS 2003). Due to a lack of riparian vegetation, poor instream habitat diversity, and hardened streambanks, overall habitat quality in this reach is poor, although it does experience high levels of coho salmon spawning. Water temperatures during the 2010 monitoring period were suitable for juvenile salmon rearing.

Figure 34: Multnomah Creek – Reach 1. View is looking upstream. Note loss of channel capacity between October 2010 (left photo) and February 2011 (right photo) due to aggradation during a January 2011 high flow event.

Constraints: Multnomah Falls is the second most popular tourist attraction in Oregon. The infrastructure that facilitates this high level of use therefore is extremely important to the local and regional economy and the experience of two million tourists each year. Additionally, this reach includes crossings of the historic highway and UPRR as well as an I-84 crossing of the historic channel alignment. Enhancement actions taken in this reach would need to consider impacts to these (as well as downstream) uses and attendant infrastructure, e.g., water quality in Benson Lake. Modifications to this reach also would need to consider the location of new infrastructure within a dynamic alluvial fan that currently necessitates routine dredging to maintain channel capacity.

Short-term: No action. Meaningful enhancement actions in this reach will require significant alterations to important tourist and recreational facilities. Consequently, these actions will require extensive planning and coordination with project partners.

Long-term: The long-term enhancement actions recommended in this project reach include (a) “softening” riparian areas by establishing vegetative buffers, (b) limiting pedestrian access to portions of the creek, (c) widening the channel migration zone, and (d) re-establishing the historic channel alignment and confluence with the Columbia River. If implemented correctly, these actions would restore important processes, e.g., sediment transport and LWD recruitment, that are important to salmonids at the site. Not only does restoration of Multnomah Creek’s historic alignment have the potential to eliminate the need for future dredging, it also would permit chum salmon to access the site thereby restoring a species that has been absent from tributaries on the Oregon side of the CRGNSA since construction of I-84 over 60 years ago. Achieving these enhancement alternatives would require significant modification of existing infrastructure, including a new I-84 crossing and relocation of the Multnomah Falls parking area, and therefore will require extensive coordination with numerous stakeholders.

Reach 2 – Multnomah Creek below Visitor Center

Existing Conditions: Reach 2 extends approximately 650 feet from the downstream end of the visitor area's historical rock wall to the inlet of Benson Lake. This channel, which was activated when Multnomah Creek was diverted to facilitate construction of I-84, is bounded by the UPRR to the south and a small, but relatively healthy, riparian forest to the north. Based on field observations and data provided by the USFS, Reach 2 has the greatest morphological/habitat diversity and appears to be on a "healing trajectory". This likely is due primarily to enhanced substrate management practices in Reach 1, which allow more substrate to be transported into Reach 2. As detailed in Section 4.2.1 and shown in Figure 35, this substrate is forming point bars, activating side channels, and providing other complex habitat features. Moderate amounts of LWD have been recruited to the stream from the riparian area to the north. Reach 2 supports high levels of coho spawning and rearing. Additional detail re: conditions in Reach 2 can be found in Section 4.

Constraints: Enhancement actions taken in this reach would need to consider impacts to the railroad embankment, which forms its southern boundary, as well as impacts to infrastructure located downstream. Access for construction will need to consider impacts to this reach's relatively healthy riparian zone.

Short-term: Short-term enhancement alternatives that should be considered within this reach include targeted LWD placement (Alternative A) and substrate management (Alternative B). LWD would be placed strategically to create desirable instream habitat features and/or increase channel/floodplain connectivity. Due to access restrictions, high levels of site use during the summer in-water work window, and existing LWD, a smaller volume of LWD would be added in this reach. It is estimated that if 30-40 pieces of LWD were added to Reach 2, it would bring overall densities to within the lower range specified by Fox and Bolton (2007). To minimize the need for anchoring, the majority of these pieces would be large in size (minimum length and DBH of 40' and 25" respectively). Pinning these structures together with rebar also may improve stability. All LWD would be placed such that it does not affect the railroad embankment.

Additionally, the project team would review and enhance current sediment management practices. This may include a reduction in Reach 1 dredging and/or placement of material removed from Reach 1 into the upstream portion of Reach 2. Overall, short-term investment in this reach would be limited as it likely would be abandoned if long-term enhancement actions are implemented.

Long-term: None. If Multnomah Creek's historical channel alignment is re-established, this reach would be abandoned.

Figure 35: Instream and riparian habitat conditions in Reach 2. View is looking upstream.

Reach 3 – Benson Lake

Existing Conditions: Benson Lake is a 22-acre man-made lake with an average depth of approximately 6 feet (Figure 33). It is fed primarily by Multnomah Creek, which enters the lake in its southeastern corner and exits in the northwestern corner. A substantial delta exists at the inlet of Multnomah Creek; this delta continues to enlarge vertically and horizontally. Detention time in the lake during low-flow months is estimated to be approximately 16 days. Thermal profiles within Benson Lake are unsuitable for salmonids (Table 13), and thermal loading from the lake impacts the lower portions of Multnomah Creek (Figure 30).

Figure 36. Benson Lake at the inlet of Multnomah Creek. View is looking west.

Constraints: Benson Lake, which is used for swimming, boating, and fishing, is the focal feature of a popular state recreation area. Consequently, enhancement actions taken in this reach (as well as upstream reaches) would need to consider impacts to this resource as well as impacts to utilities on its northern shore and the railroad embankment on its southern shore.

Short-term: No action. Meaningful enhancement actions in this reach will require significant alterations to important tourist and recreational facilities. Consequently, these actions will require extensive planning and coordination with project stakeholders.

Long-term: Long-term enhancement actions in Reach 1 would largely determine management of Benson Lake. The ideal solution from the ecological perspective would be to take the lake off-line, therefore eliminating the negative effects of the lake on stream temperature, biotic communities, etc.; however, this may negatively affect water quality and anthropogenic uses. Routing treated stormwater runoff from surrounding parking lots into the lake may help "flush" the lake and maintain its suitability for recreation, fishing, and other activities.

Reach 4 – Lower Multnomah Creek

Existing Conditions: The lower Multnomah Creek reach extends approximately 600 feet from the outlet of Benson Lake to the inlet of the I-84 culvert. ODOT excavated this reach during construction of I-84 when Multnomah Creek was diverted through Benson Lake. Hydrologic and geomorphic conditions are controlled by the inlet and outlet elevations of the I-84 culvert and Benson Lake. This reach is composed of a long, backwatered glide that extends its entire length (Figure 37). Low flow depths average 3-4 feet, channel gradient is very low (~0.01%), and planform is straight with negligible sinuosity. Channel substrate is primarily silty-sand with areas of rip-rap (presumably from freeway construction). The channel is incised with oversteepened banks. The south bank is relatively flat and is vegetated primarily with mature cottonwood trees (*Populus trichocarpa*), redosier dogwood (*Cornus sericea*) and Himalayan blackberry (*Rubus armeniacus*). The north bank is in very close proximity to the freeway embankment. Habitat quality is very poor in this reach, with limited habitat diversity, structure or cover. There is some evidence of beaver activity, with visible attempts to dam the inlet to the I-84 culvert. Additional detail re: Reach 4 can be found in Section 4.

Figure 37. Lower Multnomah Creek (Reach 4). View is looking upstream.

Constraints: Hydraulics in this reach likely do not support movement of gravel. Therefore, during design, it will be necessary to definitively assess whether gravel placed in this reach (as specified in the 2003 BiOp) would effectively seed the roughened chute in Reach 5. All enhancement alternatives also would need to account for the I-84 embankment and utilities on the creek's northern bank. Groundwater tables are predicted to have dropped within the reach due to channel incision, and revegetation efforts will have to consider this. Access for construction will need to consider impacts to this reach's riparian zone.

Short-term: Several short-term enhancement alternatives should be considered for this constructed reach with oversimplified habitat conditions. These alternatives can be combined as desired to form the reach's preferred alternative.

Alternative A: LWD placement

Under this short-term enhancement alternative, LWD would be strategically placed to create desirable instream habitat features, increase channel/floodplain connectivity, and trap substrate and organic material. Due to infrastructure that prevents LWD transport from upstream reaches and a narrow riparian corridor, LWD densities in this reach are very low. It is estimated that if 75-100 pieces of LWD were added, it would bring overall densities to within the median range specified by Fox and Bolton (2007).

Alternative B: Substrate Augmentation

Substrate delivery to Reach 4 is severely impaired by Benson Lake, which effectively traps all sediment moving through Multnomah Creek. This is causing the stream channel to incise becoming disconnected from its floodplain. Alternative B would involve reassessing the site's sediment management plan. Future management actions may include using substrate taken from Multnomah Creek dredging operations and/or Reach 6 culvert cleaning to increase the bed elevation of the channel and, if hydraulics permit, seed Reach 5's roughened chute. Substrate added to this reach likely would not exceed 500CY, the maximum amount of material anticipated to be available from these two sources.

Alternative C: Riparian Revegetation

This alternative involves site preparation (mowing and spraying of Himalayan blackberry and other invasives) followed by inter-planting within the existing riparian buffer (approximately 100 feet wide). The goal of this effort is to increase shade and organic input (including LWD) to the creek as well as provide a narrow, but healthy riparian community. Plantings will be composed of native woody and herbaceous species, including Oregon ash (*Fraxinus latifolia*) and black cottonwood.

Alternative D: Beaver Activity

Substantial evidence indicates that beaver activity is beneficial to salmonids, particularly coho salmon. Nickelson et al. (1992) suggested that, given adequate spawners, availability of winter habitat, e.g., alcove/off-channel pools and beaver ponds, limits production of coho salmon smolts in most Oregon coastal streams[1]. Beaver activity will be encouraged by creating attractive dam locations, primarily through installation of LWD that constrains the channel and provides structures for anchoring dams. Encouraging beaver activity ideally would result in construction of one or more dams in this reach.

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[1] Although not located on the coast, Horsetail and Oneonta Creeks share many characteristics with coastal streams, including hydrology and watershed elevation/topography.

Long-term: As with Reaches 2 and 3, long-term enhancement actions in Reach 1 would have a significant impact on this reach. Alternatives proposed for consideration in Reach 1 include restoring Multnomah Creek to its original alignment. Restoration of Multnomah Creek's historic channel alignment would dewater this reach rendering it obsolete. If this occurs, options for this reach might include (1) filling (abandoning) the channel, (2) enhancing it to form off-channel habitat for Wahkeena Creek, and (3) no action. If restored as off-channel habitat, treated stormwater runoff may provide a viable water source of this reach.

Reach 5 – I-84 Culvert and Outlet Channel

Existing Conditions: The combined flows of Multnomah and Wahkeena Creeks are conveyed through the I-84 road prism via a three barrel concrete box culvert that is 180 feet in length (Figure 38). Each barrel is 6 feet wide by 6 feet tall and the culvert has a uniform slope of 0.1%. All three barrels have a series of baffles that facilitate fish passage by providing hydraulic refugia (Figure 38). At the outlet of the culvert, a roughened chute (Figure 39) with a slope of 14% poses a partial barrier to adult salmon and a total barrier to juvenile salmon. Section 4.3 presents a summary of passage conditions based on a qualitative review by the project team and information reported by USFS and ODOT. Below the roughened chute, Multnomah Creek flows approximately 650 feet to its confluence with the Columbia River. Throughout this area, the active channel has pool-drop morphology and there is evidence of channel widening, braiding and vertical degradation (Figure 40). Future degradation of this reach likely will be limited due to a relict clay lens. This clay lens likely also limits the recruitment of gravel and other substrate. Based on stage-discharge relationships developed between Bonneville Dam, and two restoration sites in close proximity, the majority of this reach (although not the roughened chute) likely is backwatered on an annual basis. Additional detail regarding conditions in Reach 5 can be found in Section 4.

Constraints: There are four primary constraints to addressing passage limitations at this crossing: (1) precise inlet control is required to direct flows into any single barrel during low flow conditions, (2) replacing the culvert is challenging due to its location beneath an interstate highway, (3) access for construction, and (4) sediment delivery.

Short-term Alternatives: Three alternatives were considered to address fish passage limitations at the I-84 culvert: (A) inlet control structure, (B) reconstruction of the roughened chute, (C) culvert replacement, and (D) combination of the first two alternatives. Additionally, habitat improvements in the confluence portion of Multnomah Creek (downstream of the I-84 culvert) would be considered with all retrofit scenarios.

Given existing site infrastructure, it is not feasible to address all of the potential fish passage limitations through culvert retrofit, e.g. the existing grade of the roughened chute is too steep for any potential retrofit to improve passage success of juvenile salmonids. Rather, the focus of the retrofit alternatives (Alternatives A and B) is to (a) improve reliability of the fish passage facilities for adult salmonids during high flow conditions and (b) improve reliability of fish passage facilities for adult salmonids (particularly Chinook salmon) during low flow conditions.

> *Alternative A*: Alternative A consists of installing a flow diversion structure at the inlet of the culvert. This structure likely would consist of a 3-6" board mounted across the inlet of two of the three barrels. This board would be designed to divert the entirety of low flows through one barrel thus providing suitable depths within the preferred barrel for passage at all flows as well as concentrating low flows through the roughened chute to provide suitable depths through it for adult salmon passage at lower flow conditions. The effects of this modification on flood

conveyance capacity will need to be assessed in coordination with ODOT to ensure it meets their design criteria as specified in the 2005 Hydraulics Manual (ODOT 2005) as well as with OPRD to ensure that any rise in flood stage does not impact infrastructure located on their property.

Alternative B: Modifying the existing roughened chute would have the goal of facilitating fish passage of all life stages of Chinook and coho salmon and steelhead and cutthroat trout at the full range of flows experienced at the culvert. A low-flow channel would be designed throughout this reach during minimum summer-fall flow regimes. Large ‘key’ boulders would be located and/or excavated into the channel to create the skeleton within which lesser boulders, cobbles, gravels, and sediment would be placed and washed-in to imbricate the channel bed materials. Due to the steep slope within this reach, some of these large boulders would be left higher than others to ensure adequate hydraulic ‘shadow’ areas for fish migrating upstream. As the stability of this reach downstream of I-84 is critical to adjacent infrastructure, design must incorporate careful geotechnical analysis and assessment of hydraulic potential for material movement at all flood stages.

Alternative C: The third alternative considered in the analysis is replacement of the existing culverts with a new structure. ODFW (ODFW 2004) and NMFS (NMFS 2008) fish passage criteria would require that the replacement be accomplished with a bridge or stream simulation culvert. The feasibility of constructing a new bridge or culvert at the site will need to be further vetted with ODOT and others; however, this alternative is not practical in the short-term.

Alternative D: Alternatives A and B could be combined to form one alternative. This likely would provide the most ideal passage conditions short of culvert replacement.

Figure 38: Confluence of Wahkeena and Multnomah Creeks & inlet to I-84 culvert (left photo) and baffles located within the three culvert barrels (right photo).

Figure 39. Roughened chute located immediately below the I-84 culvert. View is looking upstream.

Downstream of the I-84 culvert, a variety of enhancement alternatives are plausible.

Alternative E: LWD placement

Under this short-term enhancement alternative, LWD would be strategically placed to create desirable instream habitat features, increase channel/floodplain connectivity, trap organic material and substrate, help control bed elevations, and/or promote lateral channel migration. Due to infrastructure that prevents transport from upstream reaches and a very narrow riparian corridor, current LWD densities in this reach are very low. It is estimated that if 40-50 pieces of LWD were added to Reach 5, it would bring overall densities to within the lower range specified by Fox and Bolton (2007). If wood is placed in this reach, the lower range would be recommended due to access limitations that may cause work in this reach to be very expensive and because some wood may be lost to the Columbia River at higher stages.

Alternative F: Substrate Augmentation

Substrate delivery to Reach 5 is severely impaired. Furthermore, due to the exposed clay lens and lack of LWD, substrate delivered to this reach likely is transported through at an artificially high rate. Alternative 2 would involve integrating this reach into the site's sediment management plan, likely by routine placement of sediment on the roughened chute which would then be allowed to migrate through the system. This substrate could be sourced from either Multnomah Creek dredging operations and/or park entrance road culvert cleaning (see Reach 7, Alternative C). Substrate added to this reach likely would not exceed 500CY, the maximum amount of material anticipated to be available from these two sources. To increase the rate of substrate retention, this approach should be combined with strategic LWD placement.

Long-term: Long-term enhancement alternatives ideally would include replacement of the existing culvert with a bridge. It should be noted that the hydrology of this reach would be altered significantly if Reach 1's preferred long-term alternative is enacted, i.e., re-establishment of Multnomah Creek's historic channel alignment.

Figure 40. Off-channel (left) and instream (right) habitat downstream of the I-84 culvert. Photo on the left and right are looking upstream. Photo on left is taken 30 feet west of the streambank and shows overflow into a backwater area from main channel.

Reach 6 – Wahkeena Creek

Existing Conditions: Reach 6 extends approximately 750 feet from the railroad bridge downstream to the I-84 culvert. The overall health of this highly altered reach changes dramatically throughout its length. The railroad bridge (Figure 41) and park entrance road culvert (Figure 42) trap much of the substrate moving through this reach such that little substrate appears to move downstream of the entrance road culvert, which is partially clogged. The upper portion of the reach has relatively healthy habitat conditions (Figure 43); however, the lack of sediment (along with cohesive stream banks) is causing the lower portion of this reach to incise such that it is disconnected from its floodplain at all but the highest flows (Figure 43). A head cut also is present near the middle of the reach.

The riparian area throughout this reach is very narrow, and its understory is composed primarily of Himalayan blackberry. Although substrate quality is poor, several coho salmon were observed spawning during the fall of 2010. The downstream extent of this reach is lower gradient and does not have suitable spawning habitat. Stream temperatures in this reach are excellent (less than 12°C throughout the 2010 monitoring period), and numerous juvenile salmonids have been observed rearing.

A diversion structure (Figure 42) located immediately upstream of the park entrance road culvert diverts a portion of the creek into Hartman Pond. Based on discharge measurements taken in 2010, the diversion to Hartman Pond appears to reduce base flows in Wahkeena Creek by approximately 40%. This has several impacts to the stream, including (a) reducing water depths during spawning periods, (b) elevating temperatures in Reach 5, and (c) impacting low-flow passage at the I-84 culvert. Additional detail regarding conditions in Reach 6 can be found in Section 4.

Figure 41. Wahkeena Creek railroad bridge. View is looking downstream. Note there is less than 1 foot freeboard remaining across the majority of the span.

Figure 42: Hartman Pond diversion structure (left photo) and park entrance road culvert (rightphoto; looking downstream). Note that right barrel of culvert is partially clogged.

Figure 43. Wahkeena Creek immediately below parking lot culvert (left photo; looking downstream) and approximately 250 feet downstream of parking lot culvert (right photo; looking upstream). Note 3-4 feet vertical banks in the right photo caused by channel incision.

Constraints: This reach is located in the heart of the state park, therefore construction will need to consider short-term impacts to recreational use. Additionally, permanent alterations that affect important infrastructure, e.g., Hartman Pond and the frisbee golf course, will need to consider their impacts to long-term recreational use. Several underground utilities also are located along this reach. Additionally, the reach's active channel morphology will need to be considered during design.

Short-term: Several short-term enhancement alternatives should be considered for this highly altered reach. These alternatives can be combined as desired to form the preferred alternative.

Alternative A: Reduce or eliminate the Hartman Pond diversion

Coarse substrate at the entrance to the diversion channel allows subsurface flow to enter Hartman Pond. Therefore effective control of the diversion could be achieved only by reconstructing the berm separating the creek and the diversion channel. Alternately, the diversion could be reduced by closing or decommissioning the head gate, although the amount by which this would reduce the diversion is unknown.

Alternative B: Eliminate the Hartman Pond discharge to Wahkeena Creek

Not only is a portion of Wahkeena Creek diverted to Hartman Pond, but one of the pond's two outlets discharges back into the creek. Although it has not been quantified, the poor water quality in the pond, e.g., elevated temperatures and algae, likely negatively affects water quality in the creek. Alternative B for Reach 6 would decommission this diversion using the other outlet to the Columbia River to control pond water levels. Pursuing this alternative would require a detailed assessment of the integrity, function, and suitability of that outlet.

Alternative C: "Clean" the entrance road culvert

The 112-foot twin-barrel concrete culvert that carries Wahkeena Creek beneath the park entrance road is undersized, due in part to it being partially clogged with substrate (Figure 42). OPRD staff report that prior to the 1996 flood, approximately 6 feet of clearance was present in the culvert. Currently, the western barrel has approximately 3 feet of freeboard while the eastern barrel has approximately 2 foot of freeboard. The culvert's undersized capacity limits sediment transport and subjects the entrance road to flooding. Under this proposal, an undetermined amount of material (maximum of approximately 150CY) would be removed from the culvert and transported further downstream to augment substrate lower in the reach. At a minimum, enough substrate would be removed from the eastern barrel such that its elevation matches that of the western barrel. It should be noted that because the culvert is undersized, it should be "cleaned" or replaced prior to elimination or reduction of the Wahkeena Creek diversion.

Alternative D: Replace the entrance road culvert

As stated above, the 112-foot twin-barrel concrete culvert that carries Wahkeena Creek beneath the park entrance road is undersized, due in part to it being partially clogged with substrate (Figure 42). This alternative includes replacement of that culvert with a structure that is able to convey Wahkeena Creek's full range of flood flows and transport native material. In addition to improving sediment transport and hydrology, its increased height and decreased length also would improve fish passage. The replacement culvert would be designed to meet ODFW and NMFS fish passage criteria (ODFW 2004; NMFS 2008).

Alternative E: LWD Placement

Under this short-term enhancement alternative, LWD would be strategically placed to create desirable instream habitat features, increase channel/floodplain connectivity, trap organic material, and help control bed elevations. Due to infrastructure that prevents transport from upstream reaches and a very narrow riparian corridor, LWD densities in this reach are very low. A relatively intense LWD effort is recommended in this reach for three reasons: (a) access is excellent, (b) the reach is highly incised and therefore would benefit from sediment entrapment, which could be facilitated by LWD, and (c) this reach would not be negatively affected by long-term site alternatives. It is estimated that if 100 pieces of LWD were added to Reach 6, it would bring overall densities to within the median range specified by Fox and Bolton (2007).

Alternative F: Substrate Augmentation

Substrate delivery to Reach 6 is severely impaired by the railroad bridge and park entrance road culvert. As detailed in Section 4 and illustrated in Figure 43, this is causing the stream channel to incise and impacts salmon habitat, including spawning habitat. Alternative F would involve integrating Wahkeena Creek into the site's sediment management plan. This likely would include using substrate taken from Multnomah Creek dredging operations and/or Wahkeena Creek culvert cleaning (see Alternative C) to reconstruct the lower portion of the channel. Substrate added to this reach likely would not exceed 500CY, the maximum amount of material anticipated to be available from these two sources.

Alternative G: Riparian Revegetation

This alternative involves expanding the existing riparian buffer (approximately 10 feet wide) along Wahkeena Creek to a width of 75-100 feet. The goal of this effort is to increase shade and organic inputs (including LWD) to the creek. Site preparation will be required to increase planting success. Plantings will be composed of native woody and herbaceous species, e.g., Oregon ash and black cottonwood.

Long-term: Although long-term plans for the site are not clear, they likely would not involve significant alterations to this portion of Wahkeena Creek. Long-term consideration should however include replacement of the railroad bridge and entrance road culvert with structures that are appropriately sized for this dynamic hydrogeomorphic setting.

Reach 7 – Parking Lots

Existing Conditions: The parking areas at Benson State Recreation Area and Multnomah Falls visitor area are 2-acres and 1-acre respectively. These parking areas, which were constructed before modern stormwater treatment regulations were enacted, discharge directly to their receiving streams (Figures 44 and 45). Given the size of these parking areas relative to the size of the receiving waters, these discharges likely have a significant negative effect on the water quality and hydrology of Multnomah and Wahkeena Creeks.

Figure 44. Benson State Recreation Area parking lot discharge to Wahkeena Creek (Reach 6). Creek can be seen in background of photo.

Figure 45. Benson State Recreation Area parking lot discharge to Benson Lake (left photo) and Multnomah Falls visitor area parking lot discharge to Reach 1 of Multnomah Creek (right photo).

Constraints: Retrofits to parking lots may be expensive and will need to consider temporary impacts to recreational and tourism use during construction. Historically significant infrastructure at Multnomah Falls visitor area will need to be considered.

Short-term: Several short-term enhancement alternatives are proposed for this highly altered area. These alternatives can be combined as desired to form the preferred alternative.

Alternative A: Wahkeena Creek

Presently, surface water runoff from the western half of the Benson State Recreation Area parking lot discharges directly to Wahkeena Creek. This alternative would involve installation of trench drains in the western half of the parking lot to capture runoff and direct it to the north side of the parking lot. Once on the north side of the lot, runoff would be routed to a wetland feature for treatment prior to discharge to Wahkeena Creek. The treatment wetland likely would be located within Wahkeena Creek's riparian area. Conveyance to the wetland feature could be via subsurface piping or a vegetated swale. The vegetated swale would provide some level of pretreatment; however, its integration into the state park would need to be addressed.

Alternative B: Benson Lake

Presently, surface water runoff from the eastern half of the Benson State Recreation Area parking lot discharges directly to Benson Lake via a ditch. Similar to Alternative A, trench drains would be installed to capture surface runoff from this portion of the parking lot; however, runoff would be directed to the south side of the lot. Here a portion of the lot would be removed to facilitate construction of a vegetated swale that would provide some level of treatment prior to discharge to the existing ditch and eventually to Benson Lake. This alternative would require removal of a small portion of the parking lot, therefore coordination with OPRD and other appropriate entities would be required to ensure that the parking lot remains functional for the diversity of vehicles that utilize the park, including public safety vehicles.

Alternative C: Multmonah Creek

Presently, surface water runoff from the entirety of the Multnomah Falls visitor area discharges directly to Multnomah Creek via a series of pipes. Impervious surfaces include parking lots, picnic areas, and walkways. Many of these areas are small and are dispersed. The largest contiguous area with a common discharge point is the primary parking lot located in the visitor area's northwest quadrant. Runoff from this area enters a grated manhole and is culverted through the stone retaining wall directly into Multnomah Creek. Alternative C involves installation of a mechanical oil/water separator or similar treatment device in the existing manhole. Installation of a mechanical treatment device coupled with regular maintenance by OPRD staff would help reduce the negative impacts to Multnomah Creek.

Long-term Proposed Alternative: None at this time. If significant alterations to the Multnomah Falls visitor area occur, which would be required if Multnomah Creek's historic alignment is re-established, regulatory requirements would require runoff from all new or retrofitted impervious surfaces be treated.

6.2 Cost Estimates

The project team developed construction cost estimates for all potential short-term enhancement alternatives to help inform the alternatives analysis and selection. Table 17 summarizes costs per alternative and reach. Note that these preliminary estimates are for construction only and do not consider costs for design, permitting, public outreach, and other project components.

Table 17. Cost estimates for construction of short-term enhancement alternatives.

	Restoration Alternative	Description	Estimated Const. Cost	Notes
Reach 1	NA	None	$0	No short-term actions proposed.
Reach 2	A, B	LWD placement	$25,000	Approx. 40 logs; all logs donated; substrate passively managed.
Reach 3	NA	None	$0	No short-term actions proposed.
Reach 4	A, B, D	LWD placement & substrate augmentation	$55,000	Approx. 100 logs and 100 CY substrate; all materials donated.
	C	Riparian plantings	$5,000	Approximately 1.5 acres; plantings completed by EP stewardship team.
Reach 5	A	Inlet flow diversion structure	$3,000	Flash board bolted to culvert.
	B	Modify roughened chute	$110,000	
	E, F	LWD placement & substrate augmentation	$40,000	Approx. 40 logs and 100 CY substrate; all materials donated.
Reach 6	A	Retrofit flow diversion structure	$5,000	Includes retrofitting berm to prevent seepage into diversion channel.
	B	Decommission pond outlet to Wahkeena Cr.	$5,000	
	C	"Clean" and shorten Wahkeena Cr. culvert	$15,000	
	D	Replace Wahkeena Cr. culvert	$45,000	Replace with stream simulation culvert approximately 50ft long.
	E, F	LWD placement & substrate augmentation	$60,000	Approximately 100 logs and 100 CY substrate; all materials donated.
	G	Riparian plantings	$5,000	Approximately 1.5 acres; plantings completed by EP stewardship team.
Reach 7	A	Wahkeena Creek stormwater treatment	$35,000	Retrofit parking lot; construct treatment wetland
	B	Benson Lake stormwater treatment	$65,000	Retrofit parking lot; construct vegetated treatment swale
	C	Multnomah Creek stormwater treatment	$10,000	Install oil/water separator in existing manhole

6.3 Selection of Preferred Alternatives

The Estuary Partnership presented enhancement alternatives to the project team at a second meeting held on March 23, 2011. In attendance were OPRD (Andrea Berkley, Mark Stevenson, and Glenn Littrell), USFS (Robin Dobson, Mark Kreiter, and Brett Carre), Henderson Land Services (Matt Koozer), and the Estuary Partnership (Paul Kolp and Chris Collins). The project team considered a wide range of factors when assessing alternatives; the following list identifies the primary factors considered for each potential alternative:

i. Number of goals and objectives addressed;
ii. Post-construction maintenance;
iii. Probability of success;
iv. Whether actions would be rendered obsolete by future long-term actions;
v. Anticipated life span; and,
vi. Cost.

To help summarize the large amount of information to be considered and facilitate decision making, the project team presented a matrix that scored each alternative based on the first five factors and presented that score alongside the estimated cost. That matrix is included as Table 18.

After extensive review and discussion, the project team selected the following short-term enhancement alternatives for implementation. Additional data collection and coordination with project stakeholders will be required before long-term alternatives can be selected.

<u>Project Reaches with Selected ***Short-term*** Enhancement Alternatives</u>:

Reach 4: Multnomah Creek – d/s of Benson Lake

i. LWD placement at the 25th-percentile specified in Fox and Bolton (2007)
ii. Encourage beaver activity
iii. Riparian enhancement (including invasives control)
iv. Substrate augmentation

Reach 6: Wahkeena Creek

i. Culvert “cleaning” or replacement
ii. Retrofit diversion to Hartman Pond
iii. Eliminate Hartman Pond outlet
iv. LWD placement at the 50th-percentile specified in Fox and Bolton (2007)
v. Riparian enhancement (including invasives control)
vi. Substrate augmentation

Reach 7: Parking Lot Stormwater

i. Construct wetland to treat runoff to Wahkeena Creek

The project team did not select short-term alternatives for Reaches 1, 2, 3, and 5, primarily because potential actions in these reaches are relatively expensive, and because these reaches would be affected by long-term enhancement actions.

MULTNOMAH FALLS @ BENSON LAKE SHORT-TERM RESTORATION ALTERNATIVES

POTENTIAL ACTIONS				BENEFIT TO GOALS AND OBJECTIVES						OTHER CONSIDERATIONS					
Study Reach	Description	Property Owner(s)	Alternative's Proposed Habitat Lift Action	Fish Passage	Hydrologic and Geomorphic Processes	Thermal Regime	Water Quality	Riparian/Floodplain Connectivity and Processes	Instream Habitat Diversity and Function	Post-Const. Maint. (Low=2; Mod=1)	Probability of Success (High=2; Mod=1)	Affected by Larger Project? (Yes=1; No=2)	Anticipated Life-span (Long=2; Mod=1)	Score	Const. Costs
Reach 2	LWD & substrate	USFS	Under Materials Management Plan, place accumulated aggregate as native streambed materials. Integrate LWD into instream and riparian habitat		1			1	1	2	2	1	1	12	$25,000
Reach 4	LWD & substrate	OPRD	Under Materials Management Plan, place accumulated aggregate as native streambed materials. Integrate LWD into instream and riparian habitat		1			1	1	2	2	1	1	12	$55,000
	Riparian plantings	OPRD	Treat invasives; plant natives			1		1	1	1	1	1	2	6	$5,000
Reach 5	Inlet flow diversion structure	ODOT	Create one primary low-flow culvert barrel on three-barrel box culvert.	1						2	1	1	2	4	$3,000
	Modify roughened chute for fish passage	ODOT	Reconstruct/augment existing roughened chute to provide greater potential for passage of salmonids.	1						1	1	1	1	1	$110,000
	LWD & substrate	ODOT	Under Materials Management Plan, place accumulated aggregate as native streambed materials. Integrate LWD into instream and riparian habitat		1			1	1	2	2	1	1	12	$40,000
Reach 6	Reduce/eliminate flow diversion	OPRD	Approximately 40% of Wahkeena Creek baseflows are diverted to Hartman Pond. Reduction or elimination of this diversion will restore creek flows	1	1	1	1	1	1	1	2	2	2	48	$5,000
	Eliminate Hartman Pond flow return to Wahkeena Creek	OPRD	Flows from Hartman Pond returning to Wahkeena Creek negatively impact downstream creek water quality and temperature regime for salmonid habitat. Eliminate outlet from Hartman Pond to Wahkeena Creek.			1	1			2	2	2	2	32	$5,000
	"Clean" and shorten culvert	OPRD	Remove accumulated cobbles and sediments within 112LF twin-barrel culvert beneath Benson State Park entry road. Culvert passage is 50-60% occluded. Remove approximately 30ft of culvert length.	1	1				1	2	1	2	1	12	$15,000
	Replace Benson State Park entry road culvert	OPRD	Existing twin-barrel box culvert is unable to mobilize cobbles and sediments from upstream reaches of Wahkeena Creek, effectively reducing downstream native streambed material availability. Replace existing culvert with appropriately-sized open bottom or similar culvert.	1	1				1	2	1	2	2	24	$45,000
	LWD & substrate	OPRD	Under Materials Management Plan, place accumulated aggregate as native streambed materials. Integrate LWD into instream and		1			1	1	2	2	2	1	24	$60,000
	Riparian plantings	OPRD	Treat invasives; plant natives			1		1	1	1	1	2	2	12	$5,000
Reach 7	Stormwater treatment - Wahkeena Creek.	OPRD	Retrofit Benson State Park parking lot to collect flow and route to treatment wetland.		1		1			1	2	2	2	16	$35,000
	Stormwater treatment - Benson Lake.	OPRD	Re-grade and retrofit Benson State Park parking lot with surface runoff bio-treatment swale to intercept and pre-treat surface water flows before discharge to ditch.				1			1	1	1	2	2	$65,000
	Stormwater treatment - Multnomah Creek.	USFS	Retrofit Multnomah Falls Visitor Center parking lot storm drain with mechanical oil-water separator manhole. Intercept and pre-treat surface water flows				1			1	1	2	2	4	$10,000

Note: The score is calculated by multiplying the sum of goals and alternatives addressed by each of the four "other considerations".

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Appendix A – Concept Design Drawings

MULTNOMAH AND WAHKEENA CREEK AQUATIC HABITAT AND WATER QUALITY ENHANCEMENT PROJECT

CONCEPTUAL DESIGN

MULTNOMAH COUNTY, OREGON

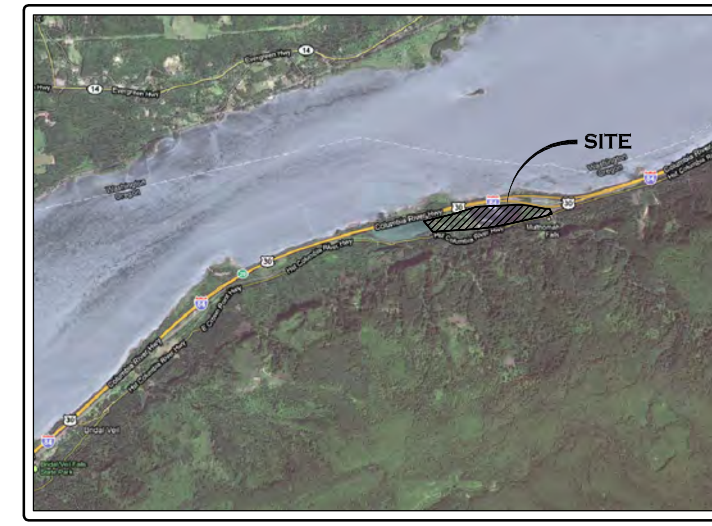
PROJECT TEAM

HENDERSON LAND SERVICES

LOWER COLUMBIA RIVER ESTUARY PARTNERSHIP

OREGON STATE PARKS

US FOREST SERVICE - DEPARTMENT OF AGRICULTURE



VICINITY MAP
NOT TO SCALE

DRAWING INDEX

S1. COVER SHEET
S2. SITE PLAN
S3. KEY ENHANCEMENT LOCATION

E1. MULTNOMAH CREEK – DOWNSTREAM OF LAKE
E2. MULTNOMAH CREEK – I-84 CULVERT OUTFALL TO COLUMBIA RIVER
E3. WAHKEENA CREEK
E4A. PARKING LOT STORMWATER – MULTNOMAH FALLS PARKING LOT
E4B. PARKING LOT STORMWATER – BENSON STATE PARK PARKING LOT

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MULTNOMAH AND WAHKEENA CREEK RESTORATION PROJECT – COVER SHEET
MULTNOMAH & WAHKEENA CREEK AQUATIC HABITAT AND WATER QUALITY ENHANCEMENT PROJECT–CONCEPTUAL DESIGN

DATE:	3/23/2011
DRAWN BY:	WJK
PROJ. MGR:	BAH
CHECKED BY:	WJK
PROJECT NUMBER	BEN 11-01
CASE FILE NUMBER	

SHEET NUMBER S1 OF 3

SHEET NUMBER	**S2** OF 3
DATE:	3/23/2011
DRAWN BY:	WJK
PROJ. MGR:	BAH
CHECKED BY:	WJK
PROJECT NUMBER	BEN 11-01
CASE FILE NUMBER	

MULTNOMAH AND WAHKEENA CREEK RESTORATION PROJECT – SITE PLAN

MULTNOMAH & WAHKEENA CREEK AQUATIC HABITAT AND WATER QUALITY ENHANCEMENT PROJECT–CONCEPTUAL DESIGN

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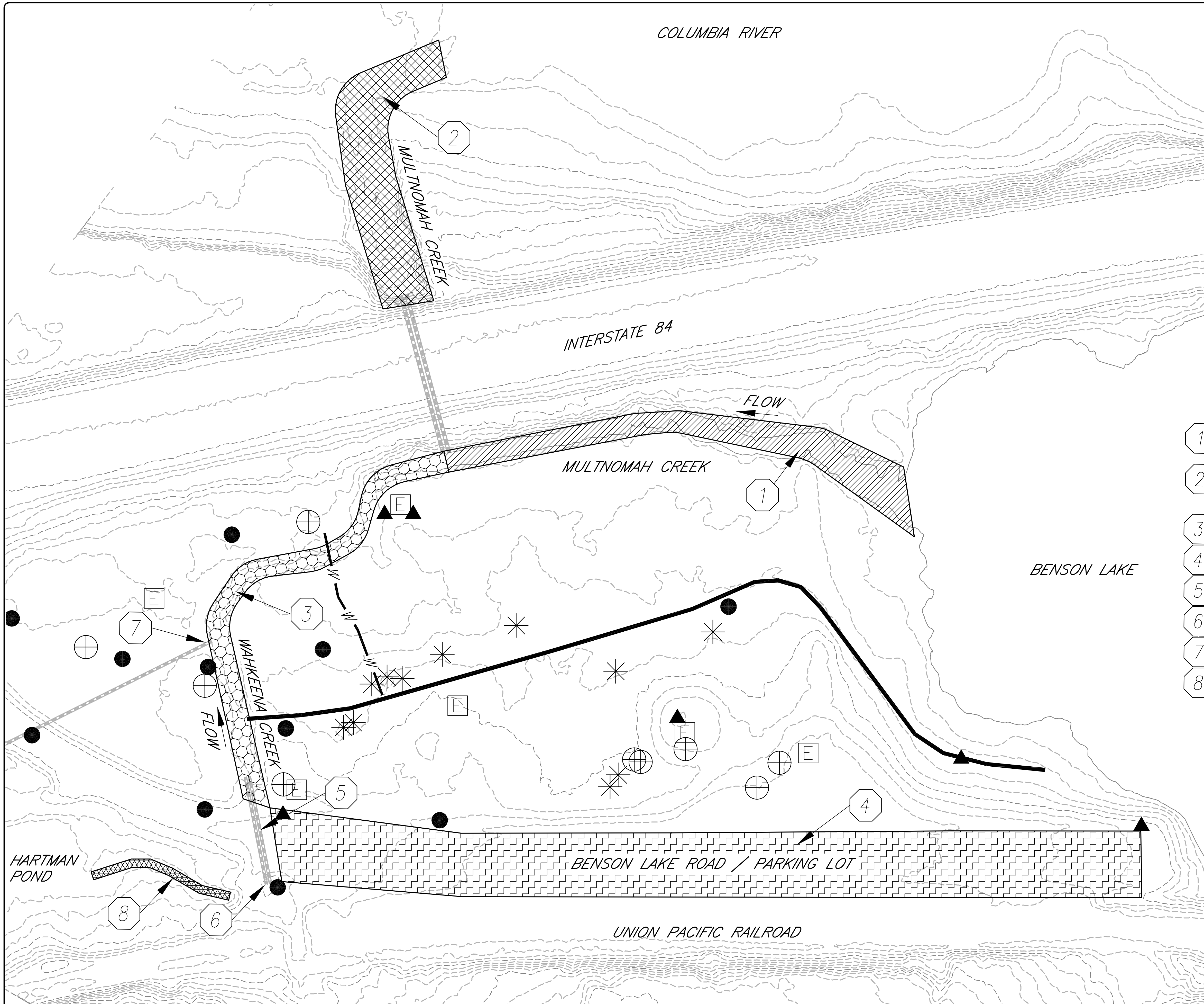

KEY ENHANCEMENT LOCATION

1. MULTNOMAH CREEK DOWNSTREAM OF LAKE. SEE EXHIBIT E1
2. MULTNOMAH CREEK. I-84 CULVERT AND DOWNSTREAM TO CONFLUENCE WITH COLUMBIA RIVER. SEE EXHIBIT E2
3. WAHKEENA CREEK. SEE EXHIBIT E3
4. PARKING LOT STORMWATER. SEE EXHIBIT E4
5. WAHKEENA CREEK CULVERT REPLACEMENT
6. HARTMAN POND DIVERSION
7. HARTMAN POND RETURN FLOW
8. HARTMAN POND DIVERSION CHANNEL

LEGEND

- EXISTING PROPERTY LINE/ROW
- EXISTING EASEMENT
- EXISTING WATER LEVEL
- EXISTING UNDERGROUND ELECTRIC/TELEPHONE LINE
- EXISTING 5 FT. CONTOUR INTERVAL
- EXISTING 1 FT. CONTOUR INTERVAL
- DIRECTION OF STORM WATER FLOW
- EXISTING PICNIC BENCH
- EXISTING WATER SUPPLY
- EXISTING IRRIGATION STRUCTURE
- EXISTING ELECTRICAL STRUCTURE
- EXISTING SITE FURNISHING
- EXISTING WATER LINE
- EXISTING TRAIL / PATHWAY

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MULTNOMAH AND WAHKEENA CREEK RESTORATION PROJECT – KEY ENHANCEMENT LOCATION

MULTNOMAH & WAHKEENA CREEK AQUATIC HABITAT AND WATER QUALITY ENHANCEMENT PROJECT–CONCEPTUAL DESIGN

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DRAWN BY:	WJK
PROJ. MGR:	BAH
CHECKED BY:	WJK
PROJECT NUMBER	BEN 11-01
CASE FILE NUMBER	

SHEET NUMBER S3 OF 3

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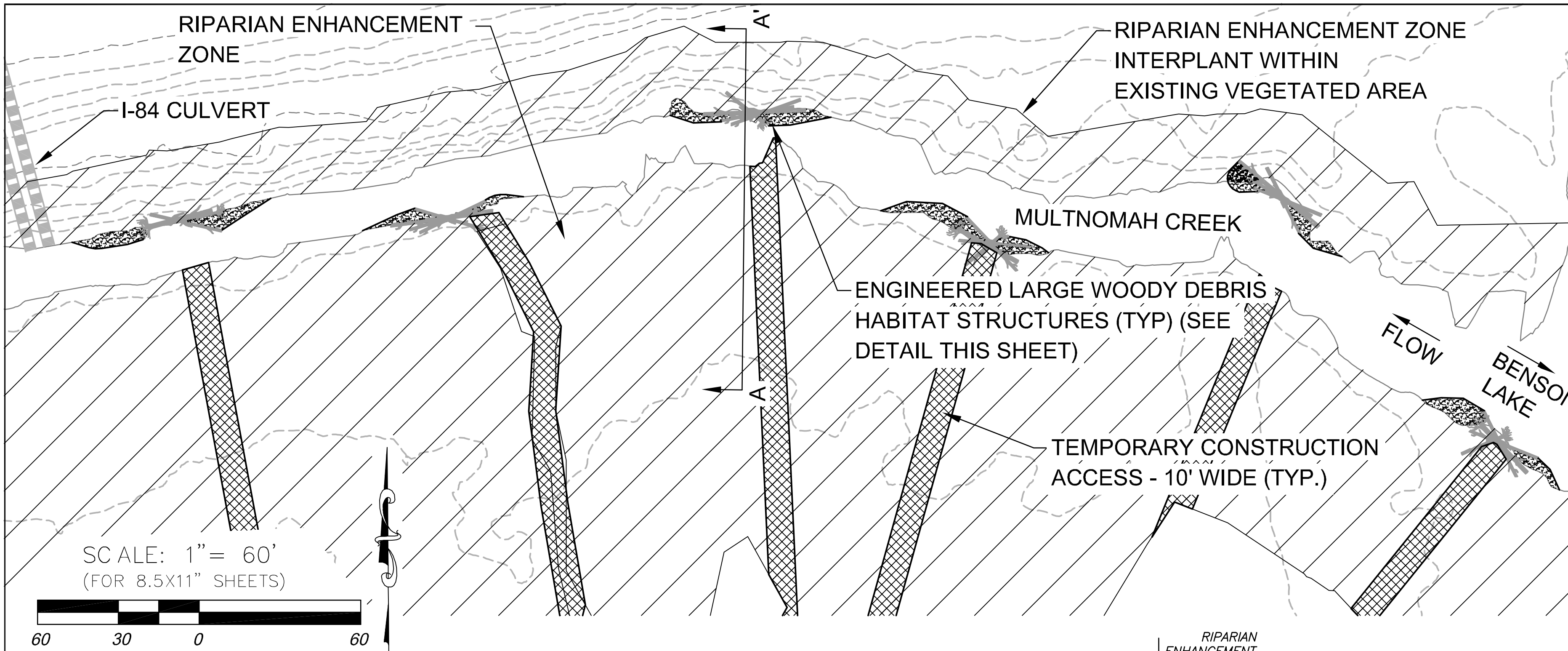
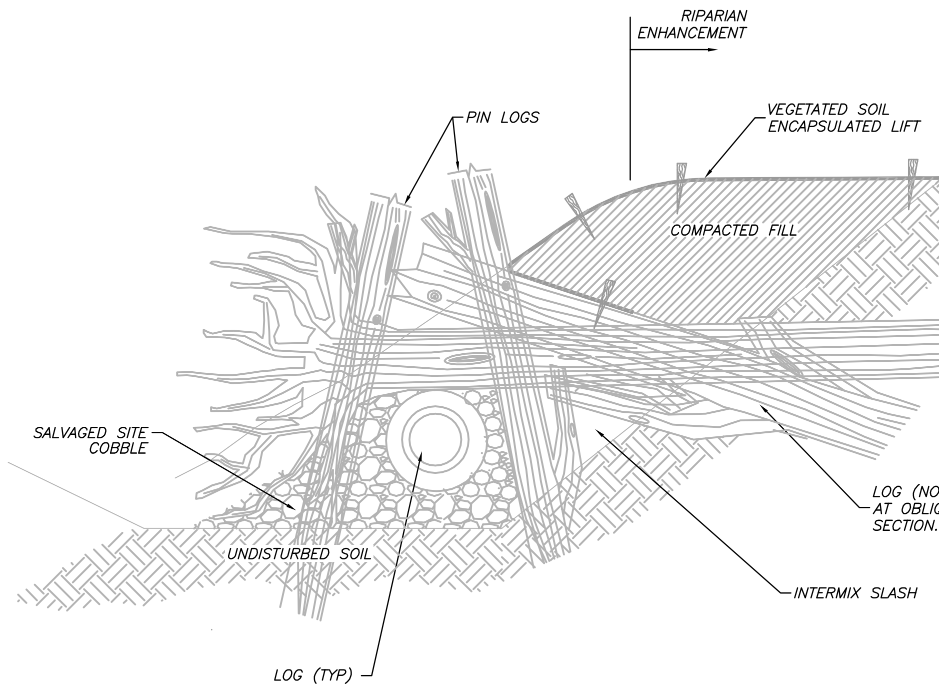


CONCEPTUAL LWD HABITAT ENHANCEMENT STRUCTURES ARE INTENDED TO VARY WITH SITE CONDITIONS. THE NUMBER OF LOGS AND ROOTWADS, ORIENTATION, FINISHED ELEVATIONS, AND PIN LOG DEPTHS FOR EACH STRUCTURE WILL BE BASED ON SPECIFIC SITE CHARACTERISTICS AND DETERMINED IN THE FIELD BY THE PROJECT DESIGN TEAM. CONFIGURATION OF PROPOSED LWD STRUCTURES IN REACH 2-UPPER MULTNOMAH CREEK WILL BE SIMILAR IN LAYOUT AND DESIGN

ENGINEERED LWD HABITAT STRUCTURES (EACH)
AVERAGE STRUCTURE LENGTH = 15'
AVERAGE WOOD PROJECTION FROM BANK = 8'
BANK KEY-IN DISTANCE = 10' OR < $\frac{1}{3}$ LOG LENGTH

	QTY	DIA	LENGTH
-ROOTWAD	5	18"	20-30'
-LOG	5	18"	10-30'
-12-16" PIN LOGS	10	6-12"	10-15'
-SLASH	10-20 (CY)	6"	10-20'
-COBBLE (SALV. ON-SITE)	10	1-8"	



CROSS SECTION A–A'

MULTNOMAH CREEK
DOWNSTREAM OF LAKE
LOWER COLUMBIA RIVER ESTUARY PARTNERSHIP
MULTNOMAH COUNTY, OREGON

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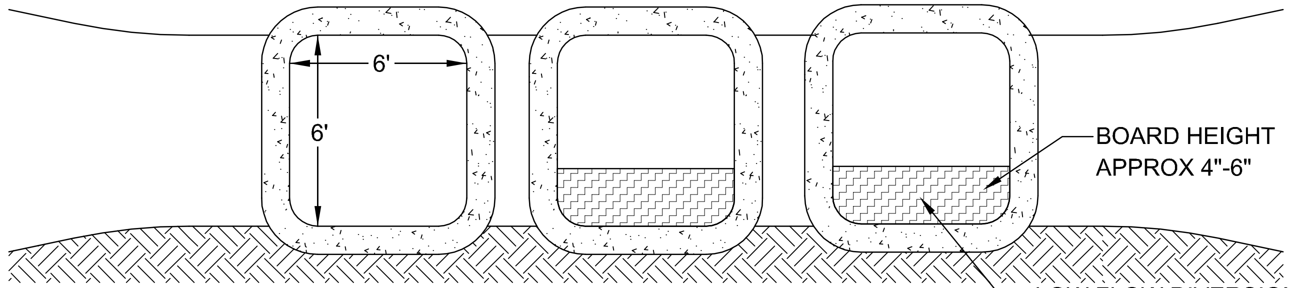
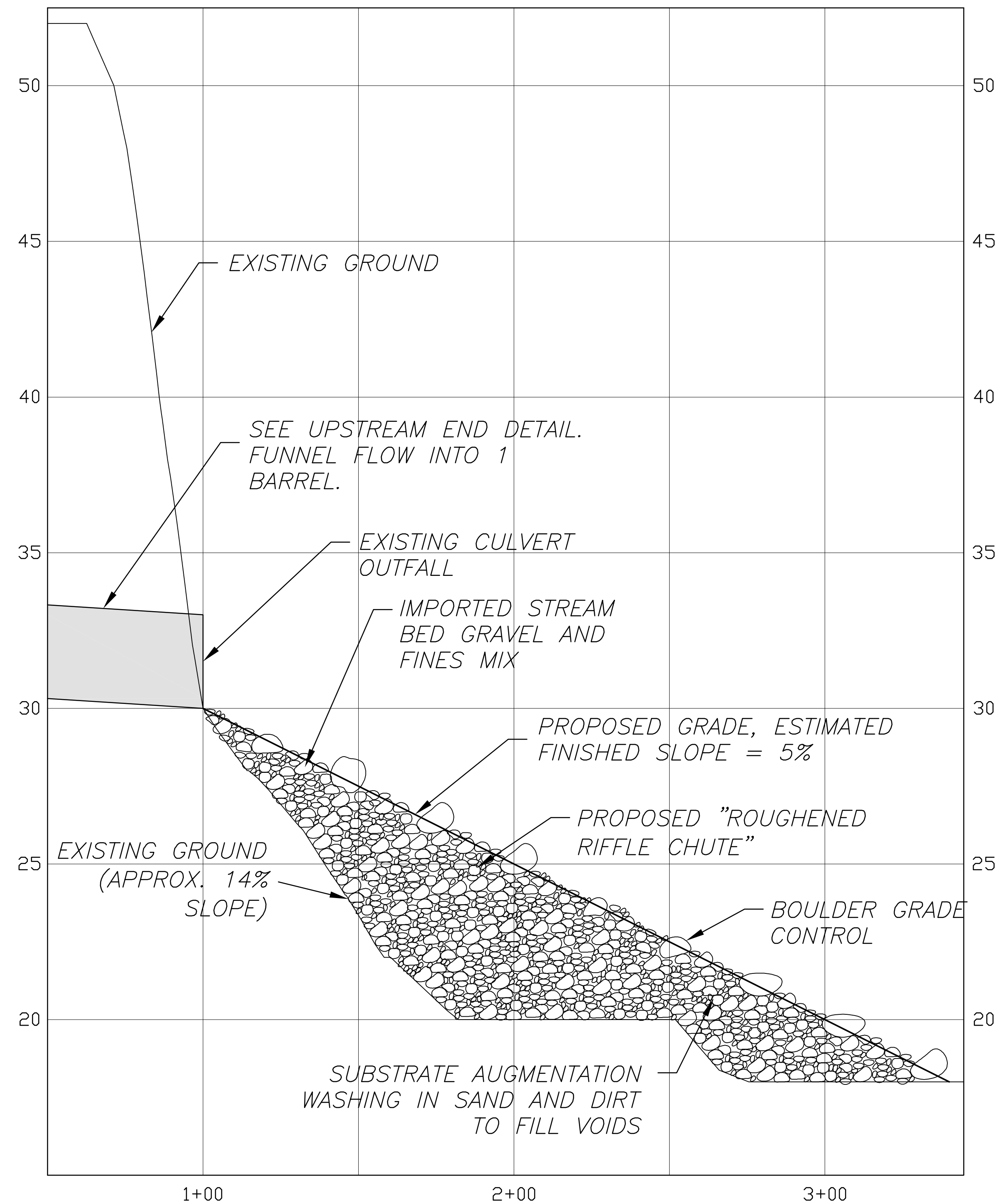
SHEET E1
MARCH 2011



UPSTREAM ENTRANCE
TO I-84 CULVERT



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MULTNOMAH CREEK

I-84 CULVERT OUTFALL TO COLUMBIA RIVER

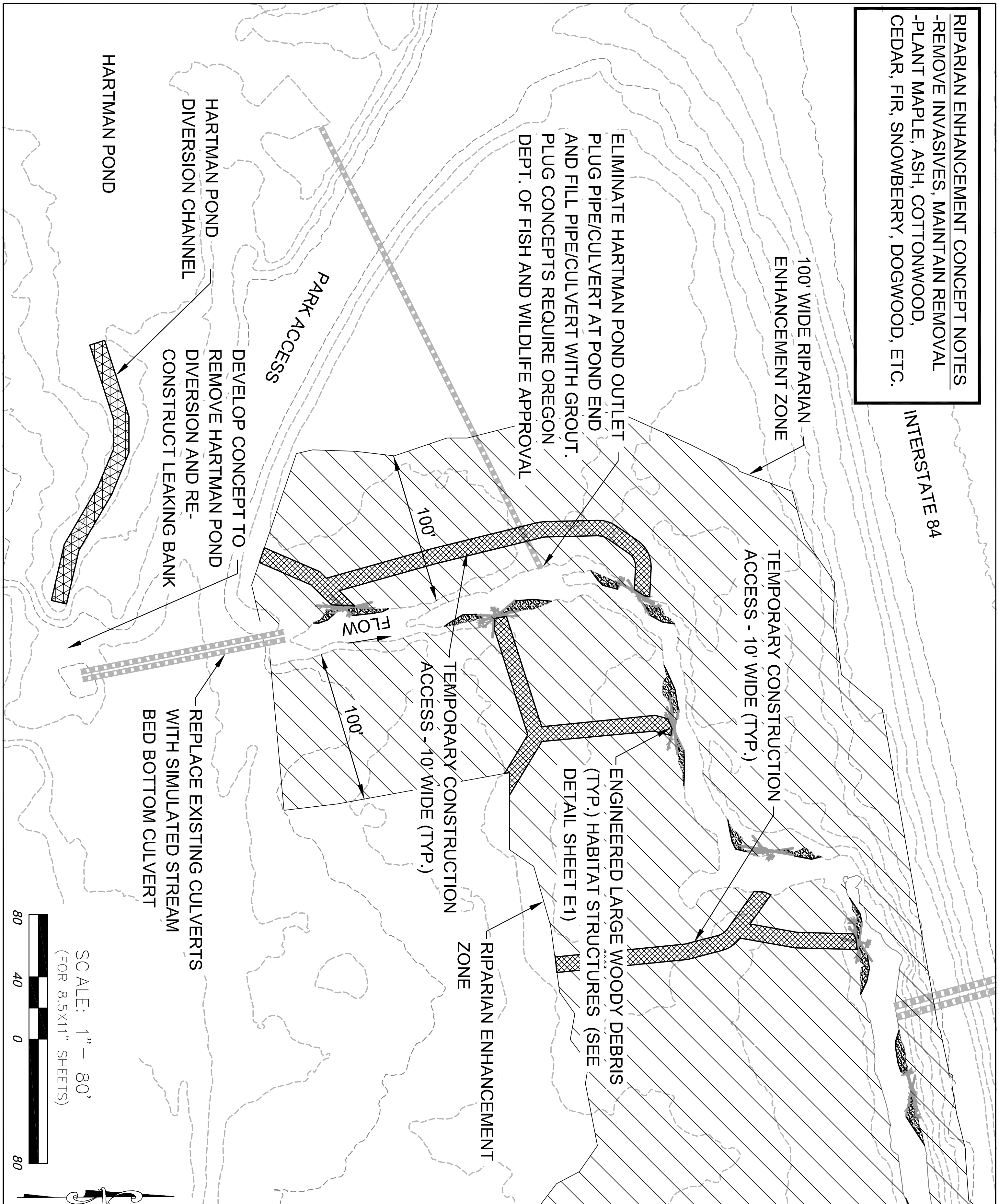
LOWER COLUMBIA RIVER ESTUARY PARTNERSHIP

MULTNOMAH COUNTY, OREGON

SHEET

E2

MARCH 2011



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WAHKEENA CREEK

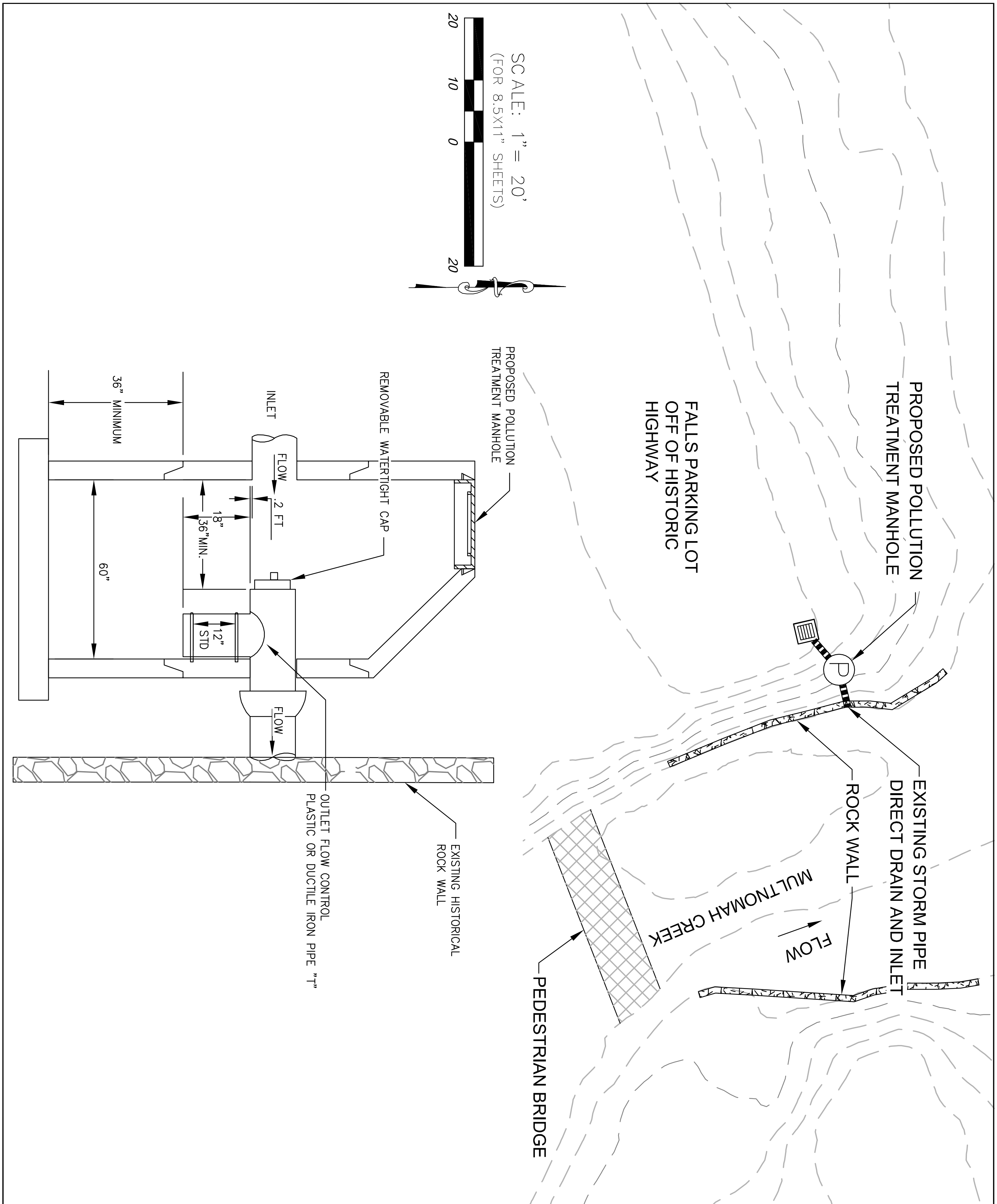
LOWER COLUMBIA RIVER ESTUARY PARTNERSHIP

MULTNOMAH COUNTY, OREGON

SHEET

E3

MARCH 2011



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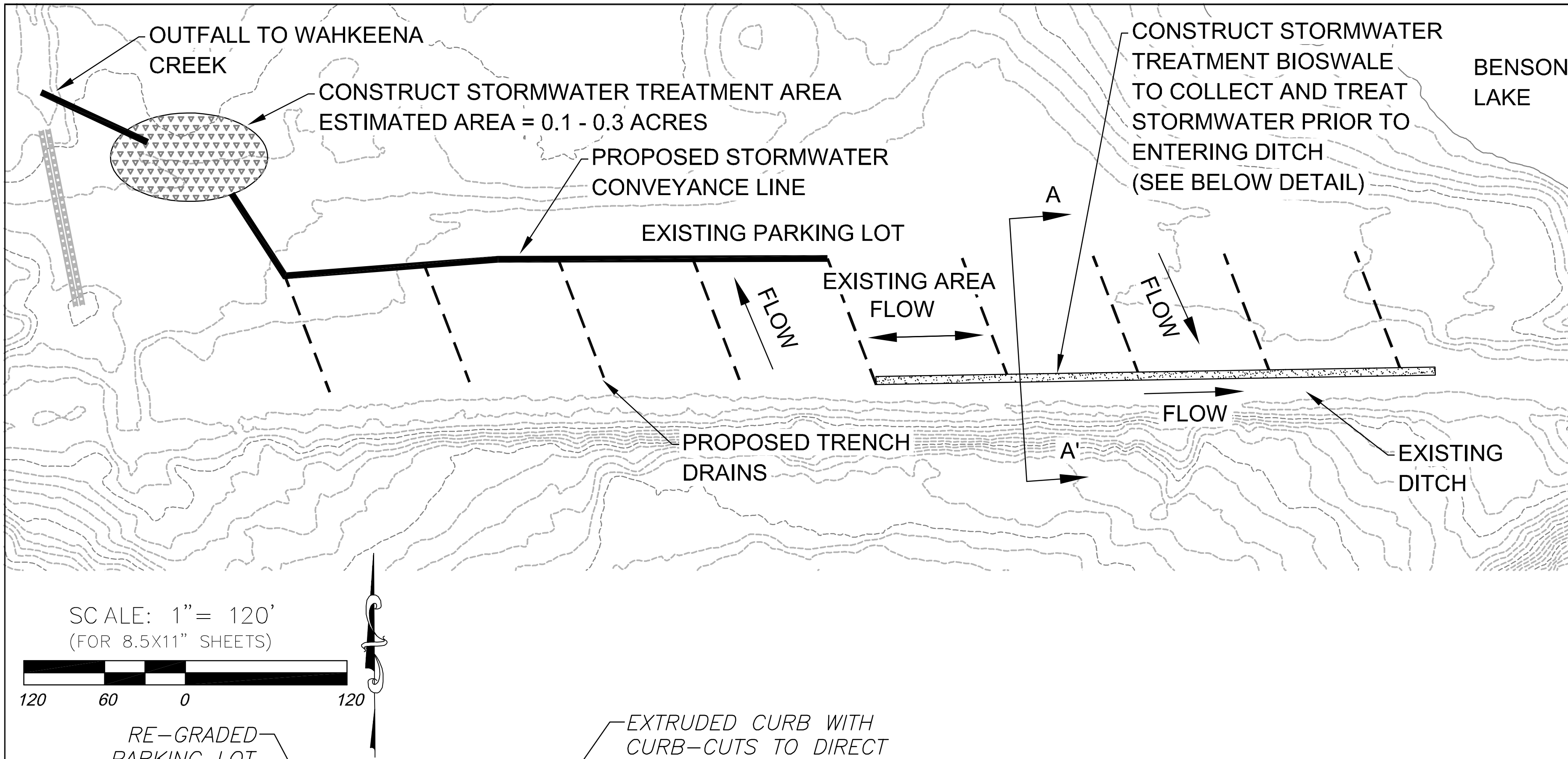
PARKING LOT STORMWATER

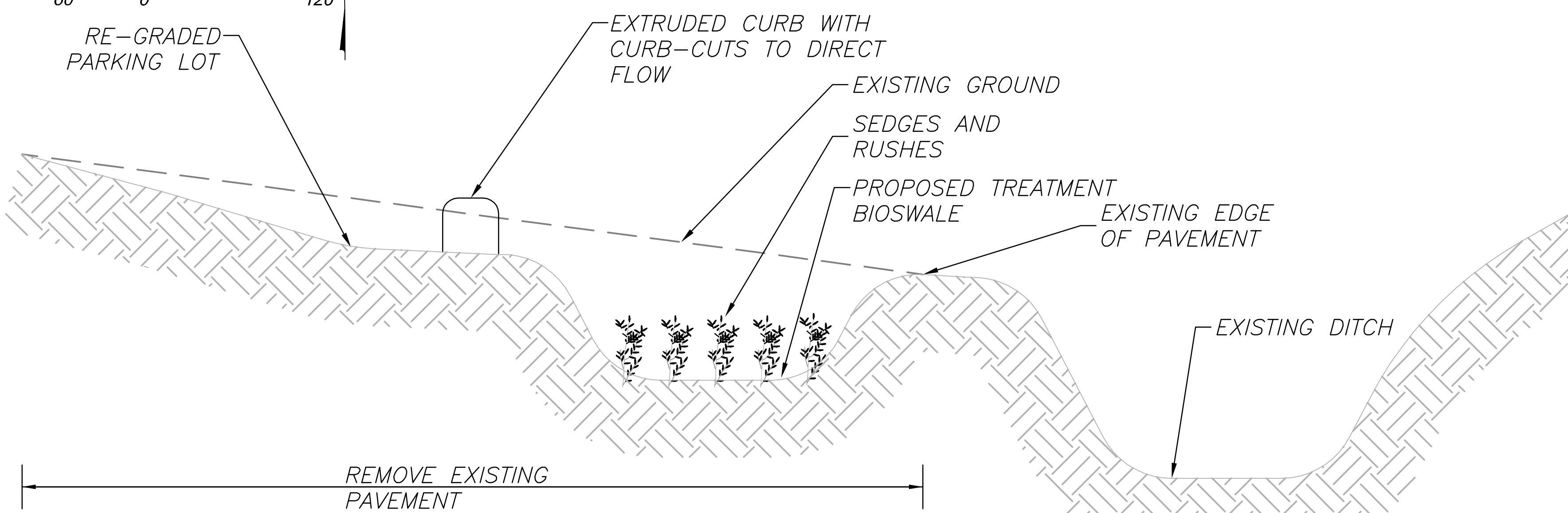
MULTNOMAH FALLS PARKING LOT
LOWER COLUMBIA RIVER ESTUARY PARTNERSHIP

MULTNOMAH COUNTY, OREGON

SHEET
E4-A

MARCH 2011





CROSS SECTION A–A'

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PARKING LOT STORMWATER
BENSON STATE PARK PARKING LOT
LOWER COLUMBIA RIVER ESTUARY PARTNERSHIP
MULTNOMAH COUNTY, OREGON

SHEET
E4-B
MARCH 2011