TUCANNON RIVER GEOMORPHIC ASSESSMENT AND HABITAT RESTORATION STUDY

Prepared for

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LIST OF ACRONYMS AND ABBREVIATIONS

Abbreviation	Definition
1-D	one-dimensional
BMP	Best management practice
CCD	Columbia Conservation District
cfs	cubic feet per second
CRB	Columbia River Basalt
CREP	Conservation Reserve Enhancement Program
Ecology	Washington State Department of Ecology
EDT	Ecosystem Diagnosis and Treatment
ELJ	engineered log jam
ESA	Endangered Species Act
ESU	evolutionarily significant unit
ISCO	in situ chemical oxidation
LP3	Log-Pearson Type III
LWD	large woody debris
mg/L	milligrams per liter
mi^2	square miles
mm	millimeter
MSA	major spawning area
NAVD	North American Vertical Datum
NRCS	Natural Resources Conservation Service
PDS	partial duration series
RM	river mile
RUSLE	Revised Universal Soil Loss Equation
SRSRP	Snake River Salmon Recovery Plan
TSP	Tucannon Subbasin Plan
TSS	total suspended solids
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service

Abbreviation	Definition
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WARSEM	Washington State Road Surface Erosion Model
WDFW	Washington Department of Fish and Wildlife
WEPP	Water Erosion Prediction Project
WDNR	Washington Department of Natural Resources

1 INTRODUCTION

Anchor QEA, LLC, was retained by the Columbia Conservation District (CCD) to conduct a geomorphic assessment of the Tucannon River and to identify habitat restoration opportunities from the mouth to river mile (RM) 51. The Tucannon River supports Endangered Species Act (ESA-) listed summer steelhead, spring Chinook salmon, fall Chinook salmon, and bull trout, which have all been identified as aquatic focal species of concern in the *Tucannon Subbasin Plan* (TSP) (CCD 2004). These species collectively utilize the entire length of the river at some stage of their lifecycles, and at least one of the species is present at a given location within the length of the Tucannon River channel at all times of the year.

1.1 Purpose

This assessment is intended to strengthen the technical understanding of existing physical conditions and geomorphic processes in the basin in order to identify and prioritize habitat restoration opportunities. Anchor QEA characterized channel and floodplain conditions, channel confinement, and the historic channel occupations area. The source, magnitude, and distribution of hydrologic and sediment inputs through the basin were evaluated and characterized. This information was used to delineate discrete reaches throughout the river; potential restoration opportunities and concepts within each reach were identified and discussed.

Understanding the existing Tucannon River system is critical to developing restoration actions that are suitable for improving habitat conditions for ESA-listed and non-listed species. Restoration strategies and recommendations were developed for each delineated reach based on habitat limiting factors identified in the *Subbasin Plan and Snake River Salmon Recovery Plan* (SRSRB 2006), salmonid life history, and site-specific physical, hydrologic, and geomorphic conditions. The restoration framework was loosely based on the process described in Figure 2 from Roni et al. (2002). The restoration actions in the Tucannon basin that correspond to the framework proposed by Roni include:

Roni et al. (2002)	Tucannon Basin
1. Protect and maintain natural processes	Promote natural hydrologic and sediment routing throughout the system, allow natural migration and wood recruitment
2. Connect disconnected habitats	Reconnect oxbows, wetlands, and former mainstem and side channels
3. Address roads, levees, and other human infrastructure impairing processes	Remove or modify culverts, levees, dredge spoils, diversion dams, and grade control structures
4. Restore riparian processes	Isolate and protect healthy riparian areas, eradicate invasive species, and plant native communities
5. Improve instream habitat conditions	Install large individual trees and LWD structures in the mainstem channel

1.2 Report Organization

Potential restoration opportunities identified for the Tucannon River are primarily based on several analyses performed to understand and describe existing physical processes. The general methods and results of these analyses are summarized in the main body of this report. A detailed review of the methodologies that were followed, plots and figures, and the complete results have been compiled into appendices at the back of this document as follows:

- Appendix A – Hydrologic Analysis Methods and Results
- Appendix B – Sediment Transport and Mobility Analysis Methods and Results
- Appendix C – Sediment Budget Analysis
- Appendix D – Reach Characteristics and Figures

Basin-scale figures are provided at the back of the report and are referred to as Figure 1 through 5. Additional figures provided in the appendices are identified by the Appendix letter followed by the figure number, for example Figure A-1.

2 BASIN DESCRIPTION

The Tucannon River basin is located in Columbia and Garfield Counties in the southeast corner of Washington State (Figure 1). The main channel is approximately 58 miles long and drains approximately 503 square miles (m^2) from its headwaters in the Blue Mountains and Umatilla National Forest, to the mouth at the Snake River approximately 3 miles upstream of the Lower Monumental Dam (CCD 2004). Several major tributaries drain into the main channel, the largest (by basin area) being Pataha Creek, which enters the main channel at RM 12.3. Pataha Creek is approximately 52 miles in length with a long, narrow watershed draining 185 mi^2. The second and third largest tributaries (by basin area) are Kellogg Creek (35 mi^2) and Willow Creek (30 mi^2).

A majority of the watershed downstream of Tumalum Creek (RM 35.5) is under cultivation, primarily consisting of grain crops (Figure 2). The valley floor is occupied primarily by livestock pastures and some cultivated crops downstream of the National Forest boundary at RM 41, except for a vegetated riparian buffer along the margins of the channel. The watershed upstream of Tumalum Creek is typically covered in evergreen forest, with scrub/shrub on the steeper, southwest-facing slopes. The valley floor is forested, with sparse undergrowth in the floodplain until upstream of Panjab Creek (RM 50.2), where tree and undergrowth density increases significantly. The riparian corridor typically contains interspersed evergreen and deciduous trees with dense undergrowth. Large forest fires in 2005 (School Fire), 2009 (Columbia Complex Fire), and 2010 (Hubbard Fire) impacted the upper basin, including the floodplain and riparian corridor.

2.1 Anthropogenic Impacts

The basin was settled in the mid-19th century and has since been heavily influenced by agriculture, forestry practices, and other developments that have typically increased fine sediment loading, degraded riparian areas, and limited natural geomorphic processes such as large woody debris (LWD) recruitment and floodplain connectivity. Native bunchgrass in the lower part of the basin that once minimized soil erosion has been replaced by grain crops, and some native floodplain and riparian areas were cleared and replaced with pastures (Beckham 1995).

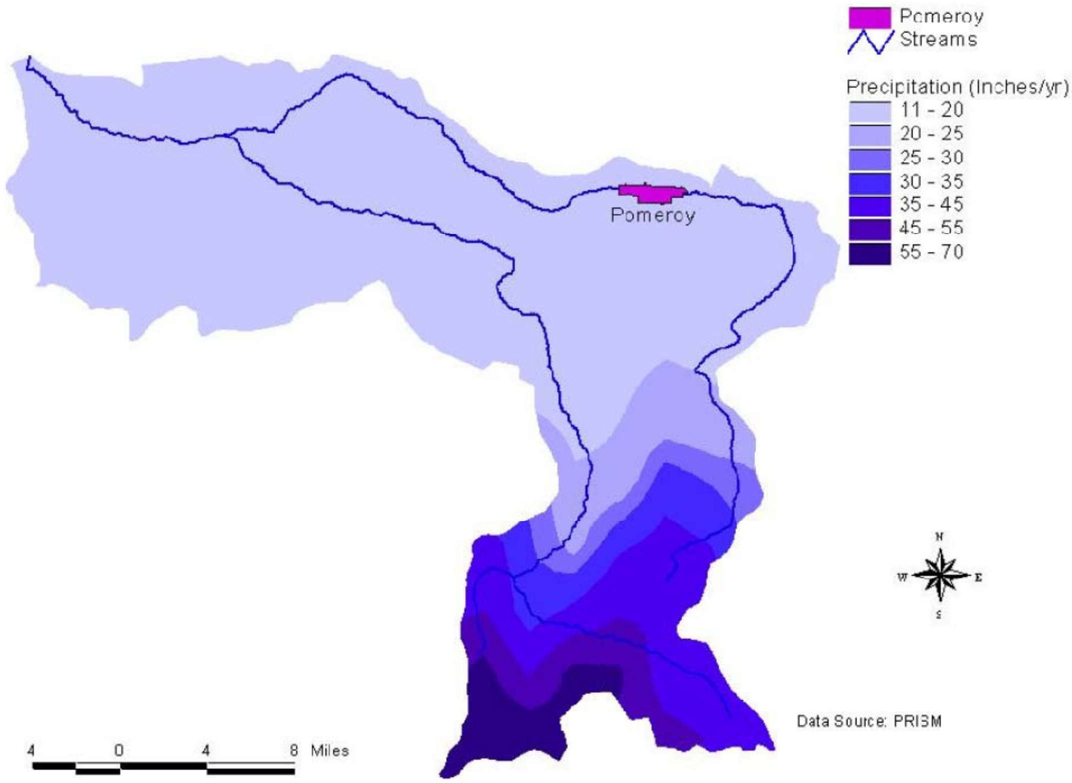
LWD volume and riparian cover has likely been significantly degraded from past conditions, particularly in the lower basin. Channel wood-clearing and straightening practices were common in the Pacific Northwest in the early 19th century and have been known to occur in the Tucannon basin from the mouth upstream to Camp Wooten (RM 46.5) and beyond. Removal of mature trees from both main channel and tributary riparian zones has decreased the average size and density of floodplain and riparian trees and contributed to a reduction in the volume of wood available for recruitment to the system and severe lack of shading that has led to increased water temperatures. Although a riparian buffer exists throughout a majority of the valley, historical accounts and aerial photography indicate that the density of mature trees and undergrowth was much heavier before extensive settling occurred; riparian trees were likely cut down for firewood and the undergrowth was grazed upon by livestock (Beckham 1995). Logging in the upper basin also likely contributed to reduction of the riparian zone; logging practices may have involved channel clearing, straightening, and otherwise reducing channel complexity for easier transport of materials. Timber harvesting of the Tucannon valley in the upper watershed continued to occur until the 1980s (SRSRB 2006).

Historic irrigation and water use practices in the Tucannon basin have created major impacts to aquatic habitat. Diversion of water for irrigation leads to a base flow that is lower than natural conditions, which greatly increases water temperatures during the dry season. However, present water conservation efforts have contributed over 10 cubic feet per second (cfs) to base flow conditions. Construction of dams in the lower basin adversely affected salmonid populations by creating fish passage barriers, reducing mainstem base flow in the summer, and by entrainment of juveniles. The De Ruwe Dam, which washed out in the 1964 flood, and the Starbuck Dam (RM 6.4) upstream of the town of Starbuck did not have sufficient fish passage features and thus blocked passage of adults into the upper watershed. The Starbuck Dam is still in place and it is believed that the dam does not currently act as a barrier for upstream migration of focal aquatic species (SRSRB 2006).

2.2 Precipitation and Runoff

The basin climate is primarily continental, with some marine influences. Precipitation occurs primarily in the winter months as frontal storms pass over the basin. Frontal and convective storms occur in late spring through early summer. In the dry, late summer months, precipitation is primarily from convective events (Hecht 1982).

Mean annual precipitation data for the basin were summarized in the TSP (CCD 2004) and were available as geospatial data from PRISM through MGS Engineering Consultants and the Oregon State Climate Service (2006), shown in Figure 2-1 below. The distribution of precipitation in the Tucannon River basin is highly dependent on elevation. Mean annual precipitation ranges from 10 inches at lower elevations to more than 40 inches at higher elevations. Runoff from precipitation events varies distinctly with antecedent moisture conditions and the extent and type of ground freezing. At higher elevations, much of the mean annual precipitation falls in the form of snow, with a basin mean annual snowfall of 65 inches (CCD 2004). The snow pack typically melts during the months of March, April, May, and June with occasional rain on snow events in December through February causing rapid snowmelt below the freezing elevation. This precipitation pattern often means that the basin experiences multiple unique discharge peaks in a water year—one peak typically occurs as the result of a winter storm and the other the result of spring snowmelt. For the period of record, 32 of the maximum annual discharges occurred in December, January, or February, while only 18 maximum annual discharges occurred in March, April, or May. The spring peak discharge is often similar in magnitude to the winter storm peak discharge, although with a much longer duration driven by the length of the spring snowmelt.



Map from CCD 2004, Figure 2-2 (Map by Ecopacific as shown in NPPC 2001, Figure 4)

Figure 2-1
Mean Annual Precipitation Distribution – Tucannon River Basin

2.3 Peak-Flow Basin Hydrology

Peak-flow basin hydrology for the Tucannon River was developed for input to the basin-scale hydraulic model (USACE 2010b, 2010c) and for use in reach delineation. Information on hydrology in the Tucannon River basin included discharge gages on the Tucannon River (U.S. Geological Survey [USGS] 13344500) and Pataha Creek (Washington State Department of Ecology [Ecology] 35F050) and spatially distributed rainfall data. Figure 3 shows major tributaries, gage locations, and subbasin areas in the Tucannon watershed. Distributing hydrologic inputs throughout the basin required the use of some standard flood frequency analysis methods along with basin scaling techniques and gage discharge correlations. A thorough description of the methodology and hydrologic results are discussed in Appendix A.

The lack of hydrologic gage sites in the upper basin, limited historic record, and local climate conditions (e.g., wet and drought year regime) created uncertainties in the flood magnitude and frequency analysis. Therefore, this assessment used a range of discharge values along the main channel that employ different methodologies for flow estimation and proportioning. The values used for this study are provided in Tables 2-1 and 2-2.

Table 2-1
Higher Range Flood Discharges Values (cfs)

Flow Change (RM)	Tributary/Location Name	Return Period (years)						
		1	2	5	10	25	50	100
4.8	Kellogg Creek	522	1,275	2,845	4,373	6,969	9,458	12,485
8.6	Smith Hollow[1]	484	1,183	2,640	4,057	6,465	8,775	11,583
12.3	Pataha Creek	479	1,171	2,613	4,016	6,401	8,687	11,467
14.8	Willow Creek	426	1,041	2,323	3,570	5,689	7,722	10,193
28.4	Marengo Gage[2]	421	1,029	2,296	3,529	5,625	7,634	10,077
35.6	Tumalum Creek	386	943	2,103	3,232	5,151	6,991	9,228
37.9	Cummings Creek	352	861	1,920	2,951	4,704	6,384	8,427
48.2	Little Tucannon R.	272	664	1,481	2,276	3,627	4,923	6,498
50.2	Panjab Creek	245	598	1,334	2,050	3,267	4,433	5,852
55.2	Above Panjab	181	443	988	1,518	2,420	3,284	4,335

Notes:

1. For the purposes of modeling, the discharge downstream of Smith Hollow was assumed to be equivalent to the discharge at the Starbuck gage.
2. The Marengo gage is located at approximately RM 26.9. The flow change location was moved upstream to RM 28.4 to better represent locations of tributary inputs.
3. The upper and lower flood discharges values are identical downstream of Pataha Creek (see Appendix A).

cfs = cubic feet per second

Table 2-2
Lower Range Flood Discharges Values (cfs)

Flow Change (RM)	Tributary/Location Name	Return Period (years)						
		1	2	5	10	25	50	100
4.8	Kellogg Creek	522	1,275	2,845	4,373	6,969	9,458	12,485
8.6	Smith Hollow[1]	484	1,183	2,640	4,057	6,465	8,775	11,583
12.3	Pataha Creek	466	1,140	2,542	3,907	6,227	8,451	11,156
14.8	Willow Creek	322	787	1,756	2,699	4,301	5,838	7,706
28.4	Marengo Gage[2]	270	659	1,470	2,259	3,601	4,887	6,451
35.6	Tumalum Creek	247	604	1,346	2,069	3,297	4,475	5,907
37.9	Cummings Creek	225	551	1,229	1,889	3,011	4,087	5,394
48.2	Little Tucannon R.	174	425	948	1,457	2,322	3,151	4,160
50.2	Panjab Creek	157	383	854	1,312	2,091	2,838	3,746
55.2	Above Panjab	116	283	632	972	1,549	2,102	2,775

Notes:
1. For the purposes of modeling, the discharge downstream of Smith Hollow was assumed to be equivalent to the discharge at the Starbuck gage.
2. The Marengo gage is located at approximately RM 26.9. The flow change location was moved upstream to RM 28.4 to better represent locations of tributary inputs.
3. The upper and lower flood discharges values are identical downstream of Pataha Creek (see Appendix A).

cfs = cubic feet per second

2.4 Flood Frequency and Historic Floods of Record

Review of the basin-scale hydraulic model indicates the river begins to overtop its banks at approximately 20% of the model cross-sections at the 2-year recurrence interval event. At the 5-year and 10-year events, it overtops the banks at approximately 35% and 50% of the sections, respectively. During the 50- and 100-year events, floodwater has overtopped the channel banks at over 80% of the cross-sections. During these extreme flood events, it is likely that a majority of the valley is inundated by some depth of water via bank overtopping, backwater, or flooding of side channels and tributaries.

Notable flood events recorded at the Starbuck gage include those in water years 1916 (February 10, 1916) at 5,740 cfs, 1930 (February 2, 1930) at 6,000 cfs, 1963 (February 3, 1963) at 4,700 cfs, 1965 (December 22, 1964) at 7,890 cfs, and 1996 (February 9, 1996) at 5,580 cfs. These events are all larger than the 10-year return period event. The flood of record (7,890 cfs) is slightly less than the 50-year return period event. Both the 1965 and 1996 water year floods had documented channel changes and floodplain inundations associated with them. During the 1965 flood, the levee in the town of Starbuck was overtopped and flooded the town with approximately 2 feet of water (USACE 2010a). Several major channel avulsions were documented and, in some cases, post-flood "restoration" was performed to re-establish a desirable channel configuration.

3 BASIN-SCALE GEOMORPHIC CONDITIONS

3.1 Regional Geology

The Tucannon watershed consists primarily of Miocene-aged Columbia River Basalt (CRB) flows of the Grande Ronde, Wanapum, and Frenchman Springs members with recent Quaternary river alluvium along the valley floor (Figure 4). Basalt is exposed at the surface upstream of Tumalum Creek (RM 35.5) and along the valley walls and gullies down from Tumalum Creek to RM 18. Downstream of RM 18, including within the Pataha and Willow Creek subbasins, the basalt is overlain by loess deposits (fine sand and silt) of the Palouse Formation. In these areas, bedrock is only exposed in gullies and along valley slopes. The valley walls in much of the lower basin downstream of RM 18 are composed of Quaternary flood outburst deposits consisting of stratified sand, gravel, and cobble. Alluvial fans line the valley floor at the mouths of tributaries; the fans tend to be large and wide in locations where tributaries drain loess-dominated subbasins, and small and narrow in basins where mainly bedrock is exposed.

3.2 Channel Patterns and Floodplain

Review of the historic aerial photographic record and traces of active channel positions through time revealed notable trends in channel form and behavior. Channel types include single-thread sections; braided, gravel bar dominated sections; and anabranching sections, which have two or more diverging channels separated by significant lengths of vegetated floodplain. The character of channel movement, or migration, was identified as both relatively steady channel migration of a riverbend through a gravel bar or floodplain, and channel avulsion where the river suddenly changes course often through historical channels abandoned through a similar process. These two channel behaviors are detailed in the sections below.

3.2.1 Steady Channel Migration

Channel migration in the Tucannon River typically occurs along the outside of a meander bend where erosive forces of the river cut into its banks (floodplain) or instream channel bars. This process is often coupled with gravel bar development along the interior of the bend. The rates of migration are influenced by the erodibility of the bank material, sediment load, magnitude of the erosive force, and orientation of flow to the eroding bank. In the Tucannon River, bank materials (with the exception of bedrock valley walls) consist of erodible alluvial materials. Some local ancient landslide and alluvial fan deposits may be more resistant if the deposit includes a relatively high amount of large cobble and boulders. This type of channel movement can occur in a lateral direction moving perpendicular to the valley grade, as well as in a downstream direction moving down the valley grade. Nearly all channel migration activity in alluvial rivers is composed of both lateral and downstream directional components. Steady migration occurs throughout the Tucannon River valley. In some cases, steady migration of a bend towards a former channel or low-lying floodplain area may result in a channel avulsion or the formation of a multiple-thread channel section.

3.2.2 Channel Avulsion

Channel avulsion in the Tucannon River typically occurs when overland flow or flow through a former or side channel attains a greater hydraulic energy grade than the existing flow path. This often occurs in the form of cutting off a large meander bend or reoccupying a former mainstem channel location. Channel avulsions may also result in split flow sections, with relatively equal flow in both channels or with a primary and a secondary or side channel. Avulsions typically result in an abrupt relocation of the mainstem channel and subsequent abandonment of the former mainstem position.

3.3 Channel Confinement and Floodplain Connectivity

Confining features along the banks of the Tucannon River and within the floodplain influence hydraulic conditions during large floods, affecting local and reach-scale geomorphic processes such as sediment mobility and channel migration. Confining features may be both natural and influenced by anthropogenic activities. However, the presence of anthropogenic features related to land use appears to be the primary factor related to channel confinement in the study area, particularly downstream of RM 47. Upstream of this point, natural features such as alluvial fans and overall valley width are more prominent. Inspection of aerial photography, LiDAR, and field reconnaissance were used to identify confining features within the study area. These features include:

- Bedrock along valley walls
- Alluvial fan deposits

- Bank armoring (e.g., riprap)
- Levees and pond berms
- Road prisms

3.4 Large Woody Debris

LWD plays an important role in the geomorphology of rivers. Wood is recruited into the system during flood events and naturally accumulates as log jams, contributing to channel and floodplain roughness, and initiating split flows and active channel widening. These jams have been identified as the most important factor influencing channel form and process in alluvial rivers. In addition, log jams have a significant influence on sediment transport and patterns of deposition. Stable log jams may be present in the same location for years to decades, recruiting additional woody debris and acting as a hard point in the river channel.

Channel clearing and riparian timber harvesting in the Tucannon basin has removed LWD from the system and greatly reduced recruitment of additional LWD, especially large-diameter mature trees that form the core of stable log jams. Previously logged and cleared riparian areas have been regenerating for approximately the last 20 to 50 years. While these trees are fairly mature, many (particularly conifers in the upper watershed) may not be large enough to remain stable within the mainstem channel. In addition, increased capacity to move sediment and woody debris in confined channel areas limits the possibility of establishing stable log jams. However, some larger wood does deposit on gravel bars and, in conjunction with other LWD, may be capable of forming log jams that will remain stable during moderate flood events. As trees mature in the basin and riparian zones recover, the size of LWD delivered to the river will generally increase. Increasing the average size of LWD in the system will increase the likelihood that log jams will form and retain additional LWD. Additionally, decreasing channel velocities by increasing floodplain and active channel widths in confined sections will significantly improve conditions for passive establishment of log jams.

3.4.1 Future Channel Evolution

The Tucannon River is currently in the process of recovering from anthropogenic disturbance and re-establishing more natural conditions for the system. Since clearing and straightening of the channel, the river has been slowly recovering, although many simplified portions of the channel remain because of confinement by infrastructure. In unconfined areas, the channel is attempting to recover with channel migration and deposition of wood and sediment. Through time, additional channel migration would further extend the length of the channel network, increase floodplain connectivity, and reduce in-channel velocities. In addition, LWD on floodplains have been maturing and some LWD materials have begun to deposit on gravel bars and shallow areas. As LWD accumulates and forms log jams, sediment deposition would be promoted in the lee of the structures. In addition, log jams help promote split channel flow and side channel development that often provides preferred habitat for juvenile salmonids and desired effects such as distribution of sediment load and organic debris across the floodplain. Split flows and side channels reduce the hydraulic energy of the mainstem, thereby promoting increased deposition of LWD and sediment. In this manner, the recovery of the system is a feedback loop where channel migration leads to LWD deposition on bars and shallow areas, which leads to log jams and split flow conditions, in turn reducing hydraulic energy in the channel, leading to additional deposition of LWD and sediment, and the feedback loop continues. The result of the process is an overall widening of the active channel and better hydraulic connectivity between the river, side channels, and floodplains.

In summary, future evolution of the Tucannon mainstem in unconfined reaches will include expansion of the active channel and increased deposition of LWD and sediment. Where unconfined reaches are located downstream of tightly confined, high-velocity transport reaches, the deposition that occurs may be magnified or accelerated due to the rapid drop in energy and transport capacity as the material enters the unconfined reach. Deposition and channel migration in unconfined reaches will lead to increased side channel and floodplain connectivity, expanding the potential flood area and the area of likely channel avulsion.

4 FISH HABITAT AND DISTRIBUTION

The Tucannon River supports four ESA-listed Snake River Basin salmonid populations throughout all or a portion of their life stages. Summer steelhead, spring Chinook salmon, fall Chinook salmon, and bull trout were identified in the TSP as aquatic focal species (CCD 2004). Collectively, these species use the main channel from the mouth to the headwaters, as well as major tributaries including Pataha Creek. The following information is summarized from the TSP (CCD 2004) and the SRSRP (2006), and revised to include new information from recent data being collected by Washington Department of Fish and Wildlife (WDFW) and others in the basin (SRSRB 2011b, email comm.; Gallinat and Ross 2010). Table 4-1 shows the spatial distribution of steelhead and Chinook salmon in the mainstem of the Tucannon River, with darker shades of gray indicating higher densities of fish present during their respective life stages. Information on bull trout was not sufficient to provide distribution data as reported for the other focal species.

Table 4-1

Distribution of Steelhead, Chinook Salmon, and Bull Trout in the Mainstem Tucannon River

Geographic Area	From (RM)	To (RM)	Summer Steelhead			Spring Chinook			Fall Chinook			Bull Trout		
			Spawning	Juvenile Rearing	Adult Holding	Spawning	Juvenile Rearing	Adult Holding	Spawning	Juvenile Rearing	Adult Holding	Spawning	Juvenile Rearing	Adult Holding
Mouth	0	0.7										Note: Migratory and resident fish. Distribution data are limited.		
Lower Tucannon	0.7	4.8												
	4.8	5.5												
	5.5	8.7												
	8.7	12.3												
Pataha-Marengo	12.3	16.5												
	16.5	18.6												
	18.6	22.8								Note: Juveniles out-migrate as subyearlings				
	22.8	26.6												
Marengo-Tumalum	26.6	35.6												
Tumalum-Hatchery	35.6	37.8												
	37.8	41.9												
Hatchery-Little Tucannon	41.9	44.6												
	44.6	45.6												
	45.6	48.1												
Mountain	48.1	50.2												

Notes:

1. Distribution data are summarized from CCD 2004 and updated based on recent data being collected in the basin by WDFW, SRSRB and others (SRSRB 2011b, email comm.). Geographic areas and river mile sections correspond to Ecosystem Diagnosis and Treatment (EDT) analysis reaches utilized during subbasin planning.
2. Darker shades of gray indicate higher densities of fish present during their respective life stages.

4.1 Steelhead Trout

Steelhead trout in the Tucannon River are of the Snake River Basin steelhead evolutionarily significant unit (ESU), which was listed as threatened in 1997. Summer steelhead trout enter the Tucannon River in September and begin spawning in late February to early March until mid-May. Spawning occurs in the mainstem from Kellogg Creek (RM 4.8) upstream to the Tucannon headwaters, as well as within Cummings Creek and in the lower portions Panjab and Sheep Creeks; the greatest concentration of steelhead spawning is typically found in the mainstem between Tucannon Falls (RM 16.5) and Beaver Lake at approximately RM 42. Juveniles also rear throughout the mainstem but are typically found in the greatest numbers between approximately RM 18 and School Canyon (approximately RM 45).

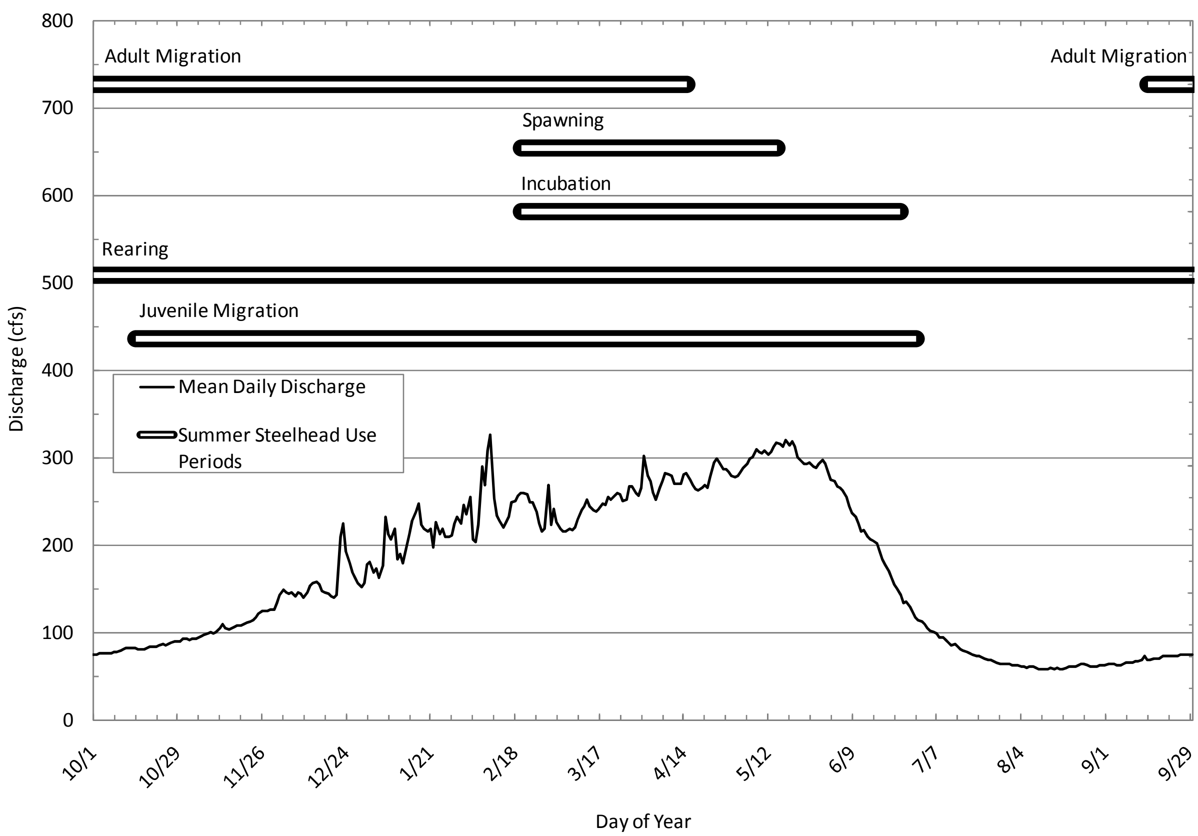


Figure 4-1
Mean Annual Hydrograph and Typical Timing of Life History Stages for Summer Steelhead Trout in the Tucannon Basin

4.2 Spring Chinook Salmon

Spring Chinook salmon in the Tucannon River are of the Snake River spring/summer Chinook salmon ESU that was ESA-listed as threatened in 1992. Spring Chinook salmon enter the Tucannon River beginning as early as late April and as late as mid-September; spawning occurs from mid-August to the end of September. Spawning occurs almost exclusively in the main channel from approximately King Grade (RM 22.9) to the mouth of Sheep Creek near RM 55 (Gallinat and Ross 2010); the greatest densities are between Marengo and the Little Tucannon River (approximately RM 48.1). Juveniles rear from approximately Tucannon Falls (RM 16.5) to the headwaters, with the highest densities located between Marengo and School Canyon (approximately RM 45).

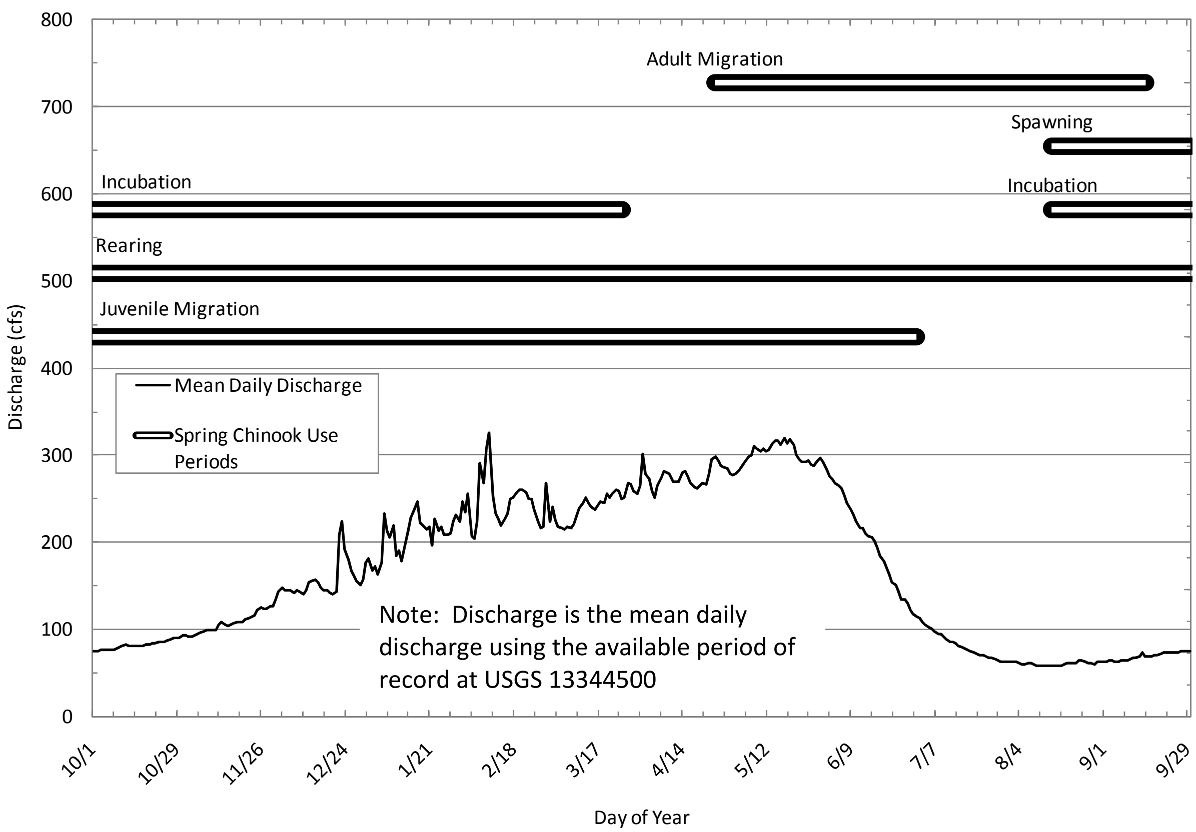


Figure 4-2
Mean Annual Hydrograph and Typical Timing of Life History Stages for Spring Chinook Salmon in the Tucannon Basin

4.3 Fall Chinook Salmon

Fall Chinook salmon are of the Snake River fall Chinook salmon ESU, also listed as threatened in 1992. Fall Chinook salmon enter the lower Tucannon River beginning in early October and have a brief holding period until spawning begins in mid-October. Fall Chinook salmon use the main channel of the river from the mouth to upstream of Pataha Creek (RM 12.3), the highest concentration of spawning being from the mouth to around the Starbuck Dam near RM 5.5. Juvenile fall Chinook salmon do not overwinter in the Tucannon River and out-migrate shortly after emergence during the late winter to early summer.

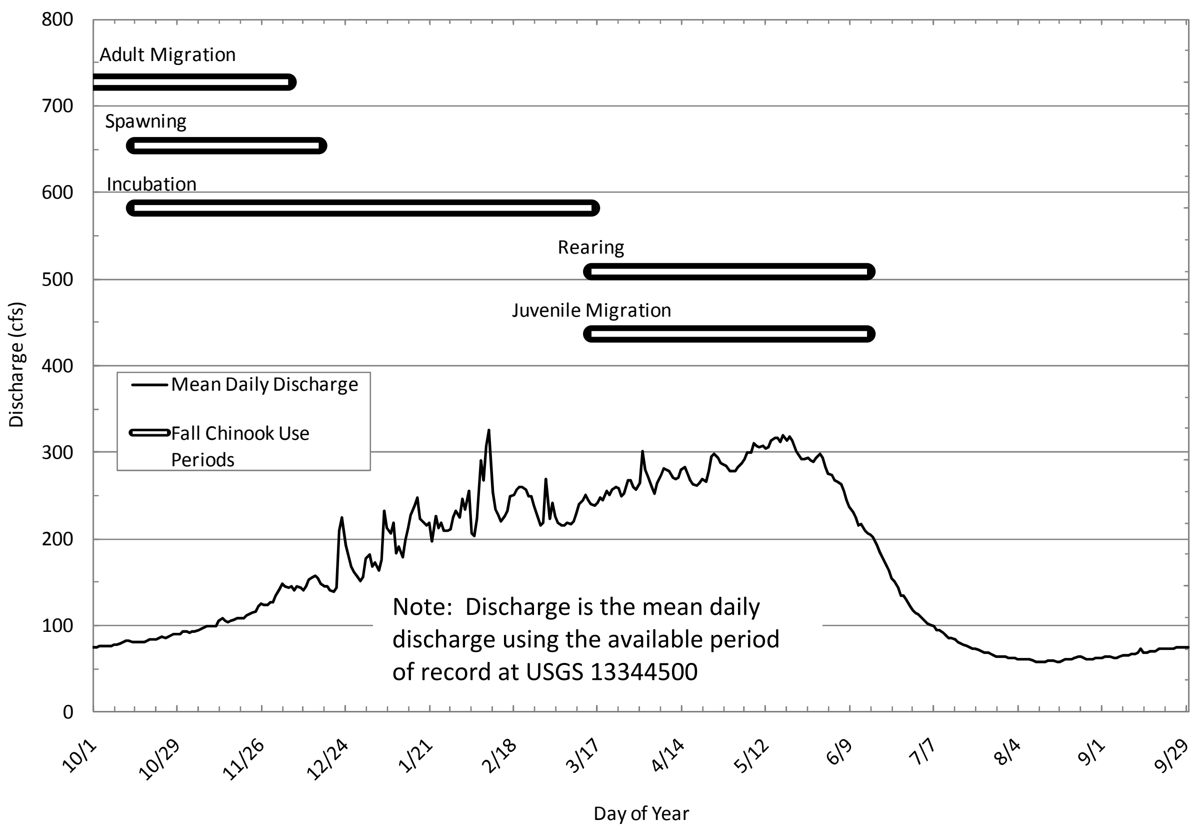


Figure 4-3

Mean Annual Hydrograph and Typical Timing of Life History Stages for Fall Chinook Salmon in the Tucannon Basin

4.4 Bull Trout

Bull trout in the Columbia Basin were ESA-listed as threatened in 1998. The Tucannon River bull trout population is part of the Lower Snake River Critical Habitat Unit (USFWS 2010). Bull trout life histories present in the Tucannon River include resident, fluvial, and adfluvial forms. Migratory bull trout move upstream from the Snake River into the upper Tucannon River in the spring and early summer. Critical habitat in the Tucannon Critical Habitat Subunit, as designated by the U.S. Fish and Wildlife Service (USFWS), includes the mainstem Tucannon, Cummings Creek, Hixon Creek, the Little Tucannon River, Panjab Creek, Cold Creek, Sheep Creek, and Bear Creek (2010). Juvenile rearing occurs upstream of Tumalum Creek to the headwaters. The lower Tucannon River is an important migratory corridor to spawning and rearing areas upstream in the watershed, including headwaters and tributary streams.

Historically, the bull trout population in the Tucannon River has been considered healthy; however, recent data suggest some population declines (USFWS 2010). As cited by USFWS, WDFW surveys indicate the number of redds in the upper Tucannon have dropped from more than 100 in 2002 and 2003 to less than 20 in 2007. This correlates with a decline in the number of adult migratory bull trout captured at the Tucannon Hatchery Trap as they were moving upstream.

5 RESTORATION STRATEGIES

The restoration strategies presented in this report are focused on consistency with management objectives recommended to address limiting factors to aquatic focal species in the Tucannon River (SRSRB 2006; CCD 2004). In addition, the results of the reach-scale geomorphic assessment performed as a part of this study identified restoration actions consistent with natural physical and ecological processes occurring in the basin. Designing restoration treatments that are consistent with natural processes is vital to providing the greatest benefit to salmonid abundance and productivity in the near term and long-term sustainability of project actions.

In developing long-term restoration strategies for a river, it is helpful to refer to the framework developed by Roni et al. (2002). The types of restoration actions (including passive methods) outlined in Figure 2 from Roni et al. (2002) and the applicable restoration opportunities identified in the Tucannon basin include:

	Roni et al. (2002)	Tucannon Basin
1.	Protect and maintain natural processes	Promote natural hydrologic and sediment routing throughout the system, allow natural migration and wood recruitment
2.	Connect disconnected habitats	Reconnect oxbows, wetlands, and former mainstem and side channels
3.	Address roads, levees, and other human infrastructure impairing processes	Remove or modify culverts, levees, dredge spoils, diversion dams, and grade control structures
4.	Restore riparian processes	Isolate and protect healthy riparian areas, eradicate invasive species, and plant native communities
5.	Improve instream habitat conditions	Install large individual trees and LWD structures in the mainstem channel

This section of the report describes the basis of the restoration objectives used to develop restoration strategies for the Tucannon basin. The general types of restoration actions that may be implemented in the study reach are described and the physical and biological benefits of each action are discussed.

5.1 Limiting Factors and Restoration Objectives

An Ecosystem Diagnosis and Treatment (EDT) analysis was performed that assessed habitat conditions in the Tucannon River for aquatic focal species (CDD 2004, Appendix B of TSP). This analysis allowed watershed planners and stakeholders to identify the primary limiting factors to aquatic focal species in discrete reaches throughout the river. These results are summarized in the SRSRP for summer steelhead and spring Chinook salmon (Table 5-1 and 5-2); the SRSRP also provides priority habitat objectives for the Upper Tucannon River major spawning area (MSA). The lower Tucannon River (downstream of Pataha Creek) is not a priority MSA and was not considered for active restoration in the SRSRP; however, the Lower Tucannon is now considered a priority MSA and was changed to a priority restoration reach beginning in 2010 (SRSRB 2011a, draft).

Table 5-1

Factors Limiting the Viability of the Tucannon River Steelhead Population (SRSRB 2006)

Geographic area priority			Attribute class priority for restoration															
Geographic area	Protection benefit	Restoration benefit	*Channel stability*	*Chemicals*	*Competition (w/ hatch)*	*Competition (other sp)*	*Flow*	*Food*	*Habitat diversity*	*Harassment/poaching*	*Obstructions*	*Oxygen*	*Pathogens*	*Predation*	*Sediment load*	*Temperature*	*Withdrawals*	*Key habitat quantity*
Tucannon R, Pataha Cr to Marengo	B	A	C		C		C		C		C		C		C	B		B
Tucannon R, Turnalum Cr to Panjab Cr	A	A	C		C		C		C	C	C		C			C		A
Pataha Cr, mouth to Pomeroy		B	B				B	C	B		A				A	C		B
Tucannon R, Marengo to Tumalum	B	B	C		C		C		C				C		C	B		B
Cummings Cr	C	C			C		C		C									B
Tucannon R, mouth to end of backwater		C	C		C		C		C				B	B	A	B		B
Panjab Cr	C	C	C				C		C									B
Pataha Cr, Pomeroy to headwaters		C	C		C		B		B		A				A			B
Tucannon R, Panjab Cr to headwaters	B	C	C						C									C
Tucannon R, end of backwater to Pataha Cr		C	C		C		C		C				C	C	B	C		B
Tumalum drainage		C	B		C		C		C					C	C			B
Bihmaier Gulch Cr			C						C		A				C			A
Dry Pataha Cr			B				B		B		A				B			B
Hixon Cr			C		C		C			C					C			B
Iron Springs Cr			B				C		B						B			B
Kellog Cr			B		C		B		B				C	C	A	B		B
Little Tucannon River drainage			B		C		C		B									B
Pataha above Dry Pataha			B				B		B	C	B				A			B
Smith Hollow Cr			B		B		B	C	B				C	C	A	B		B

Key to strategic priority (corresponding Benefit Category letter also shown)

A — High; B — Medium; C — Low; D & E — Indirect or General

Table 5-2
Factors Limiting the Viability of Tucannon River Spring Chinook (SRSRB 2006)

Geographic area priority			Attribute class priority for restoration															
Geographic area	Protection benefit	Restoration benefit	Channel stability	Chemicals	Competition (w/ hatch)	Competition (other sp)	Flow	Food	Habitat diversity	Harassment/poaching	Obstructions	Oxygen	Pathogens	Predation	Sediment load	Temperature	Withdrawals	Key habitat quantity
Tucannon R, Pataha Cr to Marengo	A	A	C				C	C	B						C	B		B
Tucannon R, mouth to Starbucks Dam		B	C				C	C	C	C			C	C	A	A		B
Pataha above Pomeroy		B	C				B	C	A	C	B				A			B
Pataha below Pomeroy		B	C				B	C	A	C	B				A	B		B
Tucannon R, Starbucks Dam to Pataha Cr		B	C				C	C	B						B	A		B
Tucannon R, Marengo to Tumalum	C	B	C		C		C	C	B	C			C		C	B		B
Tucannon R, Tumalum Cr to Panjab Cr	B	B	C				C	C	B	C						C		A
Pataha above Dry Pataha		C	C				B	C	A	C	B			C	A			B
Tucannon above Panjab		C							B	C								B
Panjab drainage			C		C		C		B	C					C			B

Key to strategic priority (corresponding Benefit Category letter also shown)
A High; B Medium; C Low; D & E Indirect or General

In order of greatest priority, the restoration objectives for the Upper Tucannon River MSA and the approaches recommended for achieving these objectives are (SRSRB 2006):

1. Riparian: 40 to 75% of maximum
    a. Improve riparian areas
    b. Improve channel and floodplain function
    c. Improve water quantity
2. Large Woody Debris: one or more pieces per channel width
    a. Improve channel and floodplain
    b. Improve riparian areas
    c. Improve instream habitat
3. Confinement: 25 to 50% of streambank length
    a. Improve channel and floodplain
    b. Improve riparian areas
4. Temperature: No more than 4 days above 72 degrees Fahrenheit
    a. Improve riparian areas
    b. Improve water quantity
    c. Improve channel and floodplain

d. Improve instream habitat

In order of greatest priority, the restoration objectives for the **Lower Tucannon River MSA** and the approaches recommended for achieving these objectives are (SRSRB 2011a, draft):

1. **Temperature:** No more than 4 days above 72 degrees Fahrenheit
2. **Embeddedness:** Less than 20% cobble embeddedness
3. **Large Woody Debris:** 1 or more pieces per channel width
4. **Riparian:** 40 to 75% of maximum
5. **Confinement:** Less than 25 to 50% of stream bank length

5.2 Habitat Restoration Actions

Throughout the area that was evaluated during this effort, enhancing instream habitat may be accomplished by undertaking a variety of treatment actions within the main channel, along the banks, and within the riparian zone and floodplain. The actions presented in the following sections address one or more restoration objectives identified in the SRSRP, which in turn address multiple limiting factors for focal species. The limiting factors that are expected to be improved by these restoration strategies are summarized in Table 5-3 below; key limiting factors for summer steelhead and spring Chinook salmon (identified as high-priority in Tables 5-1 and 5-2) for the mainstem are shaded in gray. Note that all of the proposed restoration strategies address at least two of the three key limiting factors for steelhead and Chinook salmon. The following sections discuss the physical and biological benefits of the conceptual restoration strategies. Section 7 will prioritize these strategies in the specific reaches identified within the greater study area.

Table 5-3
Steelhead and Chinook Salmon Limiting Factors Addressed by Proposed Restoration Strategies for the Tucannon River

Restoration Strategies	Key Habitat Quantity	Sediment Load	Temperature	Channel Stability	Competition (hatchery)	Flow	Food	Habitat Diversity	Harassment/Poaching	Obstructions	Pathogens	Predation
Reconnect disconnected habitats	●	●	●	●		●		●				●
Reconnect former mainstem and side channels	●	●	●	●		●	●	●				●
Levee removal or setback		●	●	●		●		●				
Modify or remove obstructions		●	●	●		●				●		●
Develop instream habitat complexity	●	●	●	●			●	●				●
Riparian zone enhancement		●	●	●			●	●				●

Notes:
1. Limiting factors are summarized from SRSRB (2006).
2. Key limiting factors for summer steelhead and spring Chinook salmon (identified as high-priority in Tables 5-1 and 5-2) for the mainstem are shaded in gray.

5.2.1 Reconnect Disconnected Habitat

Off-channel habitat provides critical holding and rearing habitat for juvenile salmonids during moderate to high flows and often provides preferred habitat conditions to main channel habitat at lower flows. Several disconnected features, such as off-channel wetlands that are wetted during part of the year and become disconnected at lower flow periods are present in the Tucannon floodplain.

Encouraging reconnection of these features will increase habitat complexity by providing off-channel habitat and increased connectivity with the channel where disconnected features become cut off or create stagnant conditions during the dry season. Reconnecting these areas will allow fish to move in and out of these features for longer periods of time and enhance water quality conditions, particularly during late summer and early fall low flows. This will also help lessen the possibility of entrapment of fish associated with the long periods of disconnection from the main channel.

Actions for reactivating disconnected habitat may include earthwork to establish hydraulic connections with the main channel and installation of LWD to provide cover or assist in keeping pathways to the main channel accessible.

5.2.2 Reconnect Former Mainstem and Side Channels

Similar to disconnected habitat, side channels often provide preferred rearing habitat during low flows and provide hydraulic refuge and cover during high flows (see Section 7 for specific locations). Encouraging multiple flow paths will increase habitat complexity by diversifying the planform, dissipating stream energy, distributing sediment load, and providing hydraulic complexity. Diverse floodplain and side channel networks often have multiple flow paths at various elevations across the valley bottom. Therefore, different channels are accessed at different water surface elevations. In this manner, off-channel habitat is accessed in different areas of the channel network under changing flow regimes providing a multitude of habitat during a large range of flow conditions.

5.2.3 Levee Removal or Setback

Tens of thousands of linear feet of levees confine the mainstem Tucannon River and prevent or limit a surface water connection to the adjacent floodplain (see Section 7 for specific locations). In these areas, levee removal and/or setback may be used to increase the active floodplain area, thereby promoting floodplain and side channel connectivity and more natural channel migration processes. In a majority of the locations identified, widening the floodplain corridor may occur without significant changes to agricultural practices by working outside the limits of existing irrigation areas as much as possible.

Removing levees and promoting floodplain connectivity encourages geomorphic processes while dissipating velocities during high flows as floodwaters are distributed onto the floodplain. This also allows fine sediment to deposit on the floodplain, promoting ecological processes. Decreased channel velocities may also lessen erosive energy along the banks in areas of concern for landowners. Allowing the channel to migrate throughout a wider corridor will encourage development of complex channel and planform geometry, distributing energy and sediment load. It will be important to consider the reach-scale effects of widening the floodplain, particularly at the downstream end of confined reaches. For example, creating an unconfined floodplain below a tightly confined section will likely result in a large amount of sediment deposition and channel migration.

5.2.4 Modify or Remove Obstructions

Three primary obstructions to fish passage were identified in the mainstem Tucannon River: Starbuck Dam, Tucannon Falls, and the Hatchery Dam. Although adult fish are able to pass these features, there may be impacts to juveniles (SRSRB 2006). In addition, the hydraulic conditions created by flow obstructions can adversely affect habitat quality. Extensive sections of upstream backwater often lead to deposition of sands and gravels on the upstream side, potentially starving the channel downstream of spawning-sized material and LWD. The low-flow velocities in backwater areas prolong water residence time and allow for increased heating from solar radiation and atmospheric exchange. Removal of obstructions would allow for more natural sediment and woody debris transport and better allow natural evolution of the channel grade and planform. Hence, a consequence of obstruction removal would likely be some adjusting of the channel bed elevation; removal must consider the future evolution associated with this action as additional bank stabilization actions may be required.

5.2.5 Develop Instream Habitat Complexity

Instream habitat complexity is correlated to hydraulic complexity created by the channel geometry, bedforms such as gravel bars and pools, hardpoints such as bedrock, and perhaps most importantly to the presence of LWD. The primary biological function of LWD in rivers and streams is to provide complexity that creates hydraulic refuge and cover for adult and juvenile salmonids. Geomorphically, LWD also plays a major role in influencing the channel form.

In natural systems, riparian trees often enter a watercourse as the result of erosion, windfall, disease, beaver activity, or natural mortality. However, in most Pacific Northwest river systems, including the Tucannon River, LWD has been removed from the river channels and cleared from riparian areas. In addition, a significant quantity of natural LWD that would otherwise be recruited from riparian areas has been removed by logging and agricultural practices. Anthropogenic activities in the basin have been detrimental to the system, leading to a decrease in the number, size, and volume of LWD being introduced to the river through natural processes. Therefore, installing LWD is necessary to supplement existing conditions, recognizing that it will take decades of riparian planting and development to begin to provide natural replenishment rates. In the long term, the added channel and bank roughness created by wood structures will help retain additional mobile wood and sediment, diversifying hydraulic and bedform complexity and contributing to increased floodplain connectivity and functionality of floodplain processes over time. For the Upper Tucannon River MSA, the SRSRP recommended at least one piece of LWD per channel width (2006). Installation of rock structures is also considered as an option to add instream complexity, particularly in areas where bedrock already interfaces with the channel.

5.2.5.1 LWD Placements

LWD placements that are suitable for placement in the Tucannon River include single-log placements or multiple-log assemblies with rootwads that are installed in the channel bed or bank to create beneficial fish habitat and desired geomorphic effects. These features emulate natural tree fall of mature riparian trees and provide a base for mobile wood to accumulate. The different types of LWD placements have varying levels of engineering and construction effort and range in magnitude of physical and biological benefit.

5.2.5.2 Engineered Log Jams

Engineered log jams (ELJs) are large wood structures that can be placed in the main channel that emulate naturally occurring, stable log jams. Historically, several log jams per mile were likely present in the main channel, but they have either been cleared or are no longer able to become established due to a lack of mature riparian trees being recruited to the system, particularly in reaches were the local riparian conditions are poor. ELJs are typically placed along the bank or mid-channel with the bottom of the structure at the anticipated scour depth and the top built to the approximate height of the 100-year flood water surface elevation. The structure is backfilled with streambed materials for stability, and a gravel bar deposit may be placed in the lee of the structure that emulates the natural sediment deposit that would occur in the lee of this type of structure.

ELJs can create large flow stagnation areas upstream and downstream of the structure and contain a substantial amount of void space within the logs and root masses, providing considerable area for fish refuge. During high flows, the rootwads interact with hydraulic forces from the river and scour large, deep pools that provide holding areas for adults while the void space within the face of the structure is used by juveniles. In addition, these structures are able to retain mobile wood debris. Because of the hydraulic conditions and hard points created by ELJs, they may also be used as "deflectors" to influence flow direction to promote channel expansion or activation of side channels.

On a reach scale, installation of multiple ELJs can influence gravel movement and deposition to create localized pool-riffle sequences, increased hydraulic complexity, and a more stable channel profile. Sediment storage and deposition adjacent to the ELJs can create large gravel bars in the active channel allowing for colonization of riparian vegetation and eventually the development of forested islands. The overall roughening of the active channel and aggrading of the riverbed promotes rehabilitation of natural processes by increasing floodplain connectivity and promoting channel migration.

5.2.6 Rock Structures

Rock structures such as rock barbs and J-hooks are another possible option to add instream complexity in simplified channel reaches. Rock structures would be considered in locations where bedrock has likely interfaced with the channel over time and likely represents a natural habitat forming analog. Rock barbs can redirect the thalweg towards the center of the channel thereby reducing energy along the outside of a bend. These structures can induce a low-energy environment around the structure and may also promote scour around the base of the rock that provides some cover for fish during low flow. Rock barbs are typically placed in sets of multiple structures at a height lower than the ordinary high water line.

5.2.7 Riparian Zone Enhancement

Riparian habitat enhancement will involve protection of healthy riparian areas, removal of undesirable vegetation, and planting of native riparian communities on the channel banks, on higher elevation gravel bars, and in the floodplain. However, establishment of the ideal riparian buffer width may be limited by the location of agricultural fields, infrastructure, and the feasibility of irrigating and maintaining plantings. Riparian planting may also be conducted in conjunction with LWD structure placement, including ELJs.

The riparian zone provides several habitat and physical process benefits including increased bank and floodplain roughness, cover, and nutrients for instream species and wildlife. Increased roughness encourages sediment deposition and decreased channel and overbank velocities during floods. Additionally, fully developed mature riparian areas are a source of LWD to the river over time. Riparian restoration should begin with protection of existing healthy riparian areas through programs such as Conservation Reserve Enhancement Program (CREP). Where riparian habitat has been degraded, removal of invasive plants and vegetation and replacing with native species in appropriate environments should be performed. For example, cottonwoods or willows may be planted in wetter areas such as along the banks, as opposed to drier floodplain terraces. Monitoring and maintenance of plantings for at least the first few years after planting, which will greatly contribute to the success of the restoration effort, may be required for permitting approval. Eradication of invasive species such as reed canarygrass will likely require a longer and more involved maintenance and monitoring effort.

6 SEDIMENT DATA COLLECTION AND ANALYSIS

A detailed analysis of sediment supply and movement throughout the study reach was performed for the mainstem river. This analysis included bedload grain size sampling from approximately RM 1.3 to the mouth of Sheep Creek in the headwaters (RM 55.0). These data were used in conjunction with review of prior research, field reconnaissance, sediment routing analysis, and hydraulic modeling to develop a decadal-scale sediment budget and to estimate the capacity of the channel to mobilize sediment throughout the study reach. The findings of these analyses were used to help understand basin-scale sediment dynamics, delineate reaches throughout the basin, and develop restoration actions.

6.1 Sediment Grain Size Sampling

Sampling of the bedload channel sediment within the main channel was conducted on gravel bars throughout 55 miles of the mainstem channel during August 2010. The average discharge at the Starbuck gage during sampling was 49 cfs. This low-flow condition exposed sediment deposits composed of material transported by recent sediment mobilizing discharges; this material is assumed to be representative of the bedload. Bulk sediment samples and Wolman pebble counts (Wolman 1954) were taken at 23 locations distributed along 55 miles of river to capture potential changes in sediment grain size distribution. Two of the 23 samples were taken in major tributaries (Pataha and Panjab Creeks) upstream of their confluence with the Tucannon River, as well as an additional sample of bank sediment from Pataha Creek. Wolman pebble counts (Wolman 1954) were used to define the surface armor grain size distribution while bulk sediment samples were used to define the subsurface grain size distribution. Details regarding the sediment grain size distribution information can be found in Appendix B.

6.2 Hydraulic Modeling

A basin-scale one-dimensional (1-D) hydraulic model (USACE 2010b, 2010c) was developed to provide estimates of main channel hydraulic conditions for the discharges shown in Tables 2-1 and 2-2. The basin-scale hydraulic model was developed using the ground surface from 2010 LiDAR data. Bathymetric data collection throughout the basin was not a part of this scope of services. The LiDAR was flown while hydrologic conditions averaged a discharge of approximately 200 cfs (Watershed Sciences 2010). Because LiDAR often captures the water surface, rather than the channel bottom, it is assumed that the channel bathymetry below the water surface elevation at this discharge is not incorporated into the basin-scale model. However, the LiDAR surface is considered adequate for the purposes of the basin-scale modeling effort. Cross-sections in the model were located to capture significant changes in channel and floodplain planform as well as changes in channel gradient, with the spacing of cross-sections varying in proportion to planform complexity of the channel and floodplain. Channel and floodplain roughness values were estimated using typical values for the land use and channel condition identified from 2010 aerial photography.

6.3 Sediment Mobility and Transport Analysis

The sediment mobility and transport capacity in the main channel of the Tucannon River was calculated at each hydraulic model cross-section location. The calculations used the results of the basin-scale hydraulic model and applicable sediment mobility and transport formulae. See Appendix B for additional details regarding the detailed sediment mobility and transport analysis methods. The results of the mobility and transport calculations were compared to armor and subarmor sediment grain size distributions at sample locations to evaluate trends in erosion and deposition (i.e., areas with the potential for temporary sediment storage). Areas of erosion and deposition typically fluctuate on a small scale (on the order of less than 1 mile), associated with changes in channel planform, confining features, and local gradient changes. However, reach-scale (i.e., multiple-mile) trends in hydraulic energy and transport capacity can be interpreted from the results. Reach-scale trends were utilized in the geomorphic reach delineation and are discussed further in Section 7.1.

During 1-year recurrence discharge events, the sediment transport capacity of the river results in a mix of mobile (transport) and potentially depositional areas. During a 2-year return discharge, the river is primarily under mobile bed conditions, although many depositional areas remain scattered throughout the basin. Discharge events above the 2-year return period further reduce the number of depositional areas, and the majority of the river has the capacity to transport existing bedload sediment. For discharges greater than or equal to the 10- year return period, the only significant depositional area shown was near the confluence with the Snake River, likely associated with slowed velocities due to backwater.

See Figures B1 through B4 in Appendix B for a presentation of the sediment mobility analysis results.

6.4 Sediment Source and Budget Analysis

A sediment budget for the Tucannon River watershed was developed to provide data on the input and transport of bedload and fines in the river system. This report section summarizes sediment budget development inputs and results. A detailed discussion of methodology, specific analyses performed, and results is provided in Appendix C.

Understanding the volume and timing of both bedload and suspended sediment movement through the proposed habitat restoration areas is an important aspect to ensuring the long-term success of enhancement projects. Bedload, the coarse-grained portion of the sediment load that moves along the bed of the river, is the basis for channel geomorphology and channel substrate that provides spawning, rearing, and hiding habitat for fish and aquatic organisms. In the Tucannon River, bedload consists of cobble, gravel, and sand-sized particles. Suspended load, the fine-grained portion of the sediment load that moves in suspension, affects turbidity (water clarity). High levels of fine-grained sediment (sand, silt, and clay) can also degrade aquatic habitat by filling the pore spaces between cobble and gravel particles on the bed, reducing the oxygen flow to incubating fish eggs and reducing macroinvertebrate habitat.

The sediment input budget considers the amount and timing of sediment delivered to the channel from different erosion processes and sediment sources. Based on a review of past studies in the watershed and field and aerial photograph analysis, the following erosion processes appear to be dominant in the basin:

- Surface and rill erosion on unvegetated soil
- Streambank erosion due to channel migration of the mainstem Tucannon River
- Stream entrenchment (incision) in some tributaries, particularly Pataha Creek and Smith Hollow

Periodic gullying of some swales during extreme rainfall events and mass wasting (landsliding) does not appear to be a dominant erosion process (USFS 2002).

Sediment inputs related to these processes were categorized for each of the following sources of sediment:

- Land use – surface and rill erosion
  - Agricultural and range land
  - Timber harvest
- Wildfire – surface and rill erosion
- Road erosion – surface erosion from unsurfaced (gravel/dirt) roads
- Streambank erosion – channel migration along the mainstem Tucannon River
- Colluvial erosion and debris flows – gullying in steep, bedrock-lined swales
- Channel incision – entrenchment along Pataha Creek and Smith Hollow

Sediment inputs were determined by estimating erosion rates and delivery to stream channels and were partitioned by source and grain size category. Table 6-1 and Figure 6-1 show current (2005 to 2010) average annual sediment input rates by source. Note that these values should be regarded as estimates of the relative magnitude of sediment inputs rather than precise quantities due to the uncertainties inherent in calculating input rates.

The majority of recent sediment input to the Tucannon River has come from channel-related sources, either by erosion/gullying in bedrock swales and mainstem channel migration during peak flows, or by channel incision in Pataha Creek and Smith Hollow. We estimated that 17 percent of recent sediment delivered to streams is from land use activities, including roads, agriculture, timber harvest, and wildfire. More soil is eroded from these land use activities, but not all of it reaches streams. This is supported by recent in situ chemical oxidation (ISCO) sampling in the watershed that shows that suspended sediment levels are correlated with streamflow, but there is little correlation between high suspended sediment levels and rainfall events.

Table 6-1
Average Annual Input from Current (2005 to 2010) Sediment Sources

Subbasin	Area (acres)	Colluvial Erosion in Bedrock Swales (tons)	Mainstem Channel Migration (tons)	Channel Incision (tons)	Road Erosion (tons)	Land Use (tons)	School Fire (tons)	Total (tons)	Average (tons/acre)
Headwaters Tucannon River	24,490	600	U	-	82	49	-	25,220	1.03
Panjab Creek	16,253	497	-	-	347	32	-	17,129	1.05
Little Tucannon River-Tucannon River (see note below)	22,073	1,558	U	-	277	322	970	25,201	1.14
Cummings Creek	12,717	740	-	-	113	139	618	14,328	1.13
Tumalum Creek	10,268	419	-	-	58	170	246	11,161	1.09
Hartsock Grade-Tucannon River	12,700	398	2,673	-	42	795	80	16,688	1.31
Town of Marengo-Tucannon River	23,023	285	9,424	-	36	413	-	33,181	1.44
Willow Creek	19,118	337	-	-	77	853	-	20,385	1.07
Headwaters Pataha Creek	18,306	825	-	-	430	112	334	20,007	1.09
Bihmaier Gulch-Pataha Creek	23,790	443	-	2,855	42	960	-	28,090	1.18
Benjamin Gulch-Pataha Creek	17,937	229	-	2,944	51	592	-	21,755	1.21
Linville Gulch	19,207	438	-	-	80	1,560	-	21,285	1.11
Chard Gulch-Pataha Creek	20,616	305	-	20,235	48	609	-	41,814	2.03
Dry Hollow-Pataha Creek	18,419	328	-	10,346	40	389	-	29,522	1.60
Smith Hollow-Tucannon River	16,697	313	2,687	3,139	35	776	-	23,647	1.42
Town of Starbuck-Tucannon River	15,476	362	1,314	-	24	443	-	17,618	1.14
Kellogg Creek	22,088	504	-	-	63	1,402	-	24,057	1.09
Tucannon River	8,429	175	2,425	-	15	86	-	11,130	1.32
Watershed Total	**321,609**	**8,754**	**18,523**	**39,519**	**1,863**	**9,703**	**2,248**	**402,217**	**1.25**

Notes:
U = unknown; mainstem channel migration was observed in the Little Tucannon-Tucannon River subbasin, as well as a minor amount in the Headwaters subbasin, but the magnitude of sediment input in these areas could not be quantified due to the lack of complete aerial photograph coverage. The estimate of average tons per acre for these subbasins may be affected.

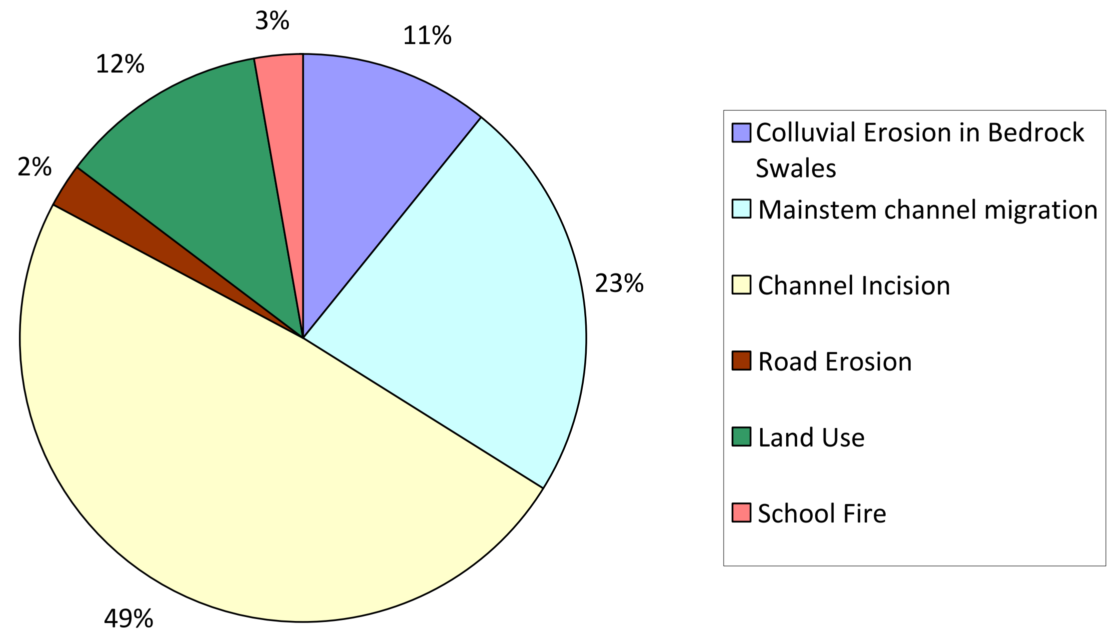


Figure 6-1
Current Sediment Inputs by Source

The sediment input budget was also calculated for three different time periods based on available aerial photographs. Sediment inputs for the 1954 to 1974, 1974 to 1996, and 1996 to 2010 periods were estimated based on channel migration and land use changes. Table 6-2 shows the sediment inputs by subbasin for each of these three periods. The primary differences between periods are higher inputs of bedload material (cobble/gravel) from channel migration during the large 1964 and 1996 flood events, and a decrease in erosion and sediment delivery from croplands through time as farming conservation efforts improved.

Table 6-2
Tucannon River Watershed Sediment Input Budget (in Tons)

Subbasin	TOTAL 1954 to 1974			TOTAL 1974 to 1996			TOTAL 1996 to 2010		
	Cobble/ Gravel	Sand	Fines	Cobble/ Gravel	Sand	Fines	Cobble/ Gravel	Sand	Fines
Headwaters Tucannon River	143	170	496	143	170	496	141	162	488
Panjab Creek	131	274	530	131	274	530	130	270	526
Little Tucannon River-Tucannon River*	400	595	1,435	400	595	1,435	388	1,027	1,868
Cummings Creek	189	273	674	189	273	674	182	551	952
Tumalum Creek	121	217	444	121	217	444	112	298	525
Hartsock Grade-Tucannon River	18,910	2,679	1,007	12,628	2,039	971	2,563	785	680
Town of Marengo-Tucannon River	58,347	1,149	743	24,969	713	596	9,356	407	425
Willow Creek	175	997	889	175	997	889	99	655	547
Upper mainstem total	**78,416**	**6,354**	**6,218**	**38,756**	**5,279**	**6,036**	**12,971**	**4,154**	**6,009**
Headwaters Pataha Creek	221	434	866	221	434	866	214	568	1,001
Bihmaier Gulch-Pataha Creek	246	2,940	1,924	246	2,940	1,924	170	2,595	1,579
Benjamin Gulch-Pataha Creek	145	2,636	1,522	145	2,636	1,522	99	2,427	1,314
Linville Gulch	358	1,507	1,597	358	1,507	1,597	224	904	994
Chard Gulch-Pataha Creek	150	14,766	6,735	150	14,766	6,735	108	14,576	6,545
Dry Hollow-Pataha Creek	110	7,698	3,601	110	7,698	3,601	83	7,575	3,478
Pataha total	**1,231**	**29,982**	**16,245**	**1,231**	**29,982**	**16,245**	**897**	**28,646**	**14,909**
Smith Hollow-Tucannon River	9,567	4,439	2,012	4,205	3,639	1,879	2,398	3,063	1,520
Town of Starbuck-Tucannon River	7,907	1,592	725	3,288	967	646	1,232	515	431
Kellogg Creek	320	1,476	1,481	320	1,476	1,481	194	910	915
Tucannon River	15,834	1,713	381	5,624	704	248	2,213	335	170
Lower mainstem total	**33,628**	**9,220**	**4,600**	**13,438**	**6,787**	**4,254**	**6,037**	**4,823**	**3,036**
Total Tucannon Watershed	**113,275**	**45,555**	**27,063**	**53,424**	**42,047**	**26,535**	**19,905**	**37,624**	**23,955**

Note: *mainstem channel migration was observed in the Little Tucannon-Tucannon River subbasin as well as a minor amount in the Headwaters subbasin, but the magnitude of sediment input in these areas could not be quantified due to the lack of complete aerial photograph coverage.

7 REACH DELINEATION

7.1 Methodology

Reaches were delineated using the results from our site reconnaissance, basin-scale geomorphic analyses, hydraulic model output, sediment mobility results, existing and past river management actions, and the distribution of major hydrologic inputs (Appendix A and B). The most prominent influence on geomorphic processes throughout the study reach is channel confinement. Confining features were digitized in ArcGIS, which include levees, road grades, apparent dredge spoils, and other anthropogenic features. LiDAR topography, geologic mapping, and field investigation was used to identify naturally confining features such as alluvial fans and bedrock. Using this information along with observation of historic channel positions and 2010 aerial imagery, the floodplain was delineated into confined, moderately confined, and unconfined zones. Confined areas are typically locations of the channel with a narrow floodplain restricted by anthropogenic features or bedrock, and unconfined areas are typically areas with wide floodplain corridors and an unrestricted channel that is able to migrate freely across the floodplain. Depositional areas, typically associated with unconfined and moderately confined areas, were also identified and mapped from observation of aerial photographs and observations in the field.

The confinement mapping was compared to sediment mobility results (i.e., critical grain size), shown in Figures B-1 through B-4 of Appendix B. In many locations, confined areas are associated with erosion and transport, while unconfined areas are associated with deposition and lower critical grain sizes. This comparison assisted in the delineation of reaches based on the identified reach-scale trends. For example, reaches with mostly unconfined floodplain and relatively low critical grain size were grouped together. Similarly, mostly confined transport reaches were grouped to help form distinct reaches.

Reach breaks were further refined by comparing historic channel migration patterns, existing channel planform (e.g., single-thread versus anabranch or braided channels), main channel gradient, and locations of major hydrologic inputs. The reach delineation process resulted in ten reaches, shown in Table 7-1 and on Figure 5. The following sections provide reach descriptions that characterize the physical characteristics of each reach, geomorphic processes including sediment inputs and transport, and biological conditions including riparian conditions and distribution and use of aquatic focal species of interest. The reach characterization included several spatial calculations to quantify certain aspects of each reach, including riparian vegetation height and density, percent confinement, and relative magnitude of low floodplain. The methods and results of these calculations are provided in Appendix D.

Table 7-1
Summary of Reach Locations

Reach	Extent	Length (RM)	Average Gradient (%)[a]	Approx. Basin Area at Downstream End (mi^2)[b]	Major Tributaries
10	RM 44.0 to 50.2	6.2	1.6	87	Little Tucannon River, Panjab Creek
9	RM 40.0 to 44.0	4.0	1.3	95	None
8	RM 32.1 to 40.0	7.9	1.1	144	Tumalum Creek, Cummings Creek
7	RM 27.5 to 32.1	4.6	0.98	159	None
6	RM 20.0 to 27.5	7.5	0.89	178	None
5	RM 13.2 to 20.0	6.8	0.74	220	Willow Creek
4	RM 8.9 to 13.2	4.3	0.57	410	Pataha Creek
3	RM 4.5 to 8.9	4.4	0.52	490	Kellogg Creek, Smith Hollow
2	RM 0.7 to 4.5	3.8	0.44	503	None
1	RM 0.0 to 0.7	0.7	0.001 [c]	503	None

Notes:
[a] Average gradient calculated from 2010 bare-earth LiDAR topography.
[b] Calculated using USGS Streamstats (2010).
[c] The gradient of Reach 1 is likely influenced by backwater from Lake Herbert G West during the LiDAR flight.

Restoration framework was loosely based on the process described in Figure 2 from Roni et al. (2002). The restoration actions in the Tucannon basin that correspond to the framework proposed by Roni include:

Roni et al. (2002)	**Tucannon Basin**
1. Protect and maintain natural processes	Promote natural hydrologic and sediment routing throughout the system, allow natural migration and wood recruitment
2. Connect disconnected habitats	Reconnect oxbows, wetlands, and former mainstem and side channels
3. Address roads, levees, and other human infrastructure impairing processes	Remove or modify culverts, levees, dredge spoils, diversion dams, and grade control structures
4. Restore riparian processes	Isolate and protect healthy riparian areas, eradicate invasive species, and plant native communities
5. Improve instream habitat conditions	Install large individual trees and LWD structures in the mainstem channel

For each of the reaches delineated below, we applied the criteria above, identified features within the reach, and provided a qualitative indication of the value or priority of the action within the reach. It is important to note that our scope and budget did not include site evaluation of the entire river and much of the information provided on restoration actions is based on previous studies, aerial photograph review, and LiDAR evaluation. Site evaluation was conducted during sediment sampling activities at those specific locations and some additional sites were visited during basin reconnaissance. However, each of the restoration actions suggested requires additional evaluation of the feasibility and merit of the action.

7.2 Reach Characterization

7.2.1 Reach 10 – River Mile 44.0 to 50.2

7.2.1.1 Physical Description

Reach 10 is located from the mouth of Panjab Creek at RM 50.2, to the downstream end of Big Four Lake (RM 44.0; Figure D-10a). The reach is within the Umatilla National Forest and Wenaha-Tucannon Wilderness area, and includes both public (WDFW) and private holdings such as the Camp Wooten natural resources learning center. The valley is forested with conifers that increase in density upstream of Panjab Creek (RM 50.2). A majority of the subbasin areas between the Little Tucannon River (RM 48.0) and the downstream end of Reach 10 were affected by the 2005 School Fire; the most severely burned areas were the Hixon and Grub Canyon basins (USFS 2008). Confinement in the reach is variable; confinement in the lower reach downstream of the Little Tucannon River is typically influenced by anthropogenic features, whereas confinement in the upper reach is associated with alluvial fans, debris flow deposits, and natural narrowing of the valley width.

Photograph 7-1

The Main Channel Near RM 49.1, Looking Upstream

7.2.1.2 Hydrology

At the upstream end of Reach 10, the main channel contains approximately 47% of the river's total discharge during a 2-year recurrence flow including the contribution from Panjab Creek (Appendix A). The Little Tucannon River and Panjab Creek are the major perennial tributaries that drain into Reach 10. Panjab Creek is the fourth largest tributary to the Tucannon River representing an approximate 35% increase in discharge at its confluence. The Little Tucannon River represents an approximate 11% increase. At the downstream end of Reach 10, the main channel contains approximately 52% of the total discharge at the mouth during a 2-year recurrence flow. The 2-year recurrence discharge at the downstream end of Reach 10 is approximately 425 to 664 cfs (Appendix A). Because most of the tributaries throughout Reach 10 drain watersheds that are higher in elevation and receive a significantly higher average annual rainfall than tributaries in other reaches, the contribution of these watersheds to peak flows in the main river channel will vary depending on the season and the catalyst for the flood event (e.g., rain or snow versus snowmelt).

7.2.1.3 Channel Patterns and Floodplain Connectivity

Channel pattern in Reach 10 transitions from a primarily single thread channel near Panjab Creek into a more diverse channel network with some side channels and braided sections toward the lower end of the reach (Figure D-10b). In the confined sections of the reach, the channel is straight and lacks gravel bars and other hydraulic complexity. Evidence of deposition is visible downstream of most of the confined reaches. Moderately confined sections are typically braided, particularly in sections with a large amount of deposition, such as at RM 46.7. A majority of Reach 10 is moderately confined, with two confined sections near the mouth of Panjab Creek and RM 47 (Appendix D).

The portion of Reach 10 from Panjab Creek to the Little Tucannon River has a narrow valley bottom, a steep gradient, and steep valley walls (Figure D-10b). Confinement in this portion of the reach is primarily dictated by alluvial fans that deposit sediment at the mouths of small, steep tributaries that contribute debris flow material.

Downstream of the Little Tucannon River to RM 44.0, the valley bottom contains alternating moderately confined and confined sections (Figure D-10b). Confinement is related mainly to the roadway, lake berms, levees (such as at Camp Wooten), and the School Canyon alluvial fan (RM 45.2). A majority of the valley bottom is low in the moderately confined sections with several old channel positions visible in the topography. Historic channel migration patterns and extent could not be assessed due to lack of historic photo coverage. However, with a high-sediment input and large area of low, accessible alluvial floodplain, it is likely that the channel has the potential to migrate in this portion of the reach.

Floodplain connectivity in Reach 10 is slightly impacted. Approximately 224 acres of low-lying floodplain area is present in the reach representing approximately 36 acres per mile (Appendix D). Approximately 11% of these areas are disconnected from the main channel by infrastructure, isolating approximately 4.0 acres per mile. The loss of floodplain area and off-channel refuge habitat is relatively low and therefore likely represents a minor impact to natural processes and juvenile rearing.

7.2.1.4 Sediment Inputs and Transport

Sediment inputs to Reach 10 are primarily from colluvial erosion and debris flows associated with bedrock swales; some sediment development related to the School Fire, road surface erosion, and land use (e.g., timber harvesting) was also identified (Appendix C). Inputs due to mainstem channel migration could not be determined due to the lack of historic photo record; however, it can be assumed that channel migration does occur in this reach and some sediment load is contributed from this source. Sediment transport calculations for Reach 10 show relatively large values for critical grain size through a majority of the reach, although these values did not exceed the sampled grain size at the sample locations during the 1-year flood event; during a 2-year flood event, the critical grain size was exceeded at all but one of the cross-sections (Appendix B). Sediment samples in Reach 10 had moderately high armor and subarmor D_{50} values relative to other samples in the basin (Appendix B).

7.2.1.5 Riparian Conditions

The riparian zone contains mixed deciduous and conifer trees, many of which are mature and exceed 75 feet in height, and a relatively dense understory. The riparian zone is in good condition except for some local areas that have been cleared by natural processes (i.e., channel avulsions) or by anthropogenic influence. In some portions of the reach, there are many standing dead trees that appear to have been affected by disease; however, many of these trees are on the adjacent slopes and not within the riparian zone of the main channel.

7.2.1.6 Fish Habitat and Use

Reach 10 is an important reach for spring Chinook, steelhead, and bull trout. Spring Chinook spawn and rear in Reach 10 with a high density of juvenile rearing in the lower portion of Reach 10. Steelhead rearing and spawning also occurs in the reach. Reach 10 and the adjacent tributaries (especially Panjab Creek) are significant areas for bull trout spawning and rearing. Reach 10 has a relatively high amount of LWD compared to other reaches; however, the historic amount of wood was likely much higher prior to timber harvesting in the valley and riparian zone (Beckham 1995). LWD in the lower part of the reach is lacking; only small, transient LWD can accumulate in confined reaches of the channel with high transport capacity.

7.2.1.7 Restoration Strategies and Recommendations

The main restoration objective identified for Reach 10 in the EDT analysis was to increase pools and LWD to address the primary limiting factor of key habitat quantity; increasing riparian function was also identified for high restoration potential (Appendix J of CCD 2004). While this analysis did not quantify the number of habitat features such as pools, we did observe a lack of LWD in the reach. Natural processes and habitat are limited by confinement, lack of LWD, and riparian function. For Reach 10, recommendations for restoration activities identified through this study are summarized in Table 7-2.

Table 7-2
Restoration Recommendations for Reach 10

Restoration Framework Actions	Priority for This Reach	Recommendations
1. Protect and maintain natural processes	Lower-Medium	Limited to current forest management best management practices (BMPs) and riparian development.
2. Connect disconnected habitat	Medium	Evaluate the benefit of reconnecting wetlands and former mainstem and side channels near RM 47.5, 48.1, and 48.4 to 48.9.
3. Address roads, levees, other anthropogenic infrastructure impairing processes	Medium	Confining structures that significantly influence floodplain connectivity should be evaluated and removed or modified. Evaluate Tucannon Road near Tucannon Guard Station (between RM 43.9 and 45.2) for impacts to floodplain connectivity. Although the lakes, Camp Wooten, and the campground roads below the Camp downstream may pose significant impact to floodplain connectivity, it is assumed that it is not feasible to modify the levees or other infrastructure associated with these features. However, setting back or reconfiguring levees and lakes would increase the available floodplain area.

Restoration Framework Actions	Priority for This Reach	Recommendations
4. Restore riparian processes	Medium	Restore local riparian areas affected by anthropogenic activities in the lower reach downstream of Panjab Creek. Restore riparian areas lacking canopy cover due to disease.
5. Improve instream habitat conditions	High	In areas of reach confined by lakes where reconfiguring the lake's position is not possible, install LWD to force pools and maintain channel complexity.

7.2.2 Reach 9 – River Mile 40.0 to 44.0

7.2.2.1 Physical Description

Reach 9 is located from RM 44.0 near Big Four Lake to the hatchery dam at RM 40.0 (Figure D-9a). The reach spans the National Forest boundary at approximately RM 41.4. The portion of the main channel riparian zone from approximately RM 40.4 to 42.8 was moderately to severely burned in the 2005 School Fire, and all of the subbasins draining into Reach 9 were moderately to severely burned, including the Waterman Gulch and Big Four Canyon areas (Figure D-9a) (USFS 2008). The portion of the valley that was not burned is primarily conifer forest with sparse undergrowth. The burned zone has few remaining trees, little understory other than grasses, and burnt tree trunks (Photograph 7-2). Approximately half of the length of the reach is unconfined with the other half moderately confined (Appendix D). These conditions result in a reach that is relatively dynamic in terms of channel planform and migration.

Photograph 7-2

A Portion of the Valley Severely Burned in the School Fire Near RM 42.1

7.2.2.2 Hydrology

No major hydrologic inputs are present in Reach 9. Tributaries are small and steep, draining bedrock-dominated swales and the adjacent hillslopes (Figure 4). The increase in main channel discharge through this reach is minor; therefore, it was assumed that the 2-year flood discharge at the downstream end of Reach 9 is the same value used for Reach 10 at approximately 425 to 664 cfs (Appendix A).

7.2.2.3 Channel Patterns and Floodplain Connectivity

Reach 9 contains two unconfined reaches on the upstream and downstream ends of the reach, separated by a moderately confined section from RM 43.4 to 41.4 that is influenced by infrastructure (Figure D-9b). The primary channel pattern observed in confined areas in

Reach 9 is a single-thread, meandering channel with local braided sections. In the unconfined sections, the river is typically a series of long anabranch channels that are often separated by forested floodplain that is several feet above the elevation of the channel. Channel confinement is related to the road, the berms around Watson and Beaver Lakes, and to narrow portions of the valley created by alluvial fans and bedrock outcrops (e.g., RM 42.8). Historic channel migration patterns and extent could not be assessed due to lack of historic photo coverage.

Floodplain connectivity in Reach 9 is moderately impacted. Approximately 201 acres of low-lying floodplain area is present in the reach representing approximately 50 acres per mile (Appendix D). Approximately 16% of these areas are disconnected from the channel by infrastructure, isolating approximately 8.0 acres per mile thereby reducing the amount of available floodplain area and off-channel refuge habitat required by juveniles. This potentially represents a moderate impact to natural floodplain processes and juvenile rearing.

7.2.2.4 Sediment Inputs and Transport

Sediment inputs to Reach 9 are primarily from colluvial erosion and debris flows associated with bedrock swales, and some sediment development directly related to the School Fire (Appendix C). Although the estimated total input quantities for Reach 9 are relatively small, it is important to note that inputs due to mainstem channel migration could not be determined due to the lack of historic photo record. It can be assumed, however, that channel migration occurs in this reach and some sediment load is contributed from this source. Sediment transport calculations for Reach 9 indicate temporary sediment storage in many areas of the reach during the 1- and 2-year recurrence interval flows, consistent with noted areas of deposition from aerial photo and field observation (Appendix B). The critical grain size is exceeded throughout a majority of the reach by the 5-year event. The sediment samples in Reach 9 had the highest armor D_{50} and a high subarmor D_{50} with a large percentage of cobble and low percentage of sand despite fire damage within Reach 9 and in the surrounding subbasins and tributaries.

7.2.2.5 Riparian Conditions

Riparian conditions are poor due to the effects of the School Fire (Appendix D). Throughout much of this portion of the reach, the channel is exposed with little cover except for overhanging grasses and immature deciduous trees growing on the margins. In the unburned areas of the riparian zone, mature deciduous and conifer trees are present, although the density of vegetation is low in many places.

7.2.2.6 Fish Habitat and Use

The reach is important for steelhead and spring Chinook, particularly for steelhead rearing, and spring Chinook spawning and rearing. Reach 9 lacks LWD and hydraulic complexity in the confined portions of the reach. A moderate amount of LWD is present in the unconfined sections, most of which is present as a result of the severe burn of the riparian zone. Canopy cover is minimal and shading is poor.

7.2.2.7 Restoration Strategies and Recommendations

The restoration objectives identified for Reach 9 in the EDT analysis were to increase to address key habitat quantity and increase riparian function (Appendix J of CCD 2004). Because the riparian zone in Reach 9 has been severely affected by the School Fire, habitat quality in the reach would benefit from riparian restoration, although establishment of adequate canopy cover will be a long-term process.

Table 7-3
Restoration Recommendations for Reach 9

Restoration Framework Actions	Priority for This Reach	Recommendations
1. Protect and maintain natural processes	Medium	Limited to current forest management BMPs and riparian development; existing healthy riparian areas should be a medium priority because of the lack of shading provided in fire-affected areas.

Restoration Framework Actions	Priority for This Reach	Recommendations
2. Connect disconnected habitat	Medium	Reach 9 is relatively diverse with several secondary channels and off-channel areas that are likely accessible during high flows. However, the benefit of reconnecting wetlands and former mainstem and side channels near RM 42.6, 41.3, and 40.5 should be evaluated.
3. Address roads, levees, other anthropogenic infrastructure impairing processes	Medium	Confining structures that significantly influence floodplain connectivity should be evaluated and removed or modified. Evaluate Tucannon Road between RM 41.3 and 41.9) for impacts to floodplain connectivity. Removal or modification of the hatchery dam at the downstream end of Reach 9 was not considered because that structure is not believed to be a salmonid passage barrier.
4. Restore riparian processes	High	Aggressive restoration actions to improve riparian area affected by the School Fire.
5. Improve instream habitat conditions	High	In areas of reach lacking sufficient LWD, install LWD to force pools and maintain channel complexity.

7.2.3 Reach 8 – River Mile 32.1 to 40.0

7.2.3.1 Physical Description

Reach 8 is located from the hatchery dam just upstream of Rainbow Lake (RM 40.0) to RM 32.1 (Figure D-8a). The upstream end of the reach is approximately the downstream extent of the riparian zone severely burned by the School Fire, where changes in channel planform and confinement also occur. The valley in Reach 8 is occupied with wooded wetland and forested floodplain, while some farmsteads and fields are present up to the mouth of Cummings Creek at (RM 37.8) where the W.T. Wooten Wildlife Area begins (Figure D-8a). The Tumalum and Cummings Creek drainages were affected by the 2005 School Fire with the greatest impacts in the Cummings Creek basin (USFS 2008). The Hubbard fire near the Hartsock Grade subbasin (RM 33.5) burned 10,000 acres in 2010; however, the effects to the river and reach are unknown at the time of this study. A majority of Reach 8 is classified as moderately confined. The most confining features in the reach are pond/lake berms and road grades.

Photograph 7-3
A Braided Channel Section Adjacent to a Bedrock Valley Wall Near RM 34.0

7.2.3.2 Hydrology

Major hydrologic inputs within Reach 8 include Cummings and Tumalum Creeks, which add approximately 30% and 10% increases to the mainstem discharge at their confluence points, respectively (Appendix A). With the contributions of Cummings and Tumalum Creeks, the discharge of the main channel at the downstream end of the reach is approximately 74% of the total discharge at the Tucannon River's mouth during the 2-year recurrence event. The 2-year recurrence discharge at the downstream end of Reach 8 is approximately 604 to 943 cfs (Appendix A). The upper watersheds of these tributary subbasins are relatively high in elevation and receive a significantly higher average annual rainfall than tributaries in other reaches; therefore, the contribution of these watersheds to peak flows in the main river channel will vary depending on the season and the catalyst for the flood event (e.g., rain on snow versus snowmelt).

7.2.3.3 Channel Patterns and Floodplain Connectivity

The primary channel pattern identified within this reach is a single-thread, meandering channel. Some small sections with braiding or side channels are present. Several former side channels and former mainstem channels are visible in the adjacent floodplain (Figure D-8b). Confinement is sporadic and primarily associated with roadways and levees protecting significant anthropogenic infrastructure such as Rainbow Lake (RM 39.5), the adjacent hatchery, and Spring Lake (RM 37.8). This has resulted in some significantly confined areas from RM 39.1 to RM 40 and near the confluence with Cummings Creek.

Floodplain connectivity in Reach 8 is highly impacted. Approximately 379 acres of low-lying floodplain area is present in the reach representing approximately 48 acres per mile (Appendix D). Approximately 24% of these areas are disconnected from the main channel by infrastructure, isolating approximately 11.3 acres per mile thereby reducing the amount of accessible floodplain area and off-channel refuge habitat required by juveniles. This represents the third highest impact per mile to natural processes and juvenile rearing in the river.

7.2.3.4 Sediment Inputs and Transport

Sediment inputs in Reach 8 are primarily from mainstem channel migration and colluvial erosion and debris flows associated with bedrock swales, although land use and sediment associated with the School Fire inputs also impact the reach to a lesser degree. Sediment transport calculations for Reach 8 indicate temporary sediment storage in much of the reach during the 1-year recurrence interval flow, and mobility throughout the reach at the 2-year event (Appendix B). Sediment storage areas identified in the reach are consistent with reductions in critical grain size observed in the sediment mobility calculations. The average D_{50} size of armor and subarmor in Reach 8 is relatively small. A small amount of fine sediment was present in a subarmor sample taken downstream of Tumalum Creek, which was an exception to all but one of the upper watershed samples (Appendix B). This is likely the result of loading of fines and sand from burned areas in the Tumalum and Cummings Creek subbasins.

7.2.3.5 Riparian Conditions

Riparian conditions in Reach 8 are relatively well developed except for some local sections within the reach that lack mature trees or density of vegetation. In general, the riparian corridor is wide (on the order of 400 or more feet) and includes mature trees greater than 75 feet in height (Appendix D). This is not the case between RM 33.2 and 34.3 where there are few trees greater than 75 feet, and between RM 34.3 and 35.6 where the riparian corridor has very little vegetation other than sparse shrubs and moderately mature trees (Appendix D, Figure D-8a). Upstream of Tumalum Creek, the density of the riparian vegetation increases and greater quantities of trees exceeding 75 feet in height are present. Riparian vegetation patterns in the historic photos appear to be fairly similar to current conditions throughout Reach 8.

7.2.3.6 Fish Habitat and Use

Reach 8 is used by steelhead and spring Chinook for spawning and rearing habitat. A high density of steelhead rearing and spring Chinook spawning and rearing occurs in the reach, and the lower portion of the reach is particularly important for juvenile rearing of both species, as well as for steelhead spawning. The reach is likely only used by bull trout during migration periods. Although Reach 8 has some areas of channel complexity and sediment deposition, minimal LWD was observed during site reconnaissance or in aerial photos. In these upper reaches of the river where the historic floodplain was more forested, historic wood loading was likely much greater than the current condition.

7.2.3.7 Restoration Strategies and Recommendations

The primary restoration objectives identified for Reach 8 in the EDT analysis were to increase pools and bed scour to address the primary limiting factor of key habitat quantity (Appendix J of CCD 2004). These objectives aim to promote high-quality pools with cooler temperatures and cover. While LWD addition was not considered in the reach for the EDT analysis, our evaluation determined that stable LWD is insufficient and is, therefore, an important restoration strategy for Reach 8.

Table 7-4
Restoration Recommendations for Reach 8

Restoration Framework Actions	Priority for This Reach	Recommendations
1. Protect and maintain natural processes	Lower	Limited to current forest management BMPs and riparian development; while not necessarily associated with natural processes, it is assumed that Spring Lake, Rainbow Lake, and the hatchery area will also be targeted for protection.
2. Connect disconnected habitat	High	The floodplain in Reach 8 contains many opportunities to reconnect wetlands and former mainstem and side channels. The most prominent of these are located near RM 38.6, 37.5, and 36.7 to 39.0. These areas should be evaluated to determine to potential benefit of reconnection.
3. Address roads, levees, other anthropogenic infrastructure impairing processes	High	Confining structures that significantly influence floodplain connectivity should be evaluated and removed or modified. The most significant confinement and constriction areas are between 39.1 and 40, and at the Tucannon Road crossing at the confluence of Cummings Creek. We recognize that many of the confining structures are providing protection for vital anthropogenic infrastructure. We suggest careful consideration be given to bridge spans and approach areas when highway improvements occur.
4. Restore riparian processes	Lower	Restore riparian conditions where vegetation is degraded, in particular between RM 33.2 and 34.3 and between RM 34.3 and 35.6.
5. Improve instream habitat conditions	High	In areas of reach lacking sufficient LWD, install LWD to force pools and maintain channel complexity.

7.2.4 Reach 7 – River Mile 27.5 to 32.1

7.2.4.1 Physical Description

Reach 7 is located from just upstream of the Tucannon Road crossing at RM 32.1 to RM 27.5 at Marengo (Figure D-7a). Land use in the valley is almost entirely pastures and hay fields up to the riparian limits. Reach 7 has a high amount of confinement and only a moderate amount of visible infrastructure as much of the confinement is due to the position of the river along the bedrock valley walls. A majority of confinement is due to anthropogenic features such as road grades, constrictions at bridges, and some levees.

Photograph 7-4

A Meander Bend Against the Bedrock Valley Wall Near RM 27.9

7.2.4.2 Hydrology

No major hydrologic inputs drain into this reach, and the valley walls are lined with steep, narrow bedrock drainages, many of which empty directly into the channel. Because the Marengo gage is located in this reach, we were able to estimate that these drainages contribute approximately 9% to the discharge at the gage location (Appendix A). At the Marengo gage location, approximately 81% of the total mainstem discharge at the mouth is present at a 2-year recurrence event. The 2-year recurrence discharge at the downstream end of the reach is approximately 659 to 1,029 cfs (Appendix A).

7.2.4.3 Channel Patterns and Floodplain Connectivity

Throughout a majority of Reach 7, the primary channel pattern is a confined, single-thread channel that is aligned closely with the bedrock valley wall. The channel is relatively straight, channelized, and lacks complexity. The floodplain has likely been graded and smoothed out such that very few remnant channel patterns are visible in the floodplain topography (Figure D-7b). The river crosses the valley four times, interacting with the roadway in each location where it is confined by road crossings and the levees and bank protection associated with the bridge approaches. The length of the mainstem alignment through Reach 7 is approximately half confined and half unconfined (Appendix D). Throughout the historic photo record, the channel has stayed in the same position, except for the section of the reach located just downstream of the bridge crossing at RM 31.8. This moderately confined section is where most of the channel migration observed in the historic photo record has occurred. Some minor change has occurred between RM 28.5 to 29.2, although it appears some grading and encroachment of the floodplain has occurred since that time and the river is likely confined at the present.

Floodplain connectivity in Reach 7 is highly impacted. Approximately 156 acres of low-lying floodplain area is present in the reach representing approximately 34 acres per mile (Appendix D). Approximately 25% of these areas are disconnected from the main channel by infrastructure, isolating approximately 8.4 acres per mile and thereby reducing the amount of accessible floodplain area and off-channel refuge habitat required by juveniles. This represents a moderate to high impact to natural processes and juvenile rearing through the reach compared to other reaches. It is important to note that this calculation does not take into account the amount of floodplain that has been impacted by floodplain grading for agriculture and channelization of the mainstem. While there is 25% low floodplain currently cut off from the channel, more low floodplain area may have existed in the past that no longer represents a potential restoration opportunity.

7.2.4.4 Sediment Inputs and Transport

Although no major subbasins are located entirely within Reach 7, sediment inputs can be estimated from looking at the results for the Hartsock Grade-Tucannon River subbasin. This subbasin had one of the lowest sediment contributions per year (Appendix C). The largest sediment contribution is attributed to mainstem channel migration, with land use and colluvial erosion and debris flows from bedrock swales contributing minor amounts of sediment. Sediment transport calculations for Reach 7 indicate that this reach primarily transports sediment with little opportunity for temporary storage (Appendix B). Reach 7 produced the highest and most consistent results with respect to the low variability of critical grain size results. About half of the cross-sections in the reach may mobilize sediment during the 1-year recurrence event, with all but two cross-sections indicating motion during the 2-year event (Appendix B). The sediment samples taken in Reach 7 were very different from one another. The sample taken from the lower reach had a very high percentage of cobble and no sand or fines; this sample had the highest subarmor D_{50} of all the sample locations and exceeded the armor D_{50}. The sample from the upper reach had a much lower subarmor D_{50} and included a moderate amount of cobble, gravel, and sand with no fines. The may be the result of local influences of channel confinement.

7.2.4.5 Riparian Conditions

The riparian corridor in Reach 7 is narrow, although the vegetative cover is relatively dense when compared to downstream reaches. Most riparian trees are in the range of 50 to 75 feet; however, there is a greater density of trees taller than 75 feet than in downstream reaches (Appendix D). The most diverse and mature riparian conditions in Reach 7 are between RM 28.8 and 29.1, and between 30.4 and 30.9. The most degraded riparian areas generally have dense understory but lack mature trees; these areas are between RM 29.1 and 29.9, RM 30.1 and 30.3, and RN 31.1 to 31.3. The extent of riparian vegetation in historical photos is similar to current conditions although it appears to be less dense than current conditions. Some grading and clearing of riparian areas appears to have occurred after the 1950s, most notably around RM 28.5.

7.2.4.6 Fish Habitat and Use

A high density of juvenile rearing of both steelhead and spring Chinook occurs in Reach 7. The reach is also significant for steelhead spawning and is also used by spring Chinook for spawning; spring Chinook also use Reach 7 for adult holding. Migratory bull trout likely only pass through this reach during migration. Reach 7 is primarily confined to a narrow floodplain with a straight, simplified channel and with little complexity or capability of accumulating LWD.

7.2.4.7 Restoration Strategies and Recommendations

The primary restoration objectives identified for Reach 7 in the EDT analysis were to increase pools and bed scour to address the primary limiting factor of key habitat quantity (Appendix J of CCD 2004). These objectives aim to establish high-quality pools with cooler temperatures and cover. Reach 7 is a highly confined reach with a narrow floodplain and riparian zone; the channel is simplified with little hydraulic complexity and the high transport capacity prevents sufficient woody debris from being present. While it is difficult to be certain, many areas through this reach appear to have been dredged and channelized for agricultural purposes. In these areas, restoration opportunities are limited because there is little low floodplain area.

Table 7-5
Restoration Recommendations for Reach 7

Restoration Framework Actions	Priority for This Reach	Recommendations
1. Protect and maintain natural processes	Lower	Healthy riparian areas that should be protected are located between RM 28.8 and 29.1, and between 30.4 and 30.9.
2. Connect disconnected habitat	Medium	The reach has limited opportunities to reconnect wetlands and former mainstem and side channels. Potential areas to be evaluated for restoration benefit are located near RM 28.6, and 31.7.

Restoration Framework Actions	Priority for This Reach	Recommendations
3. Address roads, levees, other anthropogenic infrastructure impairing processes	High	Throughout most of the reach, the road is located along the valley margin outside of the floodplain. We suggest careful consideration be given to bridge spans and approach areas when highway improvements occur, as many crossings appear to constrict the channel. In addition, there appears to be two roadway realignments that would significantly remove the roadway from the floodplain; RM 27.5 to 28.3 and 30.3 to 31.
4. Restore riparian processes	Medium	Restore riparian conditions where vegetation is degraded, in particular between RM 29.1 and 29.9, and 30.1 and 30.3.
5. Improve instream habitat conditions	High	In confined, channelized sections and sections of the reach lacking sufficient LWD, install LWD to force pools and maintain channel complexity.

7.2.5 Reach 6 – River Mile 20.0 to 27.5

7.2.5.1 Physical Description

Reach 6 is located from approximately 0.5 miles upstream of the Turner Road/Marengo Bridge crossing (RM 27.5) to RM 20.0 (Figure D-6a). The valley is primarily occupied by pastures but has large herbaceous, wetland, and forested riparian areas compared to downstream reaches. The reach is relatively unconfined with a moderate amount of anthropogenic infrastructure, except for a small confined area near RM 25.5. Levees and other hydro-modifications are generally concentrated to small areas, whereas a majority of the reach has little to no apparent confinement.

Photograph 7-5

Large Woody Debris in an Unconfined, Braided Channel Section Near RM 21.6

7.2.5.2 Hydrology

No major hydrologic inputs drain into Reach 6. The valley walls are lined with steep, narrow north-south trending bedrock drainages. The increase in main channel discharge through this reach is minor; therefore, it was assumed that the 2-year flood discharge at the downstream end of the reach is the same as Reach 7 at approximately 659 to 1,029 cfs (Appendix A).

7.2.5.3 Channel Patterns and Floodplain Connectivity

Reach 6 contains a mix of unconfined, complex multi-thread channels in the lower half of the reach from approximately RM 20 to 25, and contains a mostly single-thread meandering channel in the upper end of the reach to RM 27.5 (Figure D-6b). Depositional areas downstream of confined sections of the river are present near RM 21.7, 25.3, and 26.5. In the lower portion of the reach, the channel has migrated within the 300- to 400-foot floodplain corridor throughout the historic photo record. Although some steady migration likely occurs, it appears that relatively long anabranch channels created during avulsions are common in this part of the river. In the upper reach adjacent to Marengo, the available floodplain is narrower where the channel is pinned against the southern bedrock valley wall or where it is encroached on by developed fields. However, only 5% of Reach 6 is categorized as confined (Appendix D).

Floodplain connectivity in Reach 6 is moderately impacted. Approximately 567 acres of low-lying floodplain area is present in the reach representing approximately 76 acres per mile (Appendix D). This represents the largest potential area of available floodplain habitat in the study area. Approximately 18% of these areas are disconnected from the channel by infrastructure, isolating approximately 13.5 acres per mile and thereby reducing the amount of accessible floodplain area and off-channel refuge habitat required by juveniles. This represents a high impact to natural processes and juvenile rearing throughout the reach. This reach, along with Reach 2, has the highest restoration potential with respect to area of low floodplain per mile available for reconnection.

7.2.5.4 Sediment Inputs and Transport

The greatest volume of sediment contributed into Reach 6 is from mainstem channel migration, with land use contributing a low to moderate amount of fine sediment (Appendix C). Sediment transport calculations for Reach 6 indicate sediment may be mobilized for most cross-sections in the upper part of the reach during a 1-year recurrence interval, with more temporary storage in the lower part of the reach (Appendix B). A majority of bedload material is mobile by the 2-year and greater recurrence intervals throughout the reach. Sediment samples obtained in Reach 6 showed variable grain size distributions. The sample taken from the lower reach had a moderate subarmor and armor D_{50} grain size with a moderate amount of cobble and gravel, and a low percentage of sand and fines. The sample taken from the upper reach had a very high percentage of cobble and low sand and fines, translating to a high subarmor and armor D_{50}.

7.2.5.5 Riparian Conditions

The riparian corridor in Reach 6 is relatively wide; in many sections of the reach, it averages approximately 400 feet across. A majority of riparian trees in Reach 6 are greater than 50 feet tall with some patches of taller vegetation greater than 75 feet (Appendix D). The most diverse and mature riparian conditions based on density and canopy height are located between RM 22.1 and 25.0. The least developed riparian area is located between RM 25.8 and 26.4. This area is located in a low-lying, unconfined section of the river that appears to have frequent disruption due to flooding. The extent of riparian vegetation in historical photos is similar to current conditions, indicating less clearing than in downstream reaches. A few locations, in particular between RM 20 and 21, have been cleared and graded for agricultural use since the 1950s.

7.2.5.6 Fish Habitat and Use

Reach 6 is within the downstream extent of the area used by spring Chinook for spawning, rearing, and holding. The reach is used extensively by steelhead for spawning and juvenile rearing. Migratory bull trout likely only use this reach during migration periods. In general, Reach 6 has a relatively high level of complexity due to multiple side channels, gravel bars, and other bedforms where LWD is able to accumulate. The relatively good riparian conditions allow local recruitment of riparian trees where the channel migrates through the floodplain.

7.2.5.7 Restoration Strategies and Recommendations

The primary restoration objectives identified for Reach 6 in the EDT analysis were to increase pools, LWD, and bed scour to address the primary limiting factor of key habitat quantity, as well as to lower water temperatures (Appendix J of CCD 2004). These objectives aim to result in high-quality pools with cooler temperatures and cover. Channel conditions in Reach 6 appear to be relatively well-functioning, although it is understood that the reach generally lacks LWD.

Table 7-6
Restoration Recommendations for Reach 6

Restoration Framework Actions	Priority for This Reach	Recommendations
1. Protect and maintain natural processes	Medium	Healthy riparian areas in Reach 6, including an approximately 3-mile length between RM 22.1 and 25.0 should be protected. The dynamic nature of channel migration in Reach 6 combined with the relatively high amount of mature vegetation provides opportunity for riparian recruitment and self-sustaining natural processes in the long term.
2. Connect disconnected habitat	High	The reach appears to have several opportunities to reconnect large areas of wetlands and former mainstem and side channels, including near RM 24.8, 24.3, and 22.8.
3. Address roads, levees, other anthropogenic infrastructure impairing processes	Medium	Throughout most of the reach, the road is located outside of the floodplain or up on the hillside. Some levees are present and appear to isolate floodplain and potential side channel habitat; the most significant of these locations is near RM 25.4.
4. Restore riparian processes	Lower	A majority of the riparian area in Reach 6, although not ideal, is relatively healthy compared to other reaches. The most degraded riparian area in Reach 6 is between RM 25.8 and 26.4; this area may be evaluated for restoration benefit.
5. Improve instream habitat conditions	High	In areas of the reach lacking sufficient LWD, install LWD to force pools and maintain channel complexity.

Based on recommendations provided in the TSP, our site reconnaissance, and evaluation of available data, the primary restoration actions for the reach are improving instream habitat conditions and reconnecting disconnected habitats. Removing confining structures that significantly influence floodplain connectivity should be evaluated to determine the benefits of the action. Improving riparian protection and development is recommended to meet long-term goals.

7.2.6 Reach 5 – River Mile 13.2 to 20.0

7.2.6.1 Physical Description

Reach 5 is located from the upstream extent of the heavily modified agricultural portion of the Tucannon valley near RM 20.0, to just upstream of the mouth of Pataha Creek (RM 13.2) (Figure D-5a). The valley is mainly occupied by pastures with mostly narrow, discontinuous riparian areas. The reach is made up of alternating confined transport sections and moderately confined depositional sections. Reach 5 includes Tucannon Falls at RM 16.5.

Photograph 7-6

Stone Riprap at the Toe of a Levee Near RM 18.7

7.2.6.2 Hydrology

Willow Creek is the major hydrologic input that drains into this reach, which adds approximately 1% to the total mainstem discharge at its confluence with the Tucannon River (Appendix A). This 1% estimate may be low and an artifact of the hydrologic calculation process, although the Willow Creek watershed is not located in upper elevations and does not receive a high amount of annual precipitation and therefore does not contribute a significant amount of discharge due to snowmelt or rain-on-snow compared to tributaries in the upper basin. With the contribution of Willow Creek, approximately 82% of the total main channel discharge is present at the downstream extent of Reach 5 at a 2-year recurrence discharge. The 2-year recurrence discharge at the downstream end of Reach 5 is approximately 787 to 1,041 cfs (Appendix A).

7.2.6.3 Channel Patterns and Floodplain Connectivity

The primary channel pattern observed in historic photographs through Reach 5 is a single-thread meandering channel (Figure D-5a). Present day conditions are a mix of unconfined, meandering segments and straight, confined segments where confinement appears to be the result of levees, road placements, and channelization (Figure D-5b). In general, the confined sections in Reach 5 are created by levees that pin the river up against bedrock valley walls. Within these sections, the channel is channelized with little planform complexity; in some locations it is disconnected from floodplain features such as former channel positions. The moderately confined and unconfined sections located downstream from tightly confined portions of the channel are typically response reaches, where sediment transported through the confined channel is deposited where the floodplain opens up and channel velocities decrease. These portions of the channel are typically braided with several unvegetated or slightly vegetated gravel bars. The most prominent of these transitions are located at RM 18.5 and RM 15.1 near the mouth of Willow Creek.

Observation of historic aerial photos and channel positions indicates that a large amount of the floodplain has been graded and converted to agricultural land use. Most confined sections appear to have been confined throughout the historic photo record; however, many of the unconfined and moderately confined sections have been modified by the installation of levees and other infrastructure since the 1950s, and to a lesser degree since the 1970s.

Floodplain connectivity in Reach 5 is moderately impacted. Approximately 325 acres of low-lying floodplain area is present in the reach representing approximately 48 acres per mile (Appendix D). Approximately 20% of these areas are disconnected from the main channel by infrastructure, isolating approximately 9.4 acres per mile thereby reducing the amount of accessible floodplain area and off-channel refuge habitat required by juveniles. In addition, many of the confined lengths of the river appear to have been dredged and channelized in the past (others may be naturally confined by alluvial fan deposits). More low-lying floodplain areas may have existed in the past that no longer represent a potential restoration opportunity without increasing the bed elevation of the river. However, current conditions represent a moderate to high impact to natural processes and juvenile rearing through the reach.

7.2.6.4 Sediment Inputs and Transport

Sediment contributed by the subbasins draining into Reach 5 is variable in size depending on the source. Fine sediments are delivered primarily by Willow Creek, and colluvial erosion and debris flows from bedrock swales provides larger clast sizes. Sediment delivery also occurs via channel migration through much of the reach. Sediment transport calculations for Reach 5 display a wide range of variation of critical grain sizes (Appendix B). This is indicative of alternative zones of confinement and areas of temporary sediment storage. During a 1-year recurrence interval, the reach displays a mix of transport and temporary storage areas. A majority of bedload material is mobile by the 2-year and greater recurrence intervals throughout the reach (Appendix B). Reach 5 has a low percentage of fines, sand, and cobble and the highest percentage of gravel of all the sediment samples throughout the basin. The armor D_{50} is still comparable to downstream reaches.

7.2.6.5 Riparian Conditions

Riparian conditions in Reach 5 are typically characterized by moderately wide strips of vegetation with low density of mature growth in confined sections, while less confined sections have more diverse and mature riparian development. Confined floodplain in Reach 5 has a narrow riparian corridor on the order of 100 to 150 feet. There are typically few trees greater than 50 feet, and some locations with no mature vegetation on one or both banks

(Appendix D). Two approximately 1-mile-long sections with degraded riparian conditions are present in Reach 5, located from RM 18.8 to 19.7, and from RM 13.4 to 14.4. Unconfined and moderately confined floodplain in Reach 5 contains many trees between 50 and 75 feet tall, and some patches of tall trees greater than 75 feet. The most diverse and mature riparian conditions based on density and canopy height are located between RM 15.1 to 16.0.

7.2.6.6 Fish Habitat and Use

Reach 5 is an important part of the basin for steelhead spawning and juvenile rearing. Spring Chinook use the reach for adult holding. Migratory bull trout use Reach 5 during migration periods. Fall Chinook have been known to use Reach 5 for spawning but their documented presence is not common. The reach lacks woody debris and bedform complexity in the confined reaches; the channel is simplified, channelized, and has a high-transport capacity to move wood and sediment downstream. The moderately confined reaches have some localized woody debris accumulations associated with braided sections of the channel and some stable log jams likely exist but their numbers are low compared to historic conditions. Tucannon Falls was identified as a fish passage obstruction in the TSP; however, the degree to which it affects passage of salmonids was not evaluated as part of this study.

7.2.6.7 Restoration Strategies and Recommendations

The primary restoration objectives identified for Reach 5 in the EDT analysis were to increase pools, LWD, and bed scour to address the primary limiting factor of key habitat quantity; as well as lower water temperatures and increase riparian function (Appendix J of CCD 2004).

These objectives aim to result in high-quality pools with cooler temperatures and cover. Reach 5 has been significantly modified by anthropogenic activities; restoration strategies for the reach should focus on addressing those impacts. Levee removal or setbacks and reconnection of disconnected habitats and former side or main channels that have been cut off from the main channel will greatly increase the ability of the channel to temporarily store sediment and wood. Fish passage improvement at Tucannon Falls was not considered because that feature is not believed to be a salmonid passage barrier.

Table 7-7
Restoration Recommendations for Reach 5

Restoration Framework Actions	Priority for This Reach	Recommendations
1. Protect and maintain natural processes	Lower	Protecting and maintaining natural processes should occur from approximately RM 17.5 to 18.5 where the channel is mostly unconfined and the channel and floodplain processes presently occurring are providing high value. In addition, the area near the mouth of Willow Creek should be considered for protection.
2. Connect disconnected habitat	Medium	Reach 5 has limited opportunities to reconnect wetlands and former mainstem and side channels. The most significant area identified is near RM 15.8; this location should be evaluated for potential benefit.
3. Address roads, levees, other anthropogenic infrastructure impairing processes	High	Through most of the reach the road is located outside of the floodplain or up on the hillside. Several levees are present that appear to limit the available floodplain and potential side channel habitat; the most significant of these locations are near RM 14.4 and RM 16.7.
4. Restore riparian processes	Medium	Restore riparian conditions where vegetation is degraded, in particular between RM 18.8 to 19.7, and from RM 13.4 to 14.4.
5. Improve instream habitat conditions	High	In confined, channelized sections and sections of the reach lacking sufficient LWD, install LWD to force pools and maintain channel complexity.

7.2.7 Reach 4 – River Mile 8.9 to 13.2

7.2.7.1 Physical Description

Reach 4 is located from just upstream of the mouth of Pataha Creek (RM 13.2) to the mouth of Smith Hollow (RM 8.9; Figure D-4a). The valley is occupied mostly by grazing pasture and hay fields with a relatively wide riparian corridor compared to other reaches in the lower basin. A narrow, confined section is present between RM 10.8 and 11.5 with riparian and channel conditions that are uncharacteristic of the rest of Reach 4. The main channel in Reach 4 is typically moderately confined to unconfined. Confining features include road grades, encroachment of agricultural lands, and hardened banks.

Photograph 7-7

A Rock Weir in Confined Section Near RM 11.4

7.2.7.2 Hydrology

Pataha Creek, the largest subbasin to the Tucannon River, drains into Reach 4 at approximately RM 12.3. The basin area of Pataha Creek is approximately 37% of the total area of the Tucannon watershed. Pataha Creek is a perennial channel with several ephemeral and perennial tributaries, some of which are groundwater-dominated, such as Bihamier Springs. It is important to note that this contribution is much less than would be expected based on a similar basin size. This is further explained and supported in Appendix A of this report. Pataha Creek contributes approximately 12% of the total mainstem discharge at its confluence with the Tucannon River during a 2-year recurrence event (Appendix A). The 2-year recurrence discharge at the downstream end of Reach 4 is approximately 1,140 to 1,171 cfs.

7.2.7.3 Channel Patterns and Floodplain Connectivity

The primary channel pattern through the reach is a single-thread meandering channel. Two river segments diverge from those characteristics; RM 11.5 to 10.4 has a single-thread channel with a straight, channelized planform, and downstream of RM 10.4, the channel is highly dynamic and meandering with several side channels, unvegetated bars, and forested islands.

The upper portion of the reach from RM 13.2 to 11.5 is moderately confined to unconfined with evidence of deposition, particularly near the mouth of Pataha Creek and at the downstream end of this section. There is some confinement due to encroachment of agricultural fields and some hardened banks; however, the available floodplain is wide enough that the channel is able to migrate within it (Figure D-4b). From RM 11.5 to 10.9, the channel is confined between a levee and what is presumed to be a former railroad grade that limits migration and sediment deposition and storage. Downstream of RM 10.9, the floodplain is confined by a natural narrowing of the valley, but it does not appear to be constricted by anthropogenic features. Downstream of RM 10.4 the valley becomes wide and unconfined.

Floodplain connectivity in Reach 4 is moderately impacted. Approximately 217 acres of low-lying floodplain area is present in the reach representing approximately 51 acres per mile (Appendix D). Approximately 17% of these areas are disconnected from the main channel by infrastructure, isolating approximately 8.6 acres per mile thereby reducing the amount of accessible floodplain area and off-channel refuge habitat required by juveniles. This represents a moderate impact to natural processes and juvenile rearing through the reach.

7.2.7.4 Sediment Inputs and Transport

The greatest contributor of sediment by the subbasins associated with Reach 4 is channel incision from Pataha Creek; this material is nearly all suspended load that is easily transported downstream out of the reach (Appendix C). Land use and eroded materials from bedrock swales are lesser sources of sediment. Sediment transport capacity is variable and roughly related to channel confinement (Appendix B). Less than half of the cross-sections meet the critical grain size threshold during the 1-year event, although a majority exceed the threshold during the 2-year recurrence interval flood. The cross-sections that indicate temporary storage of sediment are associated with the unconfined areas at the downstream and upstream end of the reaches, respectively. Results from modeled 5-year and greater flood events indicate sediment mobility for all but one of the cross-sections. Reach 4 has a relatively low percentage of cobble and the highest percentage of sand compared to other reaches, most likely due to deposition of materials from the loess-dominated Pataha Creek basin (Appendix B). Some finer material contributed from the Pataha Creek basin may also be the effect of the School Fire, which burned areas of the upper basin. The relative size of armor D_{50} is the second-lowest of all the reaches evaluated.

7.2.7.5 Riparian Conditions

Riparian conditions in Reach 4 can be related to the relative amount of channel confinement; unconfined areas typically have wider, denser riparian zones and confined areas have restricted riparian zones with limited maturity. Dense clumps of trees near RM 13 and between RM 8.9 and RM 10 offer the most diverse and mature riparian conditions in Reach 4. These areas contain many trees greater than 50 feet tall, as well as some trees greater than 75 feet (Appendix D). The more degraded riparian conditions in Reach 4 are between RM 10.9 and RM 11.5 where the channel is highly confined and there are only a few riparian trees greater than 50 feet tall. Historically, the riparian zone was cleared throughout much of the reach, although the unconfined area between RM 8.9 and RM 10.0 does not appear to have been cleared.

7.2.7.6 Fish Habitat and Use

Reach 4 is used for steelhead spawning and rearing, but the density of steelhead redds and presence of juveniles is typically low downstream of Pataha Creek. Spring Chinook and bull trout use this reach during migration periods, perhaps most importantly during out-migration for juveniles. Reach 4 is important for fall Chinook as the reach is used for spawning and rearing. A moderate amount of LWD is present in the unconfined section at the downstream end of Reach 4 where riparian trees have been undercut by channel migration and fallen into the channel. The confined channel downstream of Pataha Creek lacks complexity due to channelization and the absence of substantial woody debris or stable log jams.

7.2.7.7 Restoration Strategies and Recommendations

The primary restoration objectives identified for Reach 4 in the EDT analysis were reduction of water temperatures and fine sediment load (Appendix J of CCD 2004). A majority of Reach 4 is limited by channelization and levee construction. Therefore, restoration strategies for the reach should focus on addressing floodplain confinement and decreasing temperatures by adding instream channel complexity and off-channel habitat.

Table 7-8
Restoration Recommendations for Reach 4

Restoration Framework Actions	Priority for This Reach	Recommendations
1. Protect and maintain natural processes	Medium	Protecting and maintaining natural processes should occur from approximately RM 9.0 to 10.8 and near 11.7 where the channel is mostly unconfined and the channel and floodplain processes presently occurring are providing high value.
2. Connect disconnected habitat	Lower	Disconnected habitats are generally not present, although further evaluation is required to confirm.
3. Address roads, levees, other anthropogenic infrastructure impairing processes	High	Anthropogenic infrastructure impairing natural processes is primarily associated with the levee extending from approximately RM 10.8 to 11.5. Setting back this levee should be evaluated as to its potential benefit.
4. Restore riparian processes	Medium	Restore riparian conditions where vegetation is degraded, in particular between RM 10.9 and RM 11.5 where the floodplain is highly confined.
5. Improve instream habitat conditions	High	In the confined reach and in sections of the reach lacking sufficient LWD, install LWD to force pools and maintain channel complexity.

7.2.8 Reach 3 – River Mile 4.5 to 8.9

7.2.8.1 Physical Description

Reach 3 is located from downstream end of the town of Starbuck (RM 4.5) to the mouth of Smith Hollow (RM 8.9; Figure D-3a). Land use in the valley is primarily grazing and hay pasture with a narrow riparian zone. The channel is highly confined by anthropogenic infrastructure, with several channel and bank modifications. Reach 3 includes the Starbuck Dam near RM 5.5.

Photograph 7-8

The Channel Confined Between the Starbuck Levee and the Bedrock Valley Wall Near RM 4.6

7.2.8.2 Hydrology

Major hydrologic inputs within Reach 3 include Smith Hollow and Kellogg Creeks, which add approximately 1% and 8% increases to the mainstem discharge at their confluence points, respectively (Appendix A). The proportion of discharge contributed to the main channel by these tributaries may be an underestimate due to uncertainty in the hydrology data used to determine tributary hydrology. With the contributions of these tributaries, the discharge of the main channel at the downstream end of the reach is approximately 100% of the total discharge at the Tucannon River's mouth during the 2-year recurrence event (no appreciable tributary inputs are expected between Kellogg Creek and the mouth of the river). The 2-year recurrence discharge at the downstream end of Reach 3 is approximately 1,275 cfs (Appendix A).

7.2.8.3 Channel Patterns and Floodplain Connectivity

The channel throughout Reach 3 is a highly confined, single-thread channel that follows the geometry of confining features, rather than meandering throughout its floodplain. The river is tightly confined between the southern bedrock valley wall and levees throughout a large majority of the reach. Between approximately RM 8.1 to 8.9 the river is also confined by the naturally narrow width of the valley and the Smith Hollow alluvial fan. The river is relatively channelized with little accessible floodplain; a majority of low areas are disconnected from the channel by levees. Historic photographs indicate the channel had more of a braided planform than in the present, but has remained against adjacent to the southern valley wall throughout the historic record.

Floodplain connectivity in Reach 3 is highly impacted, but the potential for floodplain connectivity opportunities may be limited due to the close proximity of infrastructure and developed areas. Approximately 89 acres of low-lying floodplain area is present in the reach representing approximately 20 acres per mile, the lowest value for any reach by approximately 14 acres per mile (Appendix D). Approximately 27% of these areas are disconnected from the main channel by infrastructure isolating approximately 5.5 acres per mile. Although Reach 3 is confined by levees throughout a majority of its length, only 13% of the valley area is low-lying. Therefore, the levees represent a moderate impact to natural processes and juvenile rearing through the reach even though the percent of disconnected channel is relatively high.

7.2.8.4 Sediment Inputs and Transport

The most significant sediment sources contributed by the subbasins in Reach 3 are channel incision (mainly from Smith Hollow), colluvial erosion and debris flows from bedrock swales, and mainstem channel migration, which is likely historic and no longer impacting the channel (Appendix C). Sediment transport capacity is generally high, likely due to increased velocities in the channelized river that create ideal conditions for mobilizing and transporting sediment (Appendix B). The critical grain size during the 1-year event is greater than the sample size D_{50} for almost all of the modeled cross-sections in the reach. The critical grain size exceeds the sample size for all the cross-sections during the 2-year recurrence interval and greater events (Appendix B).

7.2.8.5 Riparian Conditions

The riparian corridor throughout most of Reach 3 is a narrow strip approximately 100 feet wide with moderately dense deciduous growth, a majority of which is less than 50 feet in height (Appendix D). Between RM 6.6 and 7.9, the riparian zone is slightly wider (on the order of 300 feet) with a greater density of mature trees. Some areas of the reach have no mature canopy, the longest of these sections being approximately 0.5 miles long. A majority of the riparian zone had been cleared in the 1950s, with regeneration occurring by the 1970s.

7.2.8.6 Fish Habitat and Use

Reach 3 is within the downstream extent of the mainstem area used by steelhead for spawning and rearing. The reach is used by spring Chinook and bull trout as a migratory corridor. Reach 3 is significant for fall Chinook as high densities of fall Chinook redds have been found within this reach. The reach contains little LWD as observed from aerial photos and site reconnaissance, and it is unlikely that any stable log jams exist in this reach as the confined channel has a high transport capacity to move wood throughout the reach. Mobile wood caught up on the Starbuck Dam is removed by the landowner or WDFW screen maintenance crews, limiting the downstream presence of LWD.

7.2.8.7 Restoration Strategies and Recommendations

Reach 3 was identified as a protection reach in the EDT analysis; therefore, only passive methods such as CREP and riparian planting were considered at that time (Appendix J of CCD 2004). However, this reach is currently considered a priority restoration reach in the draft SRSRP (SRSRB 2011a). Because there is a high degree of confinement and disruption of natural channel processes caused by anthropogenic infrastructure, we recommend that opportunities to develop off-channel habitat via reconnection of former channels or levee setbacks should be highly considered. If floodplain connectivity projects are not feasible, adding habitat complexity via LWD will be important to creating cover and pools during low-flow periods, and refuge in this high-velocity reach during high flows. Re-establishing riparian habitat to provide shading is also highly recommended in Reach 3.

Table 7-9
Restoration Recommendations for Reach 3

Restoration Framework Actions	Priority for This Reach	Recommendations
1. Protect and maintain natural processes	Lower	The area between RM 6.6 and 7.9 may be targeted for protection; however, the existing riparian area in this location lacks diverse and mature vegetation.
2. Connect disconnected habitat	Medium	Reach 3 has limited opportunities to reconnect wetlands and former mainstem and side channels. Most opportunities are associated with infrastructure, and are therefore described in the following restoration framework action.
3. Address roads, levees, other anthropogenic infrastructure impairing processes	High	97% of the length of Reach 3 has been categorized as confined. Levees and other anthropogenic infrastructure highly impacts natural processes in the reach; channelization and dredging has greatly contributed to this impact Setting back levees through the reach should be evaluated as a part of a comprehensive plan and considered during redevelopment. Due to the confined, modified nature of the channel through this reach, any opportunity to increase the available floodplain area should be evaluated. Potential disconnected floodplain areas include near RM 8.9, from RM 6.6 to 7.2, RM 5.6 to 5.9, and near RM 5.2.

Restoration Framework Actions	Priority for This Reach	Recommendations
4. Restore riparian processes	High	Riparian processes are degraded through most of the reach due to historic clearing of trees and encroachment of infrastructure on the floodplain. Efforts should be made to restore riparian areas where feasible.
5. Improve instream habitat conditions	High	LWD is insufficient throughout Reach 3. LWD should be installed to force pools and maintain channel complexity, particularly where there is little opportunity for LWD to naturally accumulate due to the high transport capacity through the confined channel.

7.2.9 Reach 2 – River Mile 0.7 to 4.5

7.2.9.1 Physical Description

Reach 2 is located from the downstream terminus of the levee through Starbuck (RM 4.5) to the extent of backwater from the Snake River (RM 0.7; Figure D-1 and 2a). Downstream of the Highway 261 Bridge at RM 1.85, the valley is grassy with scattered trees and shrubs. Upstream of this location, the valley is occupied by grazing pastures that extend from the edge of the riparian buffer to the valley walls. Several channel and bank modifications were identified throughout the reach, including riprap, levees, berms composed of dredge spoils, rock weirs, and rock barbs. In many locations, these features restrict migration of channel bends.

Photograph 7-9

A Recent Channel Avulsion at the Split-Channel Section Near RM 3.9

7.2.9.2 Hydrology

No major hydrologic inputs drain into this reach; therefore, it is expected that the increase in mainstem discharge is minor in this reach. The 2-year recurrence discharge at the downstream end of the reach is likely similar to the Reach 3 value at approximately 1,275 cfs (Appendix A).

7.2.9.3 Channel Patterns and Floodplain Connectivity

In the upper portion of the reach near RM 4.5 where the channel exits a levee- and bedrock-confined section adjacent to the town of Starbuck, the floodplain widens significantly, resulting in a dynamic pattern of past channel migration that can be observed in the historic photographs and in former channel positions visible in the low-lying floodplain topography

(Figure D-1 and 2b). This portion of the channel is confined in places by spoil pile berms and levees that significantly narrow the floodplain corridor at approximately RM 4.2, resulting in increased hydraulic energy downstream. The main channel is a meandering, single-thread channel with a split-channel section near RM 3.8 due to a recent avulsion; the two channels are separated by a low-lying forested island. Historic photographs indicate that multiple split channels were present throughout this portion of Reach 2 in the 1950s and 1970s.

Between the Powers Bridge (RM 2.4) and approximately RM 3.8, the river is a single-thread, meandering channel through a floodplain corridor that maintains a consistent overall width; however, observation of historic photos indicates that land use practices have restricted the width of the floodplain. Many actively migrating bends were identified in this portion of the reach as evidenced by erosion on outside banks, including several downed trees in the channel. Migration of some bends is restricted by hardened banks, particularly where the bend is migrating in the direction of irrigated land.

Downstream of the Powers Bridge to the Highway 261 crossing (RM 1.8), the channel is confined by a former railroad grade, a levee and the southwest valley wall, restricting the channel and floodplain to a narrow corridor. The channel appears to migrate throughout this corridor. Downstream of Highway 261, the formerly straightened channel and cleared floodplain have evolved into a meandering channel with vegetation regenerating on the floodplain. The channel is migrating without any visible hydro-modifications, other than the Highway 261 road grade.

Floodplain connectivity in Reach 2 is highly impacted. Approximately 227 acres of low-lying floodplain area is present in the reach representing approximately 60 acres per mile (Appendix D). This represents the second-highest potential floodplain restoration per mile in the basin. However, approximately 22% of these areas are disconnected from the main channel by infrastructure, isolating approximately 13.4 acres per mile limiting the accessible floodplain and availability of off-channel habitat used by juveniles during high flows. This infrastructure represents a significant impact to natural processes and juvenile rearing through the reach.

7.2.9.4 Sediment Inputs and Transport

The most significant sediment sources into Reach 2 are attributed to land use practices, which typically contributes suspended load, and mainstem channel migration that contributes coarser bedload (Appendix C). Sediment mobility is highly variable, although the critical grain size during the 1-year event is greater than the sample size D_{50} for about half of the modeled cross-sections in the reach (Appendix B). During the 2-year event, critical grain size exceeds the sample size for a majority of the cross-sections, and for the 5- and 10-year events, the critical grain size exceeds the sample size for all but a few of the cross-sections.

During our site reconnaissance, we identified significant depositional areas near the upstream end of the reach as well as a channel avulsion that had recently occurred. The close proximity of this area to Reach 3, which is highly confined, likely leads to channel migration and increased sediment deposition in this area, which in turn leads to floodplain widening and avulsion. Sediments that are mobilized through Reach 3, deposit in Reach 2, and floodwaters spread across the broader, flooded unconfined floodplain. These processes are important consider when developing restoration actions for Reach 2.

7.2.9.5 Riparian Conditions

Riparian trees in Reach 2 are typically deciduous (cottonwood, alder, and willow) between 25 to 50 feet, with approximately one-third between 50 and 75 feet tall (Appendix D). Very few trees greater than 75 feet exist, which is likely due to extensive clearing historically. Between the 1950s and 1970s, a majority of the riparian corridor regenerated and has continued to mature until the present. Only a few locations appear to have been cleared for agricultural use since the 1970s. Some moderately dense clusters of riparian growth are present through the reach, but these areas are discontinuous throughout the reach.

7.2.9.6 Fish Habitat and Use

Reach 2 is a very important area for fall Chinook spawning. Steelhead, spring Chinook, and bull trout use this lower portion of the Tucannon when migrating to and from the Snake River, perhaps most importantly during out-migration for juveniles. The middle portion of the reach between Highway 261 and approximately RM 3.8 has a moderately high amount of

LWD due to riparian trees being recruited due to active channel migration. The remainder of the reach has local woody debris accumulations, the majority of which are likely transient. Overall however, the reach lacks substantial LWD to create stable log jams that were likely historically present in large numbers throughout the reach.

7.2.9.7 Restoration Strategies and Recommendations

Reach 2 was identified as a protection reach in the EDT analysis; therefore, only passive methods such as CREP and riparian planting were considered at that time (Appendix J of CCD 2004). However, this reach is now considered a priority restoration reach in the draft SRSRP (SRSRB 2011a). Addressing channel confinement and creating instream and off-channel habitat is recommended in Reach 2, along with riparian planting and protection. Addressing sediment transport and deposition through the reach, seeking to achieve more natural transport and deposition patterns should be factored into restoration planning.

Table 7-10
Restoration Recommendations for Reach 2

Restoration Framework Actions	Priority for This Reach	Recommendations
1. Protect and maintain natural processes	Lower	Riparian areas currently in the CREP program should be maintained and protected.
2. Connect disconnected habitat	High	Potential opportunities to reconnect wetlands and former mainstem and side channels in Reach 2 are near RM 4.0 and 1.3. Developing a more complex channel planform will promote more natural sediment transport dynamics and decrease channel velocities.
3. Address roads, levees, other anthropogenic infrastructure impairing processes	High	Levees, dredge spoils, and the Highway 261 road grade are the primary types of infrastructure impacting natural processes in Reach 2. In addition, smaller berms impact channel migration but likely have no effect on flooding. The greatest amount of confinement in the reach is related to Highway 261 and a former railroad grade between RM 1.7 and 2.1.

Restoration Framework Actions	Priority for This Reach	Recommendations
4. Restore riparian processes	Medium	Restoration of riparian conditions should be evaluated, although it is not a primary restoration goal for Reach 2. The most degraded conditions are located downstream of the Highway 261 crossing.
5. Improve instream habitat conditions	High	Although LWD is present in Reach 2, additional LWD should be installed to force pools and maintain channel complexity. LWD will distribute flow, maintain sediment transport, and provide hydraulic refuge.

7.2.10 Reach 1 – Mouth to River Mile 0.7

7.2.10.1 Physical Description

Reach 1 is located from the extent of backwater at the boat launch near RM 0.7 to the mouth of the Snake River (RM 0.0) (Figure D-1 and 2a). This portion of the river is located within steep-sided bedrock valley walls, with a wet, marshy floodplain along the east edge of the valley that is frequently inundated by backwater from the lake. The floodplain adjacent to the channel on the east side of the valley is grassy with scattered trees and shrubs.

7.2.10.2 Hydrology

No significant tributary inputs or springs are located in this reach and the change in drainage area from Reach 2 is insignificant. Therefore, it is assumed that there is no change in total discharge from Reach 2 to Reach 1. The discharge in Reach 1 is likely controlled by backwater from the Lower Monumental Dam, even during storm events.

7.2.10.3 Channel Patterns and Floodplain Connectivity

The existing channel in Reach 1 is straightened, channelized, and heavily influenced by backwater. The channel planform has remained in the same configuration against the western valley wall/Highway 261 grade since at least the 1970s. It is likely that the channel was put in this position when the Lower Monumental Dam was constructed downstream on the Snake River in the late 1960s. Prior to installation of the dam, the channel was unconfined and meandered throughout the valley. Currently the channel and floodplain has no impact from infrastructure, although there is little complexity in the backwater-dominated reach (Appendix D).

7.2.10.4 Sediment Transport

Bedload samples were not taken in Reach 1 due to the lack of gravel bars and deep water in the channel. The backwater effects of the lake likely cause sediment to drop out due to decreased velocities; this behavior is consistent with the results of the hydraulic model (Appendix B).

7.2.10.5 Riparian Conditions

Very few riparian trees are present in Reach 1, except for a thin strip of deciduous trees along the left bank on the upstream end of the reach. Riparian vegetation is 10 to 25 feet in height except for a clump of trees between 20 to 50 feet in the upper left floodplain that is located greater than 150 feet away from the channel banks (Appendix D). Historically, the floodplain was void of trees in the 1950s and some riparian vegetation has grown since that time.

7.2.10.6 Fish Habitat and Use

This reach is used heavily by fall Chinook for spawning. Steelhead, spring Chinook, and migratory bull trout use this lower portion of the Tucannon during migratory periods. Reach 1 is highly simplified due to channelization and the effects of backwater, and it lacks LWD. Historically, this area of the Tucannon had heavy riparian cover, a significant amount of LWD, and a frequently inundated floodplain with several wetlands.

7.2.10.7 Restoration Strategies and Recommendations

Reach 1 was identified as a protection reach in the EDT analysis; therefore, only passive methods such as CREP and riparian planting were considered at that time (Appendix J of CCD 2004). However, Reach 1 is currently considered a priority restoration reach in the draft SRSRP (SRSRB 2011a). Reach 1 is highly channelized with low velocities and frequent inundation due to backwater effects from the Lower Monumental Dam. Therefore, there is little that can be realistically done to create habitat complexity and healthy geomorphic processes through passive methods. Besides establishing riparian vegetation where possible to reduce water temperatures and trap fine sediments, LWD structures are recommended to provide cover and complexity.

Table 7-11
Restoration Recommendations for Reach 1

Restoration Framework Actions	Priority for This Reach	Recommendations
1. Protect and maintain natural processes	Lower	The reach is backwater-dominated with little riparian vegetation to protect.
2. Connect disconnected habitat	Lower	Disconnected habitat areas do not exist in Reach 1, except for areas that get inundated frequently.
3. Address roads, levees, other anthropogenic infrastructure impairing processes	Lower	Reach 1 is not impacted by infrastructure.
4. Restore riparian processes	High	Riparian areas are severely degraded through most of the reach due to historic clearing of trees. Restoration efforts in this reach should be focused on riparian restoration; frequent inundation should be considered when developing appropriate restoration plans.
5. Improve instream habitat conditions	High	Backwater conditions and channelization lead to a highly simplified channel that lacks complexity. LWD structures are recommended to add complexity to the channel and provide cover.

8 LIMITATIONS

We have prepared this report for use by the CCD to evaluate geomorphic conditions in the Tucannon River and to identify appropriate conceptual restoration strategies in the study reach. The information presented in this report is based on available data and limited site reconnaissance at the time of report development. Conditions within the study reach may change both spatially and with time, and additional scientific data may become available. Significant changes in site conditions or the available information may require re-evaluation. Within the limitations of scope, schedule, and budget, our services have been executed in accordance with generally accepted scientific and engineering practices in this area at the time this report was prepared.

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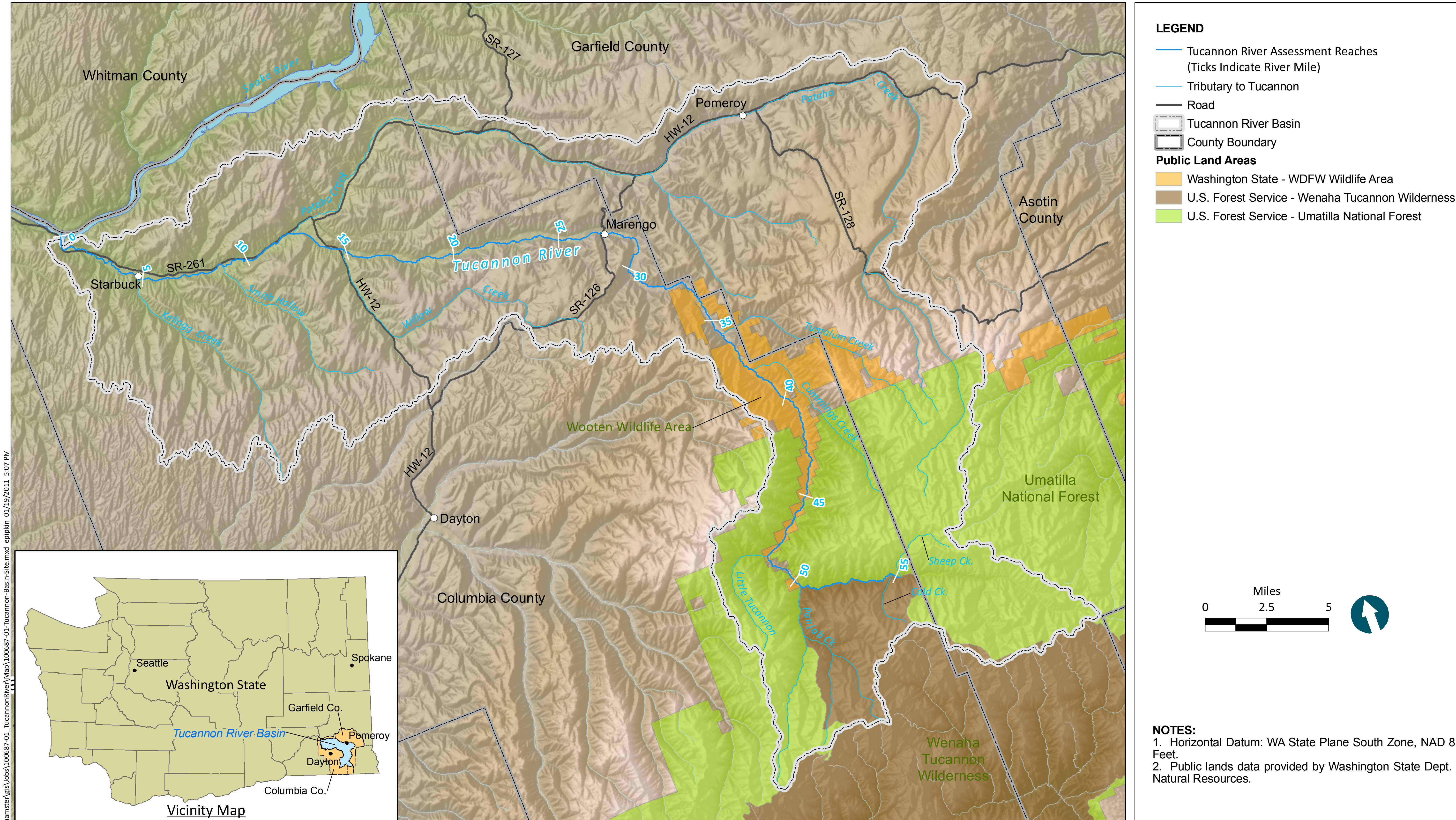
FIGURES



NOTES:
1. Horizontal Datum: WA State Plane South Zone, NAD 83, Feet.
2. Public lands data provided by Washington State Dept. of Natural Resources.

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ANCHOR QEA

Figure 1
Basin Vicinity and Site Map
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District

LEGEND

Tucannon River Assessment Reaches (Ticks Indicate River Mile)

Tributary to Tucannon

Tucannon River Basin

Tucannon River Subbasins

Land Cover

Open Water

Barren Land

Deciduous Forest

Evergreen Forest

Mixed Forest

Ermergent Herbaceuous Wetlands

Woody Wetlands

Herbaceuous

Shrub/Scrub

Hay/Pasture

Cultivated Crops

Developed

Miles

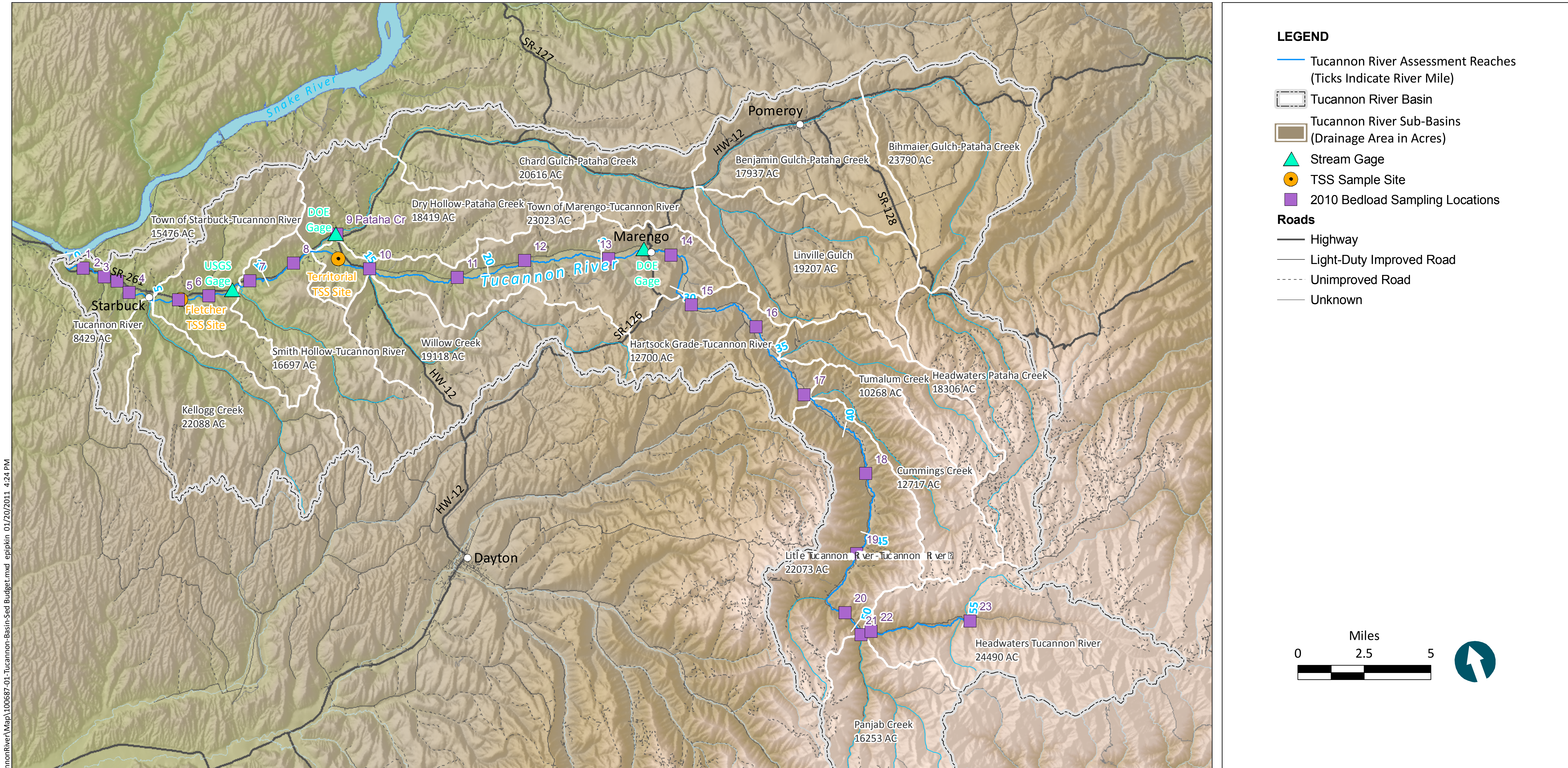
0 2.5 5

NOTES:

1. Horizontal Datum: WA State Plane South Zone, NAD 83, Feet.
2. Land use data derived from National Land Cover Database.
3. Sub-basins are based on USGS HUC areas.

ANCHOR QEA

Figure 2
Landcover Units and Subbasins
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District



NOTES:

1. Horizontal Datum: WA State Plane South Zone, NAD 83, Feet.
2. Road data provided by Washington Dept. of Natural Resources.
3. Sub-basins are based on USGS HUC areas.

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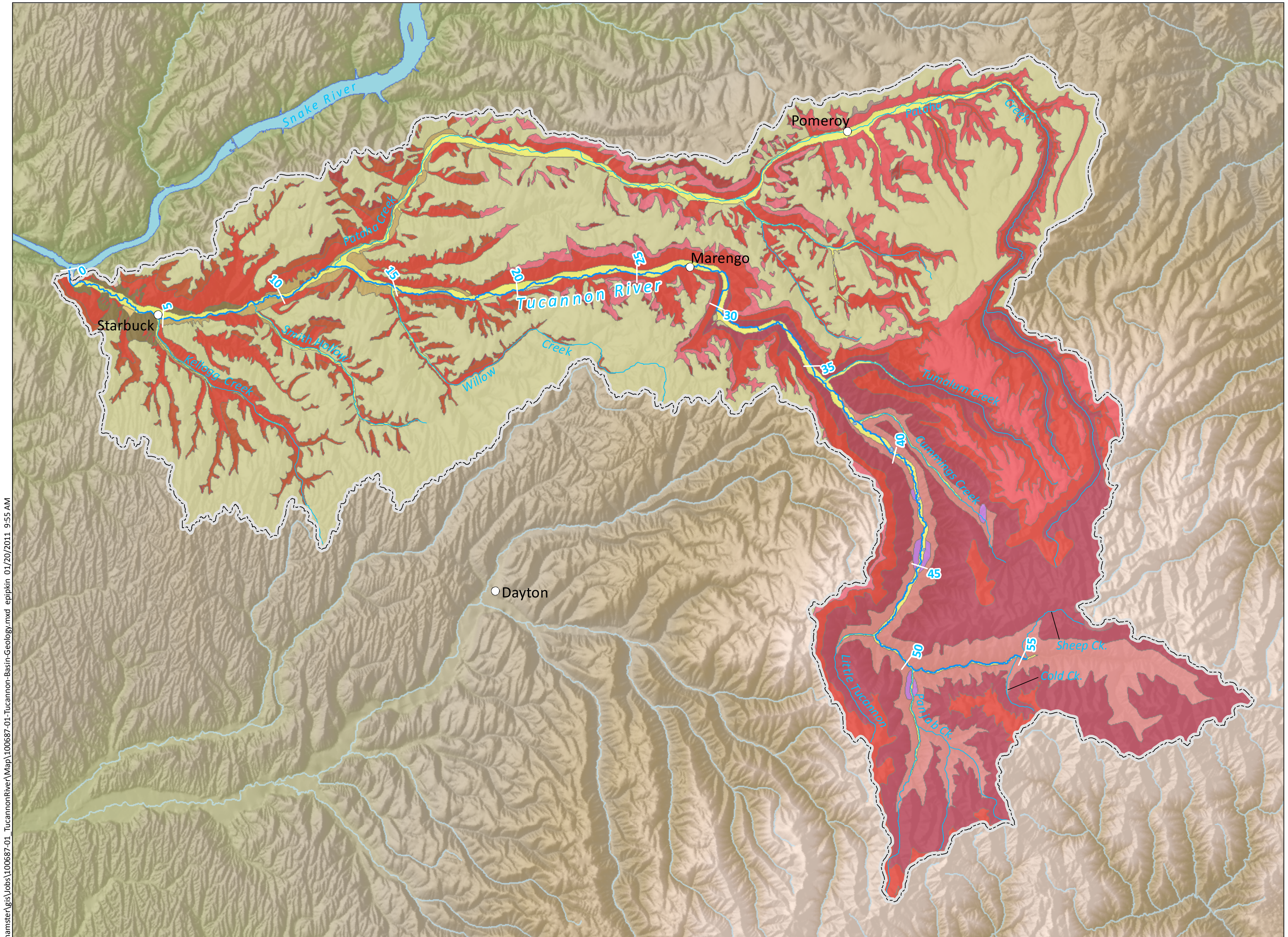
Figure 3
Subbasin Areas, Stream Gages, and Sediment Sampling Sites
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District



LEGEND

- Tucannon River Assessment Reaches (Ticks Indicate River Mile)
- Tributary to Tucannon
- Tucannon River Basin

Tucannon Basin Geologic Units

- Mv(gN1) - basalt flows (Grande Ronde, lower norm.)
- Mv(gN2) - basalt flows (Grande Ronde, upper norm.)
- Mv(gR2) - basalt flows (Grande Ronde, upper rev.)
- Mv(slm) - basalt flows (lower Saddle Mtn.)
- Mv(sp) - basalt flows (Pomona Member)
- Mv(su) - basalt flows (Umatilla Member)
- Mv(w) - basalt flows (Wanapum undiv.)
- Mv(wem) - basalt flows (Eckler Mtn.)
- Mv(wfe) - basalt flows - (Frenchman Spr. and Eckler Mtn.)
- Mv(wfs) - basalt flows (Frenchman Spr.)
- Mv(wr) - basalt flows (Roza)
- Qa - alluvium
- Qaf - alluvial fan deposits
- Qf(bg) - Bonneville flood deposits
- Qfs(t) - outburst flood deposits, sand and silt
- Ql - loess
- Qls - mass wasting deposits
- pTmt - metasedimentary and metavolcanic rocks
- Water

Miles
0 2.5 5

NOTES:
1. Horizontal Datum: WA State Plane South Zone, NAD 83, Feet.
2. Geologic unit data provided by Washington State Dept. of Natural Resources.

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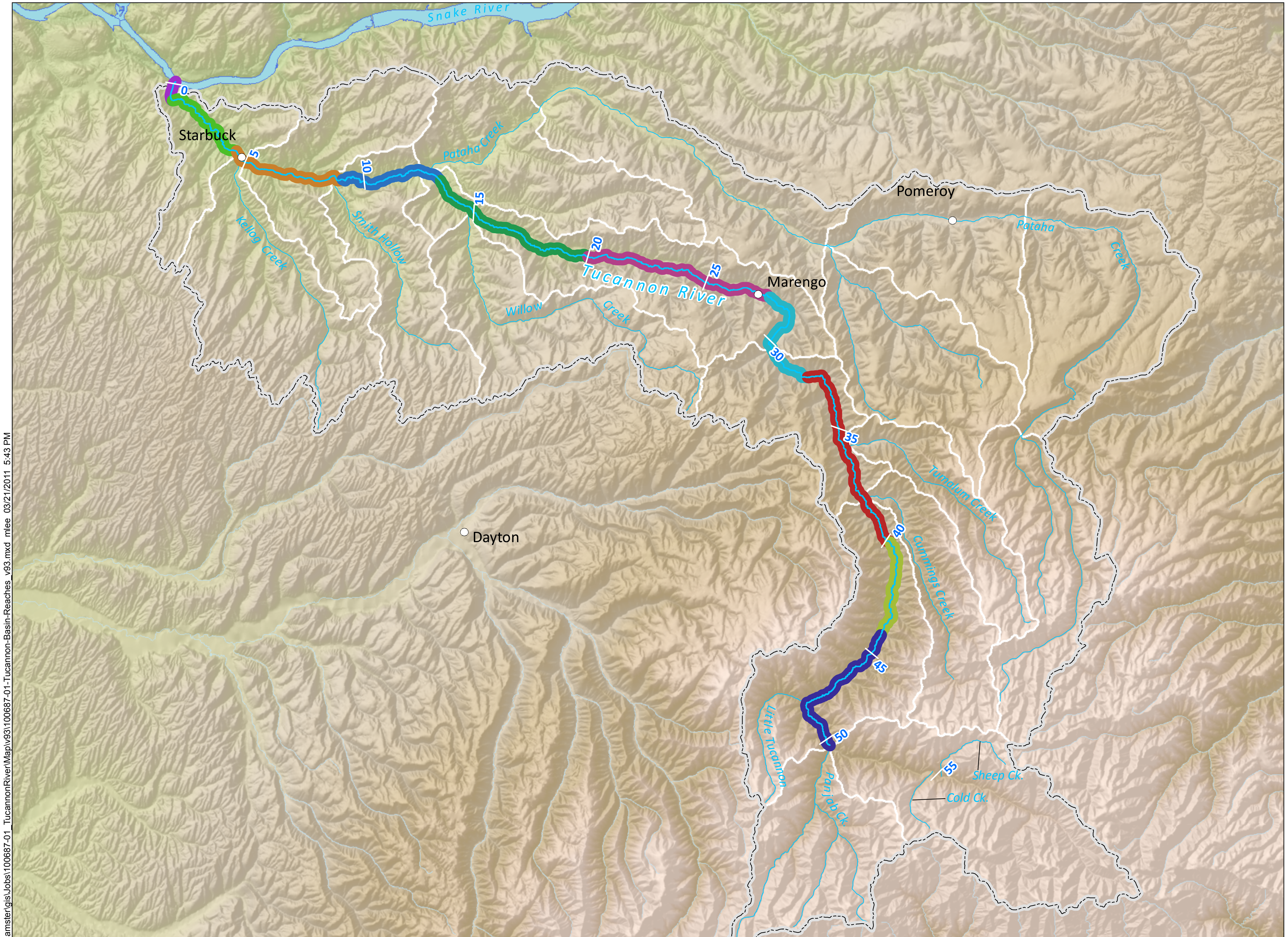
Figure 4
Basin Geology
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District



LEGEND

- Tucannon River Assessment Reaches (Ticks Indicate River Mile)
- Tributary to Tucannon
- Tucannon River Basin
- Tucannon River Sub-Basins

Geomorphic Reaches

- Reach 10 (RM 50.3 - RM 44.0)
- Reach 9 (R.M. 44.0 - R.M. 40.0)
- Reach 8 (R.M. 40.0 - R.M. 32.1)
- Reach 7 (R.M. 32.1 - 27.5)
- Reach 6 (R.M. 27.5 - R.M. 20.0)
- Reach 5 (R.M. 20.0 - R.M. 13.2)
- Reach 4 (R.M. 13.2 - R.M. 8.9)
- Reach 3 (R.M. 8.9 - R.M. 4.5)
- Reach 2 (R.M. 4.5 - R.M. 0.7)
- Reach 1 (R.M. 0.7 - R.M. 0.0)

Miles

0 2.5 5

NOTES:
1. Horizontal Datum: WA State Plane South Zone, NAD 83, Feet.
2. Subbasins are based on USGS HUC basin areas.

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Figure 5
Geomorphic Reach Extents
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District

APPENDIX A
HYDROLOGIC ANALYSIS METHODS AND RESULTS

A.1 HYDROLOGIC INFORMATION

Information on hydrology in the Tucannon River basin was available from multiple stream gages (both on the Tucannon River and its tributaries) and spatially distributed rainfall data. Subbasin delineations were also available for use in estimating discharge contributions from tributaries that are not gaged.

A.1.1 Stream Discharge Data

Stream discharge data were available from three gages on the Tucannon River and its major tributaries. See Figure 3 of the main report for a basin map including stream gage locations. The following sections provide a brief description of the gages used to help evaluate basin hydrology.

A.1.1.1 U.S. Geological Survey Gage near Starbuck, Washington

Discharge data in the Tucannon River near Starbuck were available from the U.S. Geological Survey (USGS) gage #13344500. The gage is located at approximately river mile (RM) 8.2, just downstream of the Smith Hollow road crossing and the confluence of the Smith Hollow tributary. The drainage basin upstream of the gage is approximately 431 square miles. The available period of record for the gage is from October 1, 1914, through September 30, 2010. Three significant data gaps exist in the period of record: one from water years 1918 to 1928, a second from water years 1932 to 1958, and a third from water years 1991 to 1994. A total of 54 water years are available in the gage data. Approved peak steamflow data were available for 53 of the water years (water year 2010 peak streamflow was not approved for publication at the time of this analysis).

A.1.1.2 Department of Ecology Gage near Marengo, Washington

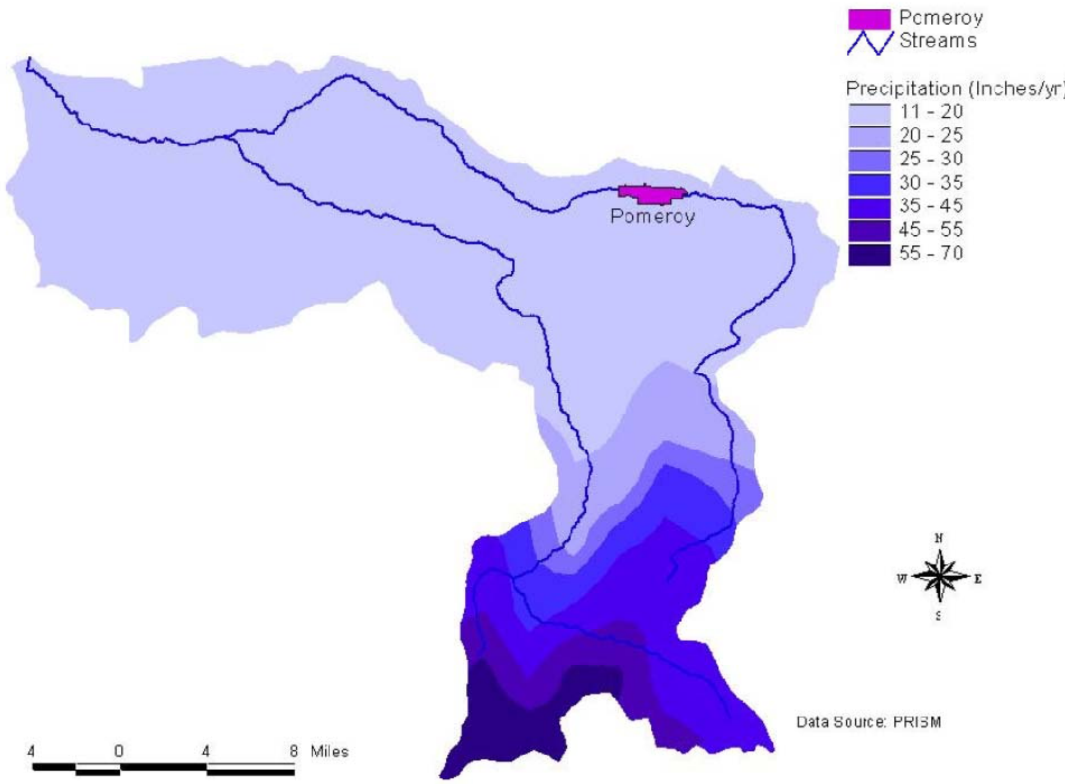
Discharge data in the Tucannon River near Marengo were available from the Washington State Department of Ecology (Ecology) gage 35B150. The gage is located at approximately RM 26.9, just downstream of Marengo and the Turner Road crossing. The drainage basin upstream of the gage is approximately 160 square miles. The available period of record for the gage is from June 2003 to the present. This location was also the site of a former USGS gage (#13344000). The available period of record for the former USGS gage is from water years 1913 to 1930. The data from the former USGS gage were not used in the analysis.

A.1.1.3 Department of Ecology Gage on Pataha Creek near the Mouth

Discharge data in Pataha Creek near the confluence with the Tucannon River were available from Ecology gage 35F050. The gage is located on Pataha Creek at approximately RM 1.2, just downstream of the State Route 261 crossing. Pataha Creek enters the Tucannon River at approximately RM 12.5. The drainage basin upstream of the gage is approximately 184 square miles.

A.1.2 Precipitation Data

Precipitation data for the basin were summarized in the Tucannon Subbasin Plan and were available as geospatial data from PRISM through MGS Engineering Consultants and the Oregon Climate Service (2006). The distribution of precipitation in the basin is highly dependent on elevation. Mean annual precipitation ranges from 10 inches at lower elevations to more than 40 inches at higher elevations. Figure A-1 shows the distribution of mean annual precipitation over the Tucannon River basin (CCD 2004).



Map by Ecopacific as shown in NPPC 2001, Figure 4.

Figure A-1
Mean Annual Precipitation Distribution – Tucannon River Basin

A.1.3 Basin Delineations

Basin and subbasin delineations are available as geospatial data (BLM 2009) for the Tucannon River. These delineations provided information on contributing area, basin shape, slope, and elevation. The major subbasins and gage locations in the Tucannon River basin are listed in Table A-1.

Table A-1

Major Subbasins and Flow Change Locations

Major Tributary/ Location on River	Location (RM)	Tributary Area (sq mi)	Basin Area Above Confluence (sq mi)	Basin Area Below Confluence (sq mi)	Basin Area Increase (sq mi)
Mouth	0	-	504	504.0	14.0
Kellogg Creek	4.8	34.5	455.5	490.0	58.5
Starbuck Gage	8.2	-	431.5	431.5	0.77
Smith Hollow	8.6	20.6	410.1	430.7	25.8
Pataha Creek *(Gaged)*	12.3	184.8	220.1	404.9	189
Willow Creek	14.8	29.9	186.4	216.3	56.3
Marengo Gage	26.9	-	160	160.0	22.2
Tumalum Creek	35.6	16.0	121.8	137.8	19.7
Cummings Creek	37.9	19.9	98.3	118.2	42.1
Little Tucannon R.	48.2	8.4	67.7	76.1	12.4
Panjab Creek	50.2	25.4	38.3	63.7	25.4
Above Panjab Creek	55.2	-	38.3	-	-

Notes:

1. Entries that are not tributaries do not have a tributary area associated with them.
2. Total increase in drainage area includes Tucannon River Valley hill slope area and tributary area.
3. RM = river mile
4. sq mi = square miles

A.2 HYDROLOGIC ANALYSIS

An hydrologic analysis was conducted for the Tucannon River and its major tributaries to develop peak flow hydrology. The goal of the analysis was to provide reasonable estimates of discharge in the river through the study area ranging from the 1- to 100-year return period. The results were then used as flow input to the hydraulic model and also to aid with the processes of reach delineation and characterization.

A.2.1 Flood Magnitude and Frequency Analysis

A flood magnitude and frequency analysis for the Tucannon River was conducted using peak discharge data from the gage at Starbuck. Two methods were used in the selection of the peak discharge event series for the flood magnitude and frequency analysis:

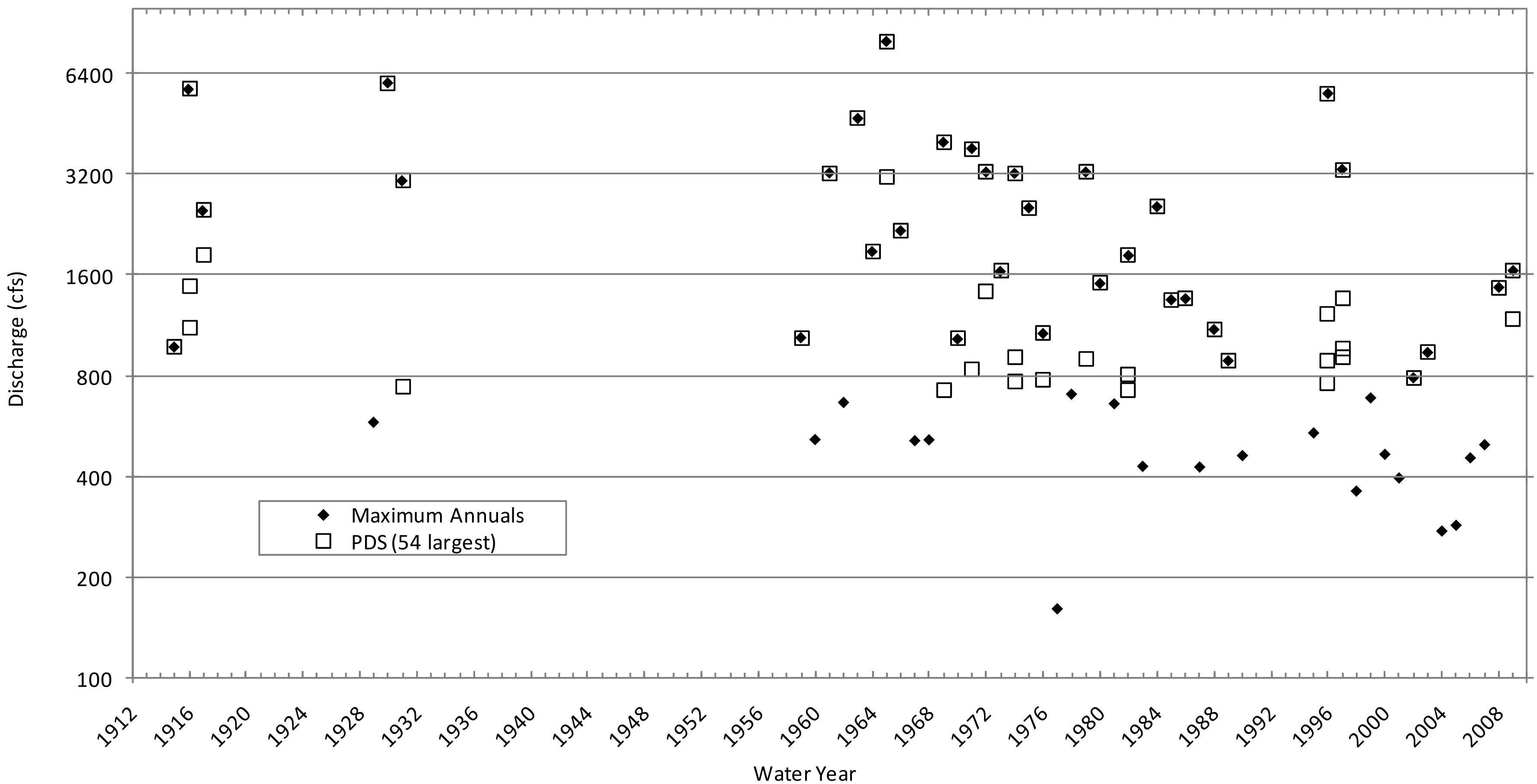
1. The series of annual peak discharges for the period of record.
2. All independent discharge peaks above a threshold of 720 cubic feet per second (cfs). This threshold provided a series of 54 independent flood events (equivalent to the number of years of record). This selection method is also known as a partial duration series (PDS) analysis (Madsen et al. 1997).

The two peak discharge series selection methods were justified given the nature of the basin hydrology (i.e., the occurrence of drought years with no appreciable flood event) and the goals of the analysis. The peak discharges series are shown with respect to water year in Figure A-2. The drought year peak discharges can be seen below the PDS threshold of 720 cfs. Each peak discharge series was used to develop a Log-Pearson Type III (LP3) exceedance probability curve. Overall, the PDS method typically provides larger peak discharges for the more frequent events (i.e., 1- and 2-year return periods) while only providing slightly smaller peak discharges for the less frequent flood events when compared to using the annual peak discharge series method. The results of the LP3 analysis using both data sets are shown in Table A-2 and in Figure A-3.

Table A-2

Flood Magnitude and Frequency at the Starbuck Gage

Return Period (yr)	Annual Exceedance Probability	LP3, Annual Peaks	LP3, Peaks Over Threshold	Percent Difference
		Peak Discharge (cfs)	Peak Discharge (cfs)	
1	100%	147	484	230%
2	50%	1,183	1,517	28%
5	20%	2,640	2,743	4%
10	10%	4,057	3,898	-4%
25	4%	6,465	5,861	-9%
50	2%	8,775	7,770	-11%
100	1%	11,583	10,140	-12%



Notes:

1) Annual peak discharges from USGS gage 13344500 for the approved period of record (1915-2009).
2) Partial Duration Series (PDS) is the 54 largest events in the period of record. The PDS method is also known as the Peaks Over Threshold method. A partial-duration flood series is a list of all flood peaks that exceed a chosen base stage or discharge, regardless of the number of peaks occurring in a year (also called basic-stage flood series, or floods above a base).

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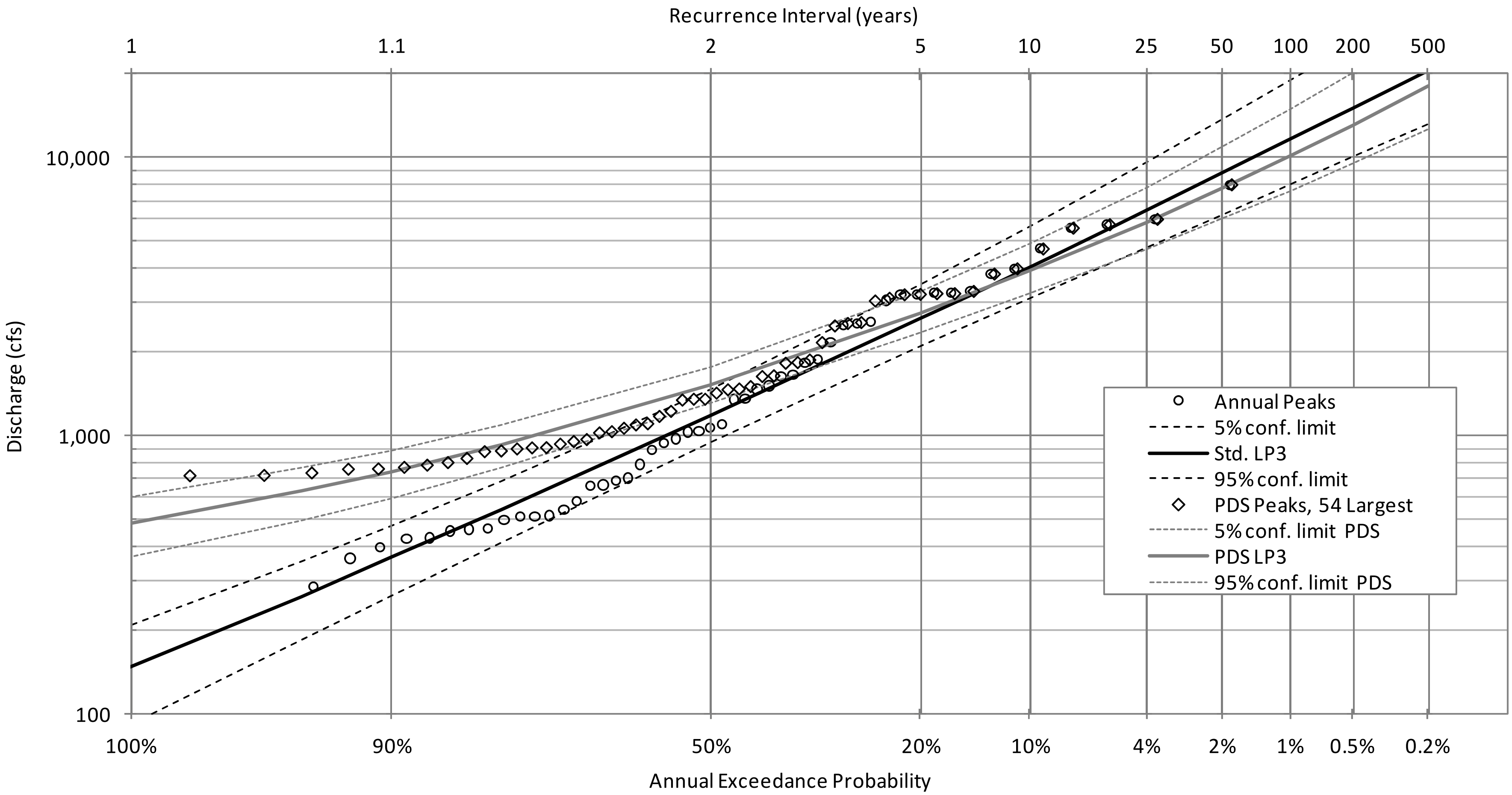
Figure A-2

Historical Peak Discharges – Tucannon River at Starbuck

Tucannon River Geomorphic Assessment and Habitat Restoration Study

Columbia Conservation District



Notes:

1) Annual peak discharges from USGS gage 13344500 for the approved period of record (1915-2009).
2) The Log Pearson Type 3 (LP3) analysis is for all annual peaks using HEC-SSP software.
3) Washington State Stream Stats regressions for the drainage area.
4) Partial Duration Series (PDS) is the 54 largest events in the period of record.
5) The LP3 analysis is for the PDS using HEC-SSP software.
6) Also shown for each analysis are the 5% and 95% confidence limits.

Figure A-3
Flood Frequency Analysis – Tucannon River at Starbuck
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District

It is important to note the large difference in the peak discharge between the LP3 analysis using the annual peaks series and the PDS for the 1-year return period. Using the annual peak discharges series for the LP3 analysis yields a 1-year return period discharge less than the mean annual discharge. However, using the PDS method for the LP3 analysis yields a 1-year return period discharge roughly 3 times the magnitude of the mean annual discharge. This difference is the result of drought years in the annual peak discharge series and the absence of small peak discharges from drought years in the PDS method. As the exceedance probability decreases, the results of the two methods become more similar, with the PDS method providing a slightly smaller discharge for return periods longer than 5 years.

For the 1-year return period, the peak discharge from the LP3 analysis using the PDS was used for subsequent analysis. For the 2-, 5-, 10-, 25-, and 100-year return period, the peak discharges from the LP3 analysis using the annual peak discharge series were used for subsequent analysis.

A.2.2 Basin Area Discharge Scaling

To calculate the discharge contributions for ungaged flow change locations on the Tucannon River, the basin area scaling method developed by Thomas et al. (1994) and referenced in the USGS Fact Sheet *Methods for Estimating Flood Magnitude and Frequency in Washington* (2001) was used. Thomas' basin area scaling method (Equation A-1) uses the basin area proportions and a regional exponent to scale discharges from a gaged location to an ungaged location. The method is suitable for ungaged basins with a basin area between 50 and 150% of the gaged location basin area.

$$Q_u = Q_g \left(\frac{A_u}{A_g}\right)^x \qquad \text{(A-1)}$$

where:

Q_u = is the peak discharge, in cfs, at the ungaged site for a specific recurrence interval

Q_g = is the peak discharge, in cfs, at the gaged site for a specific recurrence interval

A_u = is the contributing drainage area, in square miles, at the ungaged site

A_g = is the contributing drainage area, in square miles, at the gaged site

x = is the exponent for the region in which both sites are located

The regional exponent (x) for the Tucannon River basin is 0.59 (Table 3, USGS 2001). The results of this method applied to the major tributary basin areas are shown in Table A-3 as flow proportion percentages.

It should be noted that several ungaged flow change locations in the upper basin are less than 50% of the gage location's basin area. These estimates are beyond the recommended limitations of the method and should therefore be compared with other methods for determining basin contributions including stream gage data correlations.

A.2.3 Stream Gage Correlations

To improve the flow estimates provided by the basin area scaling method, correlations between discharge at the Starbuck gage and two other gages (Marengo and Pataha) were made. Although the period of record at these gages is not sufficiently long to conduct a flood frequency analysis using the LP3 method, the gage data were sufficient to develop reasonable discharge correlations to the gage at Starbuck. To develop the correlation, mean daily discharges at the Marengo and Pataha Creek gages were plotted against mean daily discharges greater than or equal to 400 cfs at the Starbuck gage and a linear trend line with an origin of (0,0) was fit to the data. These correlations showed that:

- Discharge at the Marengo gage was typically 87% of the discharge at the Starbuck gage (Figure A-4)
- Discharge at the Pataha Creek gage was typically 11% of the discharge at the Starbuck gage (Figure A-5)

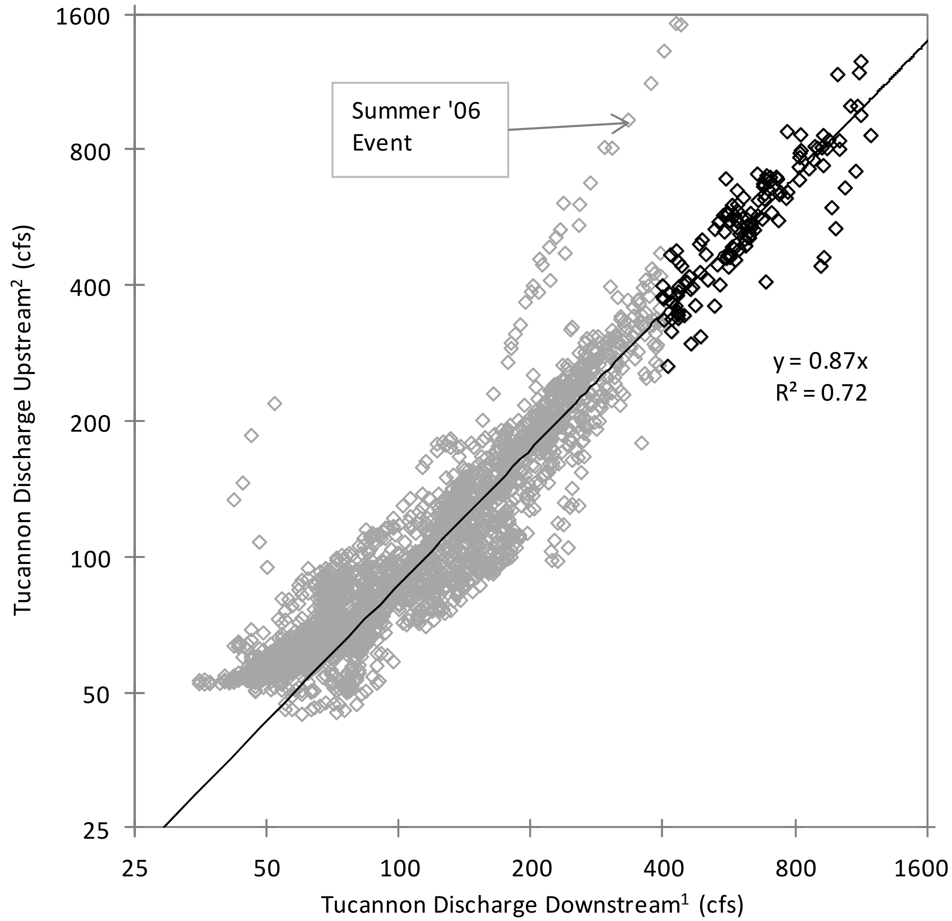
The results of applying these gage correlation corrections to the basin area scaling method are shown in the column titled "Flow as % of Starbuck, w/ gage corrections" in Table A-3 as flow proportion percentages. The table also shows the difference in flow proportions between the basin area scaling method and the gage correlation corrections to the basin area scaling method. The flow change locations and discharge contributions are also shown in Figures A-6 and A-7 with respect to RM.

Table A-3

Flow Change Locations Discharge Proportions

Major Tributary/ Location on River	Thomas (1994) flow proportion as % of Starbuck	Flow as % of Marengo[5]	Flow as % of Starbuck, w/ gage corrections	Difference in Proportion
Kellogg Creek	108%	-	108%	0%
Starbuck Gage	100%	-	100%	0%
Smith Hollow[1,3]	100%	-	100%	0%
Pataha Creek[2]	96%	-	99%	3%
Willow Creek[3]	67%	-	88%	21%
Marengo Gage[4,5]	56%	100%	87%	31%
Tumalum Creek	51%	92%	80%	29%
Cummings Creek	47%	84%	73%	26%
Little Tucannon R.	36%	64%	56%	20%
Panjab Creek	32%	58%	51%	18%
Above Panjab Creek	24%	43%	37%	13%

Notes:
1. For the purposes of modeling, the discharge downstream of Smith Hollow was assumed to be equivalent to the discharge at the Starbuck gage.
2. The gage correlation correction for Pataha Creek is 11% of the discharge at Starbuck.
3. The remainder of the discharge proportion for the gage correction method was split evenly between Smith Hollow and Willow Creek, with both tributaries accounting for 1% of the discharge at the Starbuck gage.
4. The gage correlation correction for the Marengo gage is 87% of the discharge at Starbuck.
5. Proportioning of the discharge at Marengo to tributaries used Thomas' basin area scaling method with Marengo as the gaged location.



Notes:

1) Discharge at the USGS Starbuck Gage (13344500), RM 8.6, drainage area 431.5 sq mi
2) Discharge at the Ecology Marengo Gage (35B150), RM 26.9, drainage area 160 sq mi
3) Grey data points are not included in the regression; these are discharges less than 400 cfs at the Starbuck gage.

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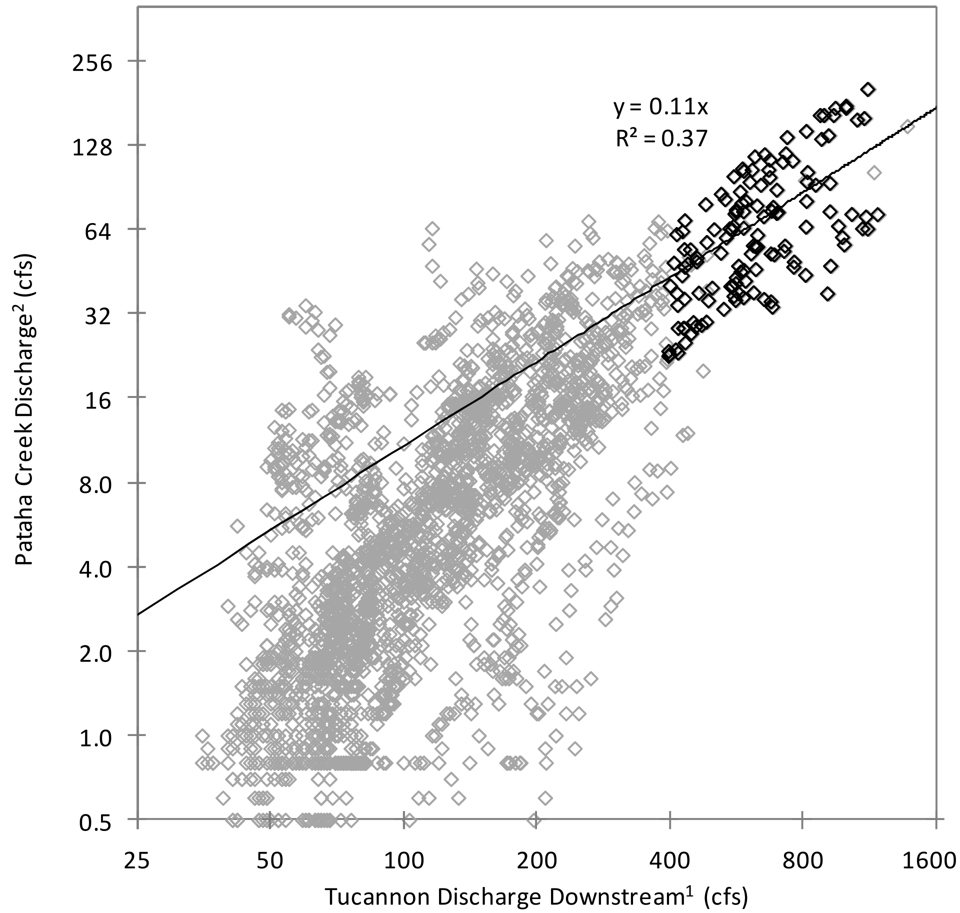
Figure A-4
Discharge Correlations – Starbuck and Marengo Gages
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District



Notes:

1) Discharge at the USGS Starbuck Gage (13344500), RM 8.6, drainage area 431.5 sq mi
2) Discharge in Pataha Creek at Ecology Gage (35F050), drainage area 184.8 sq mi
3) Grey data points are not included in the regression; these are discharges less than 400 cfs at the Starbuck gage.

Figure A-5

Discharge Correlations – Tucannon River at Starbuck and Pataha Creek Gages

Tucannon River Geomorphic Assessment and Habitat Restoration Study

Columbia Conservation District

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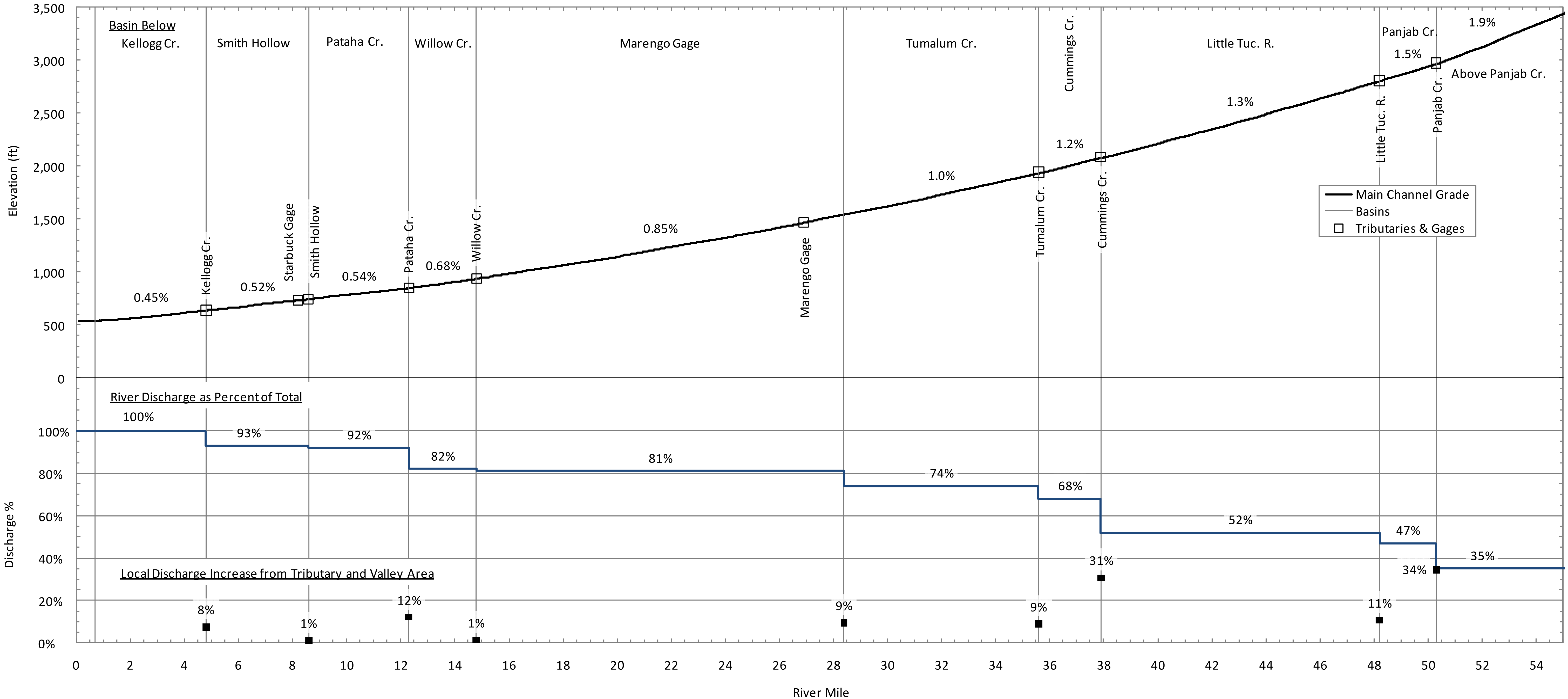

Notes:

1) Notes Main channel grade elevation based on aerial LiDAR from 2010
2) River stationing developed by Anchor QEA (2010) using aerial photography for channel centerline delineation
3) Slope shown for each basin is the average channel slope calculated at 100 ft intervals
4) For additional information on discharge increase from tributaries and hills slopes see discussion in the text

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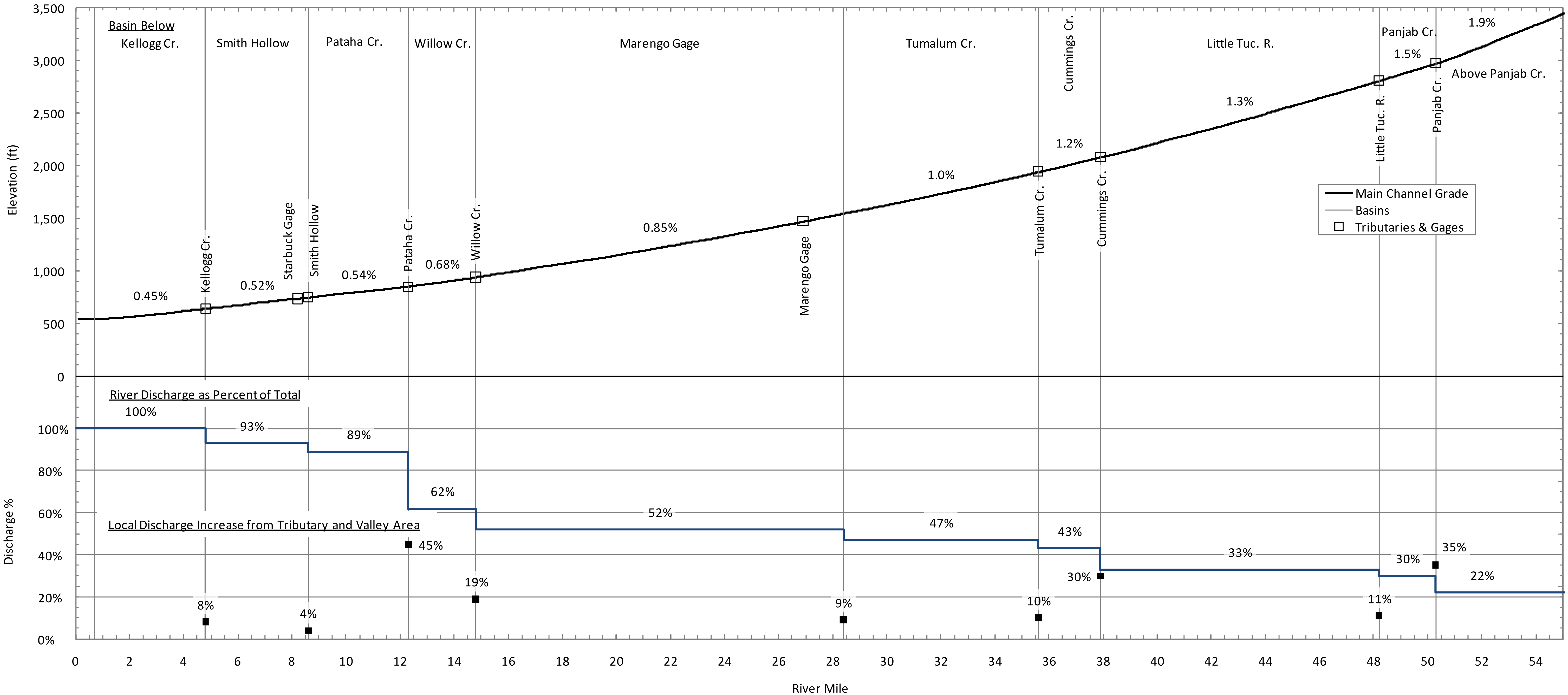
Figure A-6
Tucannon River Hydrology – Flow Change Locations and Discharge Contributions (Higher Flow Values)
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District



Notes:

1) Notes Main channel grade elevation based on aerial LiDAR from 2010
2) River stationing developed by Anchor QEA (2010) using aerial photography for channel centerline delineation
3) Slope shown for each basin is the average channel slope calculated at 100 ft intervals
4) For additional information on discharge increase from tributaries and hills slopes see discussion in the text

Figure A-7
Tucannon River Hydrology – Flow Change Locations and Discharge Contributions (Lower Flow Values)
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District

Table A-3 shows the basin area scaling method's underestimation of the discharge at Marengo and overestimation of discharge from Pataha Creek. The differences can be attributed to differences in the shape of the contributing areas and the distribution of mean annual precipitation in the basins. Although the Pataha Creek subbasin comprises approximately 43% of the contributing area to the Tucannon River at the Starbuck gage, it produces a significantly smaller percentage of the discharge as shown by the gage data correlation. Two primary factors reduce the relative discharge contribution of Pataha Creek:

- The long and narrow shape of the Pataha Creek basin is not conducive to producing large peak discharges.
- The Pataha Creek basin receives less precipitation per area compared to the upper portion of the Tucannon River. For example, only 8.8% of the Pataha Creek subbasin receives more than 30 inches of precipitation per year, compared to nearly 59% of the Tucannon River Basin above Pataha Creek.

The stream gage correlation results are consistent with previously published hydrologic analysis results (Hecht et al. 1982). Hecht et al. focused on a single water year (1980) and found that, relative to total average annual flow at the Starbuck gage, Pataha Creek contributed approximately 11% of the average annual flow while the Tucannon basin upstream of Pataha Creek contributed approximately 85% of the flow.

A.2.4 Model Discharges

Given the uncertainty in both the flood magnitude and frequency analysis and the proportioning of discharge to ungaged tributaries, the hydraulic model was run using a higher and lower discharge for the selected return periods.

The higher discharges values were calculated for the flow change locations using the basin area scaling method (Thomas et al. 1994) with corrections for flow contribution at known locations and allocation of remaining flows between flow correction locations. This process set the discharge in the Tucannon River at the Marengo gage to 87% of the discharge at the Starbuck gage. It also reduced to contribution of Pataha Creek to only 11% of the discharge at the Starbuck gage. These modifications to the basin area scaling method allocated a larger proportion of the discharge to the wetter upper portions of the basin.

The lower discharges values were calculated for the flow change location using only the basin area scaling method (Thomas et al. 1994) without corrections for flow contribution at known locations. This process estimated the discharge in the Tucannon River at the Marengo gage to be 56% of the discharge at the Starbuck gage. It also estimated the contribution of Pataha Creek to be 29% of the discharge at the Starbuck gage. The basin area scaling method distributed the discharge contributions evenly based exclusively on basin area without regard for variation in precipitation. Compared to the method used to develop the higher discharges, this method reduced the discharge in the upper portions of the river and increased the contribution of lower elevation tributaries.

The discharges used in the hydraulic model are shown in Tables A-4 and A-5. These discharges allow the examination of a wide range of hydraulic conditions along the length of the Tucannon River while representing uncertainties in basin hydrology.

Table A-4
Higher Flood Discharges Values (cfs)

Flow Change (RM)	Tributary/Location Name	Return Period (years)						
		1	2	5	10	25	50	100
4.8	Kellogg Creek	522	1,275	2,845	4,373	6,969	9,458	12,485
8.6	Smith Hollow[1]	484	1,183	2,640	4,057	6,465	8,775	11,583
12.3	Pataha Creek	479	1,171	2,613	4,016	6,401	8,687	11,467
14.8	Willow Creek	426	1,041	2,323	3,570	5,689	7,722	10,193
28.4	Marengo Gage[2]	421	1,029	2,296	3,529	5,625	7,634	10,077
35.6	Tumalum Creek	386	943	2,103	3,232	5,151	6,991	9,228
37.9	Cummings Creek	352	861	1,920	2,951	4,704	6,384	8,427
48.2	Little Tucannon R.	272	664	1,481	2,276	3,627	4,923	6,498
50.2	Panjab Creek	245	598	1,334	2,050	3,267	4,433	5,852
55.2	Above Panjab	181	443	988	1,518	2,420	3,284	4,335

Table A-5
Lower Flood Discharges Values (cfs)

Flow Change (RM)	Tributary/Location Name	Return Period (years)						
		1	2	5	10	25	50	100
4.8	Kellogg Creek	522	1,275	2,845	4,373	6,969	9,458	12,485
8.6	Smith Hollow[1]	484	1,183	2,640	4,057	6,465	8,775	11,583
12.3	Pataha Creek	466	1,140	2,542	3,907	6,227	8,451	11,156
14.8	Willow Creek	322	787	1,756	2,699	4,301	5,838	7,706
28.4	Marengo Gage[2]	270	659	1,470	2,259	3,601	4,887	6,451
35.6	Tumalum Creek	247	604	1,346	2,069	3,297	4,475	5,907
37.9	Cummings Creek	225	551	1,229	1,889	3,011	4,087	5,394
48.2	Little Tucannon R.	174	425	948	1,457	2,322	3,151	4,160
50.2	Panjab Creek	157	383	854	1,312	2,091	2,838	3,746
55.2	Above Panjab	116	283	632	972	1,549	2,102	2,775

Notes:
1. For the purposes of modeling, the discharge downstream of Smith Hollow was assumed to be equivalent to the discharge at the Starbuck gage.
2. The flow change location for the Marengo gage was moved up to RM 28.4 to better model the increase in discharge near the Marengo gage.

A.2.5 Basin Data Tables and Plots

Full reporting of the basin and tributary hydrology is provided in Tables A-6 and A-7. Table A-6 presents the basin data using the higher flood discharge values and Table A-7 presents the basin data using the lower flood discharge values. The tables provide additional information on flow change locations and conditions in the Tucannon River between flow change locations. Additional information includes:

- The reach where the flow change occurs
- The elevation of the flow change location
- The main channel gradient between flow change locations
- The change in river discharge as the proportion of the total, increase of total, and local increase
- The slope discharge product for the 2-, 10-, and 100-year return period discharge

The information presented in these tables was used in reach delineation and descriptions (see Appendix D). Information presented in these tables is also displayed in Figures A-6 and A-7 for the higher and lower discharges, respectively.

Table A-6

Basin Data Table – Higher Discharge Values

Reach	Flow Change Location (RM)[1,2]	Flow Change Name	Drainage Area (mi^2)				Elevation[4] (ft)	Channel Gradient (ft/ft)[5]	Return Period Peak Discharge (cfs)			Change in Tucannon Discharge			Slope Discharge Product, 2-year (cfs)	Slope Discharge Product, 10-year (cfs)	Slope Discharge Product, 100-year (cfs)
			Tributary Only	Tucannon Above Tributary	Tucannon Below Tributary	Total Increase[3]			2-year	10-year	100-year	Proportion of Total	Increase of Total	Local Increase			
1	0	*Mouth*[6]	-	504	504	14.0	540	0.00	1,275	4,373	12,485	100%	-	-	0.00	0.00	0.00
3	4.8	Kellogg Cr.	34.5	456	490	58.5	638	0.0045	1,275	4,373	12,485	100%	7%	8%	5.68	19.5	55.6
3	8.2	*Starbuck Gage*	-	432	432	0.77	731	0.0052	1,183	4,057	11,583	93%	0%	0%	6.15	21.1	60.2
3	8.6	Smith Hollow	20.6	410	431	25.8	744	0.0049	1,183	4,057	11,583	93%	1%	1%	5.79	19.9	56.7
4	12.3	Pataha Cr.	185	220	405	189	848	0.0054	1,171	4,016	11,467	92%	10%	12%	6.36	21.8	62.3
5	14.8	Willow Cr.	29.9	186	216	56.3	939	0.0068	1,041	3,570	10,193	82%	1%	1%	7.03	24.1	68.8
7	28.4	*Marengo Gage*	-	160	160	22.2	1,549	0.008	1,029	3,529	10,077	81%	7%	9%	8.70	29.8	85.2
8	35.6	Tumalum Cr.	16.0	122	138	19.7	1,942	0.010	943	3,232	9,228	74%	6%	10%	9.63	33.0	94.3
8	37.9	Cummings Cr.	19.9	98.3	118	42.1	2,083	0.012	861	2,951	8,427	68%	15%	30%	10.3	35.3	101
10	48.2	Little Tuc. R.	8.36	67.7	76.1	12.4	2,806	0.013	664	2,276	6,498	52%	5%	11%	8.80	30.2	86.1
10	50.2	Panjab Cr.	25.4	38.3	63.7	25.4	2,973	0.015	598	2,050	5,852	47%	12%	35%	8.95	30.7	87.6
10	55.2	*Above Panjab*	-	38.3	-	-	3,469	0.019	443	1,518	4,335	35%	-	-	8.50	29.1	83.2

Notes:

1. Flow change locations are reported to the nearest tenth of a mile.
2. River miles (RM) are based on 2010 main channel center line alignment as delineated by Anchor QEA using aerial photographs.
3. Total increase in drainage area includes Tucannon River Valley hill slope area and tributary area.
4. Elevations are from 2010 Aerial LiDAR bare earth returns.
5. Slope for basins is the averaged 100-foot channel segment gradient below the flow change location to the next flow change location.
6. Although total drainage area increases by 14 square miles between Kellogg Creek and the mouth of the river, no appreciable increase in peak discharge is expected from the valley wall slopes.

Table A-7
Basin Data Table - Lower Discharge Values

Reach	Flow Change Location (RM)[1,2]	Flow Change Name	Drainage Area (mi^2)				Elevation[4] (ft)	Channel Gradient (ft/ft)[5]	Return Period Peak Discharge (cfs)			Change in Tucannon Discharge			Slope Discharge Product, 2-year (cfs)	Slope Discharge Product, 10-year (cfs)	Slope Discharge Product, 100-year (cfs)
			Tributary Only	Tucannon Above Tributary	Tucannon Below Tributary	Total Increase[3]			2-year	10-year	100-year	Proportion of Total	Increase of Total	Local Increase			
1	0	*Mouth*[6]	-	504	504	14.0	540	0.00	1,275	4,373	12,485	100%	-	-	0.00	0.0	0.0
3	4.8	Kellogg Cr.	34.5	456	490	58.5	638	0.0045	1,275	4,373	12,485	100%	7%	8%	5.68	19.5	55.6
3	8.2	*Starbuck Gage*	-	432	432	0.77	731	0.0052	1,183	4,057	11,583	93%	0%	0%	6.15	21.1	60.2
3	8.6	Smith Hollow	20.6	410	431	25.8	744	0.0049	1,183	4,057	11,583	93%	3%	4%	5.79	19.9	56.7
4	12.3	Pataha Cr.	185	220	405	189	848	0.0054	1,140	3,907	11,156	89%	28%	45%	6.20	21.2	60.6
5	14.8	Willow Cr.	29.9	186	216	56.3	939	0.0068	787	2,699	7,706	62%	10%	19%	5.31	18.2	52.0
7	28.4	*Marengo Gage*	-	160	160	22.2	1,549	0.008	659	2,259	6,451	52%	4%	9%	5.57	19.1	54.5
8	35.6	Tumalum Cr.	16.0	122	138	19.7	1,942	0.010	604	2,069	5,907	47%	4%	10%	6.17	21.1	60.3
8	37.9	Cummings Cr.	19.9	98.3	118	42.1	2,083	0.012	551	1,889	5,394	43%	10%	30%	6.58	22.6	64.5
10	48.2	Little Tuc. R.	8.36	67.7	76.1	12.4	2,806	0.013	425	1,457	4,160	33%	3%	11%	5.63	19.3	55.1
10	50.2	Panjab Cr.	25.4	38.3	63.7	25.4	2,973	0.015	383	1,312	3,746	30%	8%	35%	5.73	19.6	56.1
10	55.2	*Above Panjab*	-	38.3	-	-	3,469	0.019	283	972	2,775	22%	-	-	5.43	18.7	53.2

Notes:
1. Flow change locations are reported to the nearest tenth of one mile.
2. River miles (RM) are based on 2010 main channel center line alignment as delineated by Anchor QEA using aerial photographs.
3. Total increase in drainage area includes Tucannon River Valley hill slope area and tributary area.
4. Elevations are from 2010 Aerial LiDAR bare earth returns.
5. Slope for basins is the averaged 100 feet channel segment gradient below the flow change location to the next flow change location.
6. Although total drainage area increases by 14 square miles between Kellogg Creek and the mouth of the river, no appreciable increase in peak discharge is expected from the valley wall slopes.

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APPENDIX B
SEDIMENT TRANSPORT AND MOBILITY ANALYSIS METHODS AND RESULTS

B.1 SEDIMENT DATA COLLECTION AND ANALYSIS

The sediment mobility and transport capacity in the main channel of the Tucannon River was calculated using the results of the HEC-RAS one-dimensional (1-D) hydraulic model and applicable sediment mobility and transport formula. These results were then compared to sediment grain size distributions from samples to evaluate erosional and depositional trends at locations along the Tucannon River.

B.1.1 Sediment Grain Size Sampling

Sampling of the bedload channel sediment within the main channel was conducted on gravel bars throughout 55 miles of the mainstem channel during August of 2010. The average discharge at the Starbuck gage during sampling was 49 cubic feet per second (cfs). This low-flow condition exposed sediment deposits transported by recent sediment mobilizing discharges; this material is assumed to be representative of the bedload. Bulk sediment samples and Wolman pebble counts (Wolman 1954) were taken at 23 locations distributed along 55 miles of river to capture potential changes in sediment grain size distribution. Two of the 23 samples were taken in major tributaries (Pataha and Panjab Creeks) upstream of their confluence with the Tucannon River, as well as an additional sample of bank sediment from Pataha Creek. Wolman pebble counts were used to define the surface armor grain size distribution, while bulk sediment samples were used to define the subsurface (sub-armor) grain size distribution. Details regarding the sediment grain size distribution for each sample are provided in the sediment grain size distribution reports at the end of this appendix as Attachment B-1. These reports also contain additional sample site notes and information.

B.1.2 Threshold Sediment Grain Size

The threshold (or critical) sediment grain size is the grain size that is just mobile under given hydraulic forces. This analysis used the dimensionless critical shear stress concept (Shields 1936) to define the mobility threshold for sediment grains exposed to the force of flowing water. The approach uses the following relationship between critical grain size (D_c) and critical dimensionless shear stress (τ^*_c):

$$\tau^*{}_c = \frac{\tau}{(\rho_s - \rho) g D_c} \qquad \text{(B-1)}$$

where:

τ	=	bed shear stress
ρ_s	=	sediment grain density
ρ	=	water density

For this evaluation, a critical dimensionless shear stress (τ^*_c) of 0.050 was used. This value is valid for critical grain sizes in the cobble size range (Fischenisch 2001).

B.1.3 Relative Mobility (Transport Stage)

The relative mobility of a given sediment grain size can be quantified using the dimensionless form of shear stress, Equation B-1, to determine the transport stage (Φ), Equation B-2.

$$\emptyset = \tau^*/\tau^*{}_c \quad \text{(B-2)}$$

where:

τ^*	=	dimensionless shear stress of a given grain size for a known shear stress
τ^*_c	=	dimensionless critical shear stress

Transport stage values less than 1.0 indicate an immobile grain size, whereas values greater than 1.0 indicate a mobile grain size. As the transport stage increases beyond a value of 1.0, the expected transport rate increases exponentially.

B.1.4 Sediment Mass Transport Capacity

The sediment mass transport capacity in the river was analyzed for the modeled flow events using representative grain sizes that are present in the bedload material. Four sediment transport models were used in this analysis: 1) Wilcock and Crowe (2003); 2) Wilcock (2001); 3) Meyer-Peter and Müller (1948, as modified by Wong and Parker 2006); and 4) Cui (2007). See the documents cited in the Reference section for a presentation and explanation of each sediment transport model. These models are most appropriate for systems with coarse sediments with median grain sizes larger than 2 millimeters (mm) (0.08 inches) (fine gravel).

The sediment transport models were used to calculate the spatial distribution of dimensionless transport rate (W^*) in the river during the modeled flow events. This information was used to calculate the sediment mass transport rate (Q_b) as follows in Equation B-3:

$$Q_b = \frac{W^* B {u^*}^3 \rho_s}{(s-1)g} \tag{B-3}$$

where:

W^*	=	dimensionless transport rate
B	=	transport width
u^*	=	shear velocity ($u^* = \sqrt{\tau/\rho_w}$)
τ	=	shear stress
ρ_w	=	fluid density
ρ_s	=	sediment grain density
s	=	sediment specific gravity
g	=	gravitational acceleration

B.1.5 Results

The results of the sediment mobility and transport analysis are presented in sets of plots organized by return period (*Figures B-1 through B-4 at the end of Appendix B*). Four plots in each figure cover the length of the model and show the following:

- The threshold (critical) sediment grain size at each model cross-section for the high and low discharges (Q) with error bars for a reasonable range in the critical dimensionless shear stress ($0.045 \leq \tau^*_c \leq 0.055$)
- The armor and sub-armor D_{50} (mm) at the sample locations (Pataha and Panjab Creek samples are labeled)
- The channel relative confinement, shown as a multi-colored bar near the top of the plot
- The locations of depositional areas as identified by the sediment mobility analysis and professional judgment
- The locations of the major tributaries used as flow change locations in the model
- The delineated reaches as defined in the main body of the report

Depositional Area Indicators

Areas that are likely to be depositional at a particular discharge may show any combination of the following:

- A critical grain size smaller than a nearby sediment sample grain size
- Visual evidence of gravel deposits in aerial photography or from site visits
- A sediment supply rate from upstream greater than the local transport capacity

Erosional Area Indicators

Areas that are likely to be erosional at a particular discharge may show any combination of the following:

- A critical grain size larger than a nearby sediment sample grain size
- Visual evidence of a plain bed channel with limited bed forms and steep banks
- A sediment supply rate from upstream less than the local transport capacity

Sediment Transport Rating Curves

Several sediment transport rating curves were developed for two locations on the Tucannon River: one just upstream of the Marengo discharge gage at RM 27.2 and the other near the Starbuck discharge gage at RM 8.1. These rating curves were developed using the methods described in Section B.1.4 - Sediment Mass Transport Capacity. The curves provide the unit mass transport capacity in the main channel for sediments with median grain sizes of 32, 48, 64, and 70 mm over a discharge range from 400 cfs to 5,000 cfs (approximately the 10-year return period peak discharge). For discharges larger than 5,000 cfs, backwater influences and extensive floodplain interaction disrupt the rating curve trend. Evaluation of transport capacity for events greater than the 10-year return period requires additional considerations. These rating curves are used in the sediment budget analysis (Appendix C) to determine annual sediment transport capacity.

B.1.6 Evaluation Summary

On the basin scale, the results of the analysis indicate:

- For a 1-year return period, the river is a mix of erosion and depositional areas.
- For a 2-year return period, the river is transitioning to mostly erosional, although

many depositional areas may remain.

- For a 5-year return period, the river is mostly erosional, although some depositional areas may remain.
- For a 10-year return period, the river is almost entirely erosional, although some small depositional areas may remain.

For events greater than the 10-year return period, the results indicate that the river is essentially entirely erosional during the peak discharge. However, at these large flood events, overbank flow and floodplain sediment deposition is likely.

In general, if the system is not entirely supply-limited, sediment will selectively deposit during the falling limb of event hydrographs in locations that tend to produce lower shear stresses than locations immediately upstream.

Potential Erosional Area Drivers

In general, the areas that tend to be erosional in the system have one or more of the following characteristics:

- Channel confinement relative to upstream sections. Confinement is natural in some locations but is most often the result of levees, roads, or bridge abutments. As the channel is confined, the depth for a given flow increases, resulting in greater hydraulic energy and erosional forces (i.e., shear stress).
- A local increase in channel slope over a distance sufficient to increase the flow velocity and decrease the flow depth. Overall variation in channel slope is gradual as the riverbed follows a concave down profile from the headwaters to the mouth. However, some increases in slope are sufficient to create local erosional areas.
- A change in discharge disproportionate to the change in channel cross-sectional area. However, these increases in discharge are often associated with tributaries that may also provide an increase in sediment supply, thus reducing the potential for net erosion.

Potential Depositional Area Drivers

In general, the areas that tend to be depositional in the system have one or more of the following characteristics:

- A wide accessible floodplain that limits channel confinement relative to upstream sections. Floodplain accessibility and the presence of side channels reduce the hydraulic forces in the main channel by dissipating hydraulic energy in the floodplain and reducing the discharge in the main channel.
- A local decrease in channel slope over a distance sufficient to decrease the flow velocity and increase the flow depth. Overall variation in channel slope is gradual as the riverbed follows a concave down profile from the headwaters to the mouth. However, some decreases in slope are sufficient to create local depositional areas (i.e., near the confluence with the Snake River).
- A backwater from a downstream channel constriction. Some locations upstream of major channel constrictions become backwatered as flow depth increases to pass through the constriction. These depositional areas may also limit the supply of sediment through the constricted channel section, thus increasing the likelihood of erosion through the constriction.
- A change in sediment supply disproportionate to the change in sediment transport capacity. These increases in sediment supply are associated with tributaries and other hill slope sediment sources.

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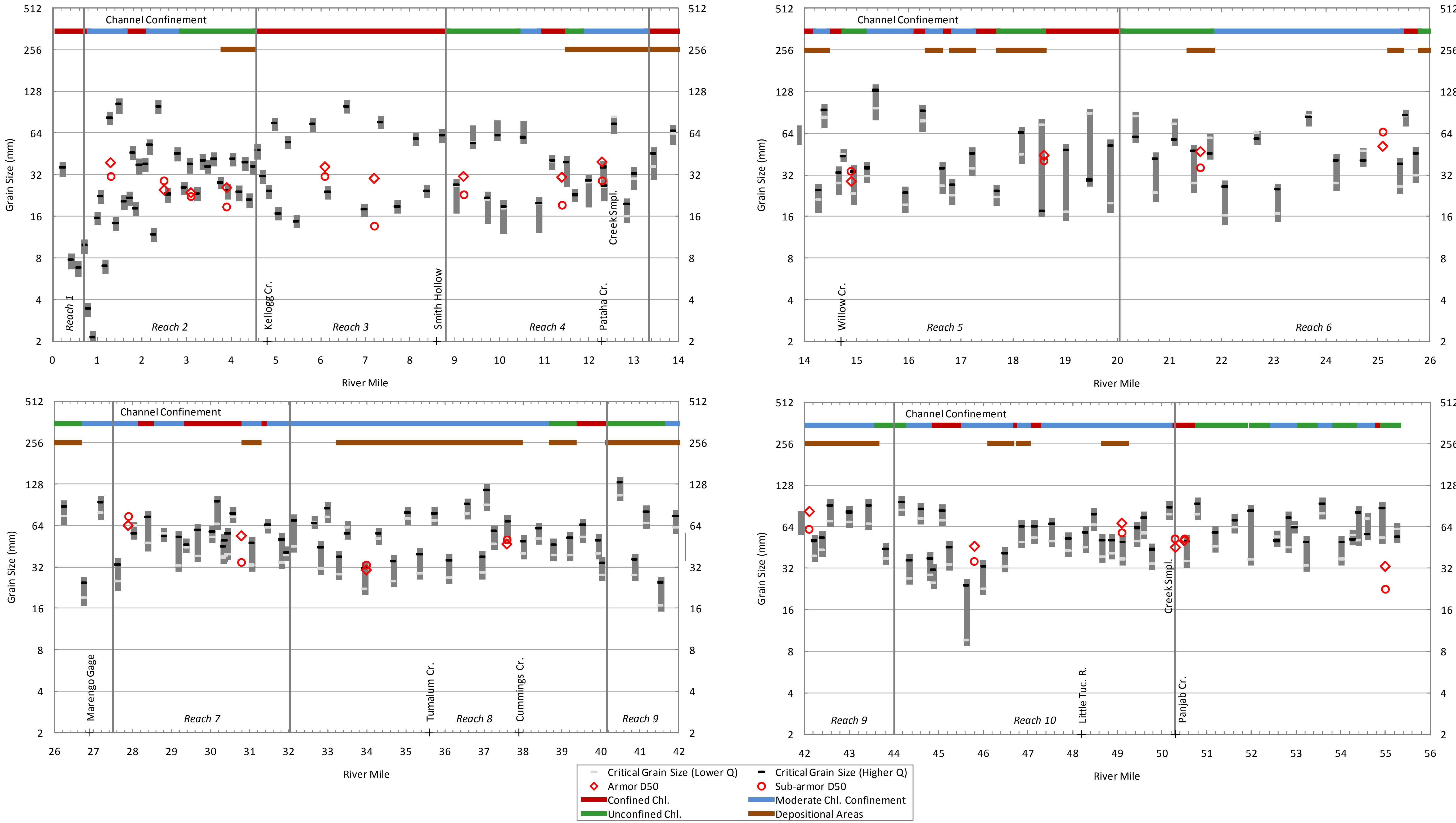
FIGURES

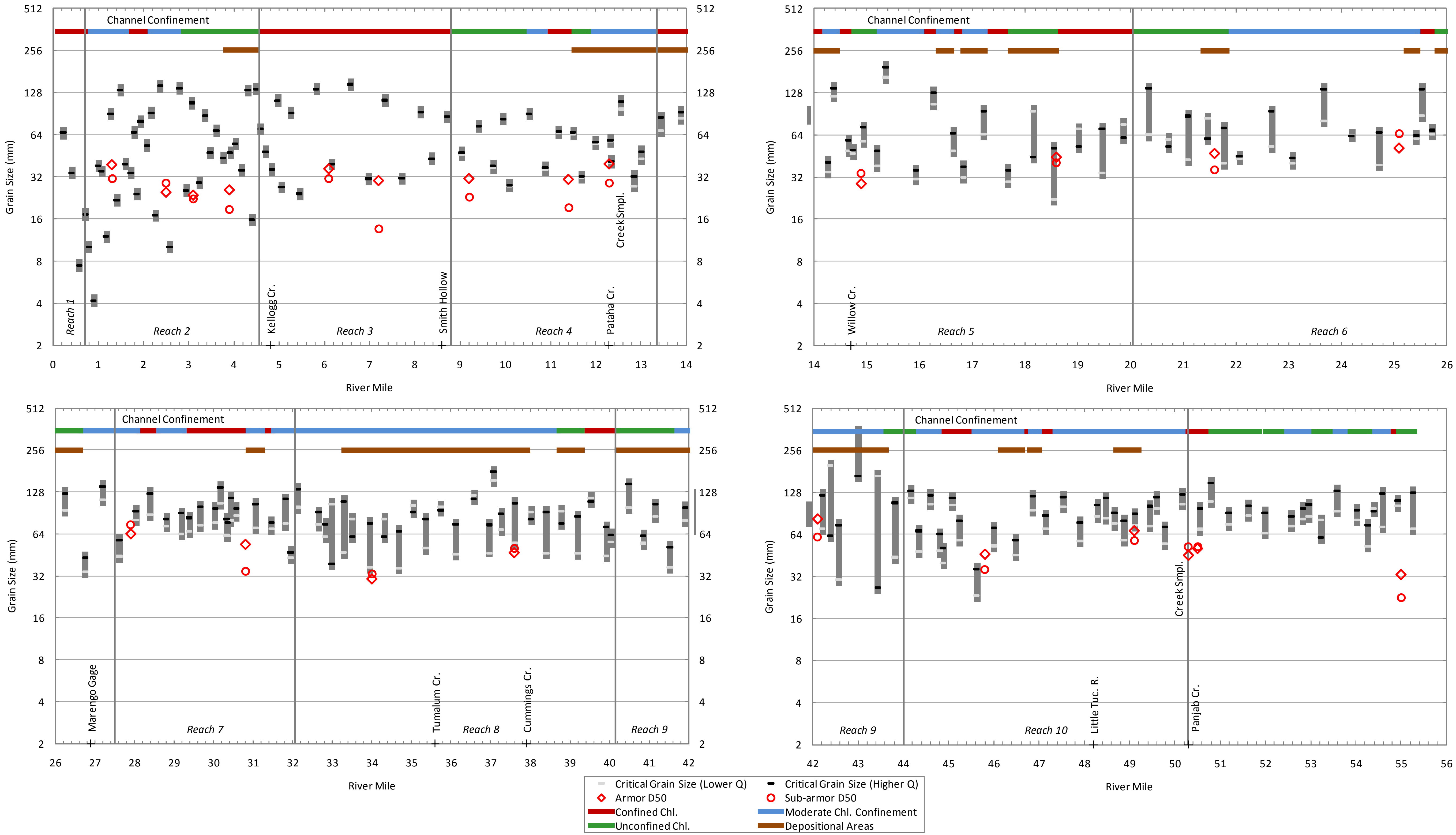


Notes:

1) Critical grain sizes are for a τ*c of 0.050 for the high and low discharge (Q) in the range.
2) Error Bars are for a τ*c of 0.045 and 0.055 above and below the range of discharges.
3) Armor and Sub-armor D50 is from field samples collected on gravel bars at low flow.
4) The 1 year return period flow (484 cfs at Starbuck) is estimated using a partial duration series for flood peaks and an LPIII analysis.
5) Flow change locations are labeled with the tributary name. The location of the gage at Marengo is also labeled.
6) Calculations use the main channel hydraulic conditions from the HEC-RAS 1-D basin scale LiDAR generated surface model. See Appendix and Report text for more information.
7) Channel confinement based on aerial photographs, valley bottom topography, and professional judgment.

ANCHOR QEA

Figure B-1
Erosion/Depositional Tendencies, 1-year Return Period Discharge Range
Draft Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District



Notes:

1) Critical grain sizes are for a τ*c of 0.050 for the high and low discharge (Q) in the range.
2) Error Bars are for a τ*c of 0.045 and 0.055 above and below the range of discharges.
3) Armor and Sub-armor D50 is from field samples collected on gravel bars at low flow.
4) Flow change locations are labeled with the tributary name. The location of the gage at Marengo is also labeled.
5) Calculations use the main channel hydraulic conditions from the HEC-RAS 1-D basin scale LiDAR generated surface model. See Appendix and Report text for more information.
6) Channel confinement based on aerial photographs, valley bottom topography, and professional judgment.

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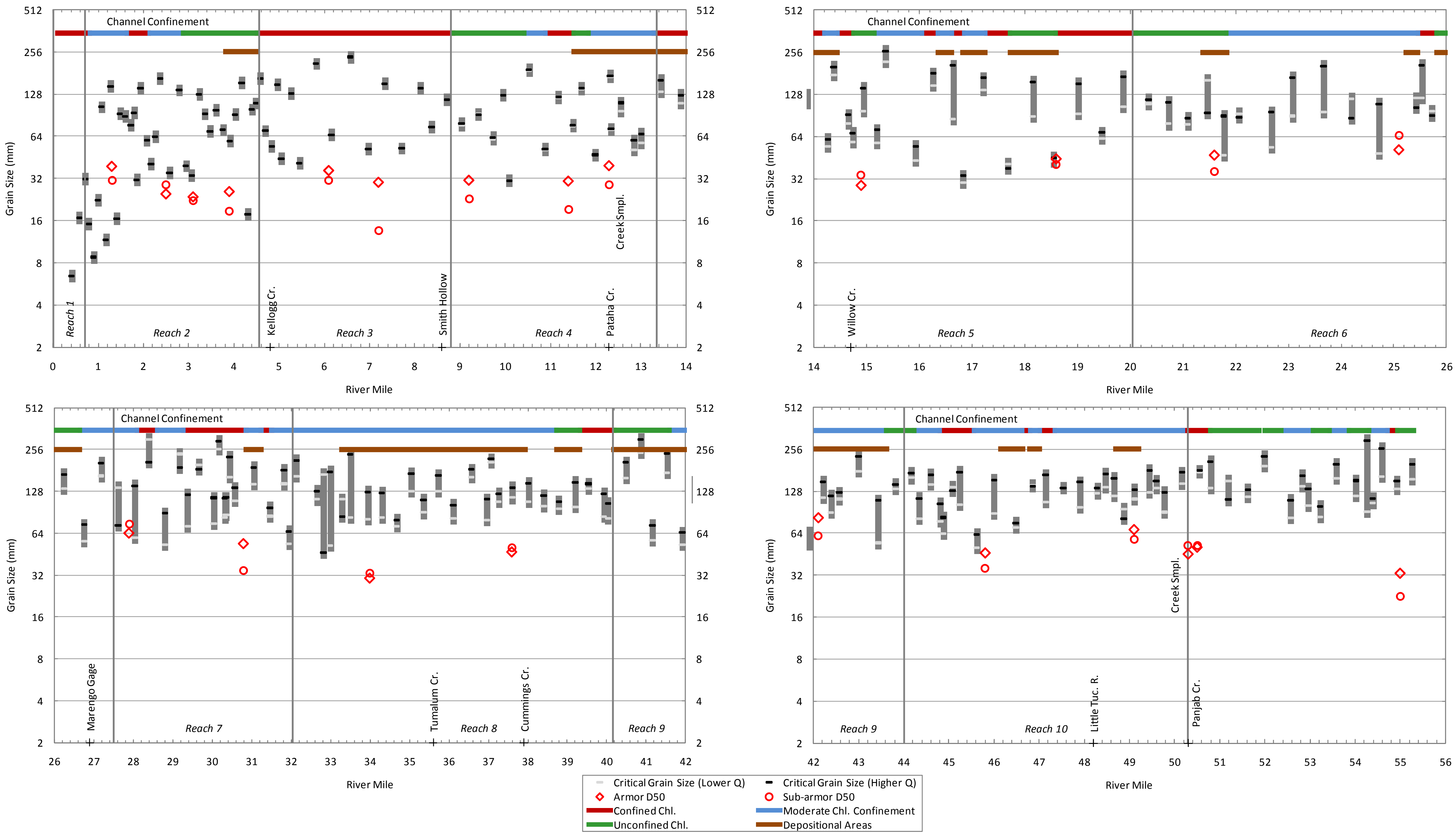
ANCHOR QEA

Figure B-2
Erosion/Depositional Tendencies, 2-year Return Period Discharge Range
Draft Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District

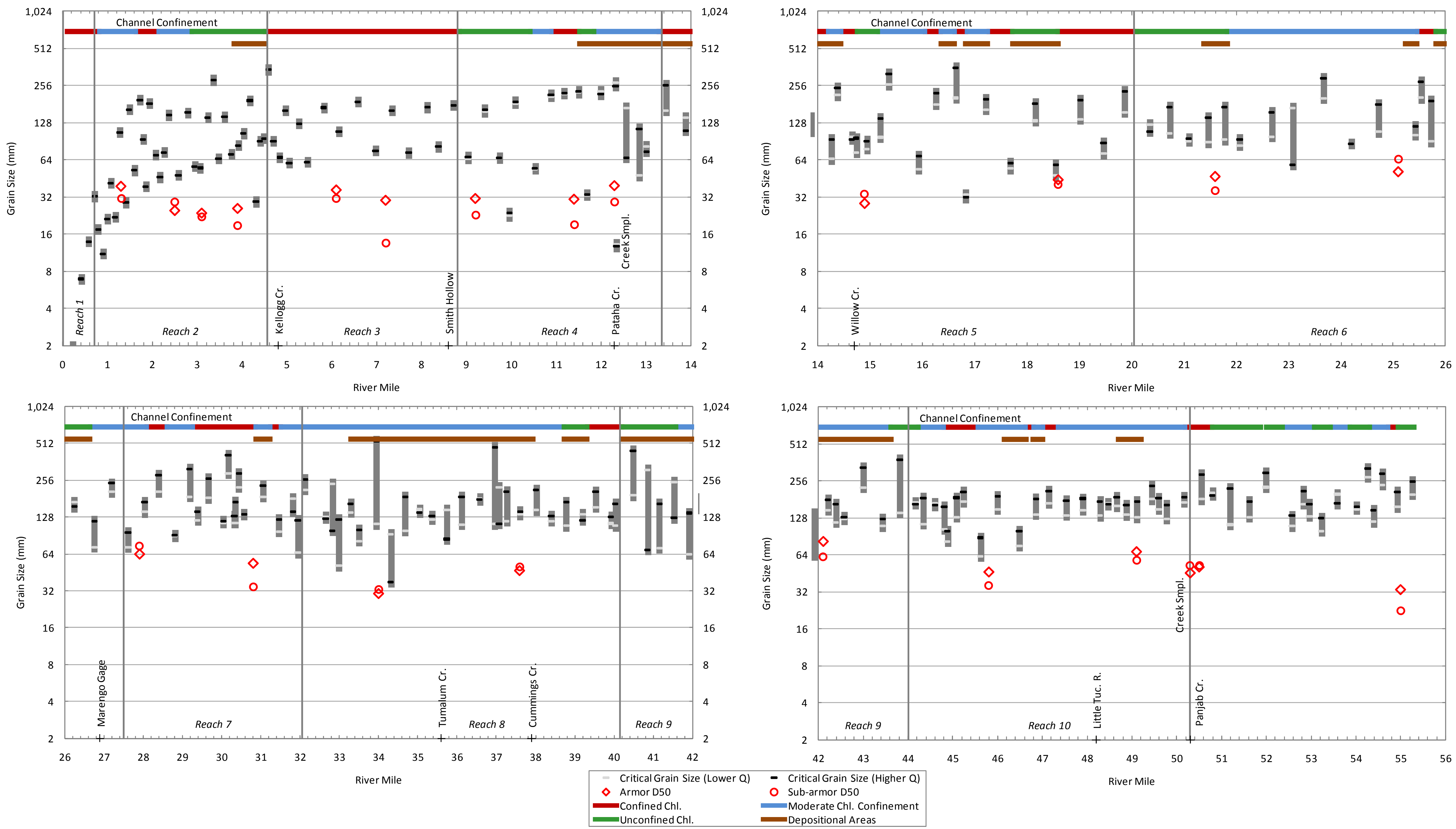


Notes:

1) Critical grain sizes are for a τ*c of 0.050 for the high and low discharge (Q) in the range.
2) Error Bars are for a τ*c of 0.045 and 0.055 above and below the range of discharges.
3) Armor and Sub-armor D50 is from field samples collected on gravel bars at low flow.
4) Flow change locations are labeled with the tributary name. The location of the gage at Marengo is also labeled.
5) Calculations use the main channel hydraulic conditions from the HEC-RAS 1-D basin scale LiDAR generated surface model. See Appendix and Report text for more information.
6) Channel confinement based on aerial photographs, valley bottom topography, and professional judgment.

ANCHOR QEA

Figure B-3
Erosion/Depositional Tendencies, 5-year Return Period Discharge Range
Draft Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District



Notes:

1) Critical grain sizes are for a τ*c of 0.050 for the high and low discharge (Q) in the range.
2) Error Bars are for a τ*c of 0.045 and 0.055 above and below the range of discharges.
3) Armor and Sub-armor D50 is from field samples collected on gravel bars at low flow.
4) Flow change locations are labeled with the tributary name. The location of the gage at Marengo is also labeled.
5) Calculations use the main channel hydraulic conditions from the HEC-RAS 1-D basin scale LiDAR generated surface model. See Appendix and Report text for more information.
6) Channel confinement based on aerial photographs, valley bottom topography, and professional judgment.

ANCHOR QEA

Figure B-4
Erosion/Depositional Tendencies, 10-year Return Period Discharge Range
Draft Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District

ATTACHMENT B-1
SEDIMENT GRAIN SIZE DISTRIBUTION REPORTS

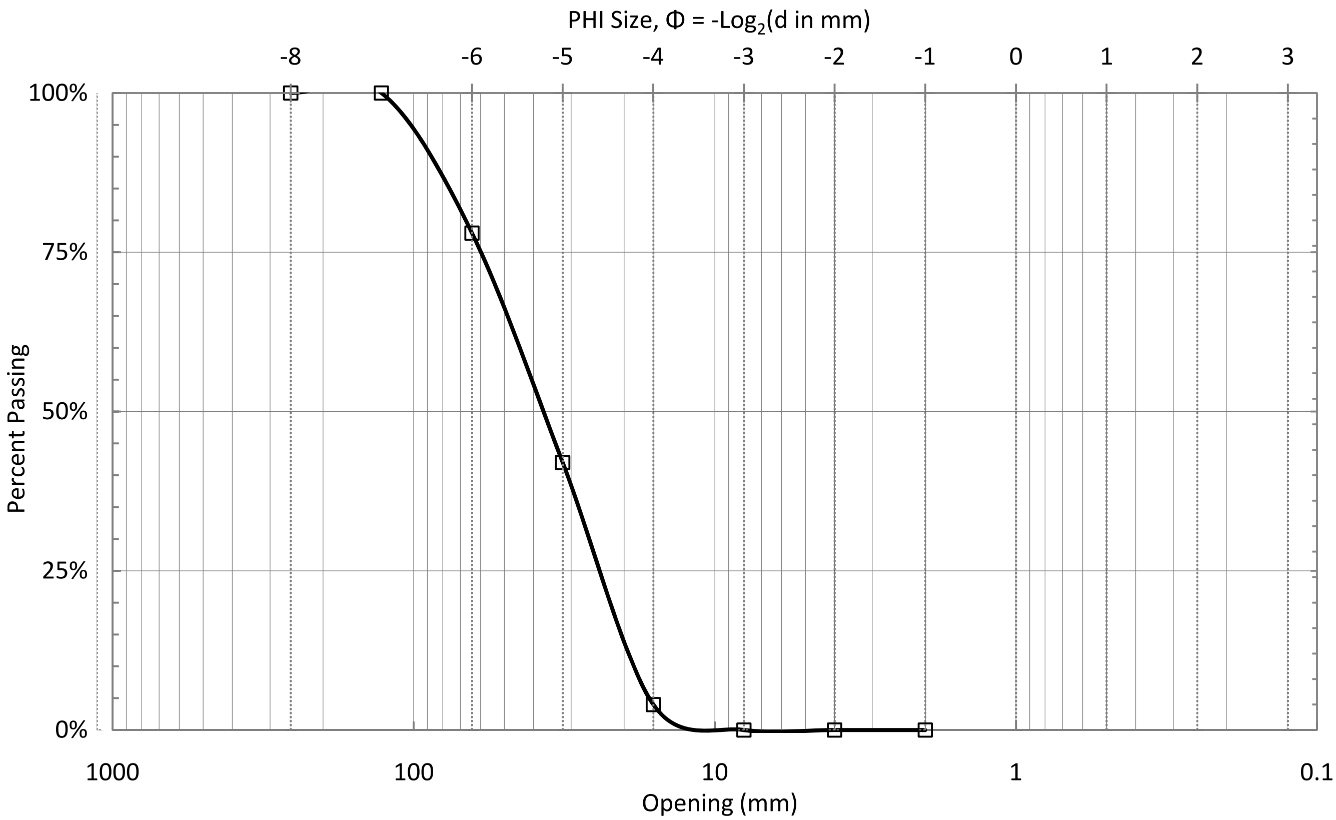
Sediment Grain Size Distribution Report

Summary

Project: Tucannon River
Client: CCD

		Grain Size (in mm)		Percent in Subarmor Layer				
				64-256 mm	2-64 mm	0.625-2mm	<0.625 mm	64-256 mm
Sample	**River Mile**	**Armor D_{50}**	**Sub-armor D_{50}**	**Cobble**	**Gravel**	**Sand**	**Fines**	**Cobble**
Tucannon 1 - Downstream of 261 Bridge	1.3	39	31	16%	73%	9%	2%	
Tucannon 2	2.5	25	29	2%	92%	6%	1%	
Tucannon 3 - Lower Tucannon Ranch	3.1	24	22	2%	85%	12%	1%	
Tucannon 4 - Upper Tucannon Ranch	3.9	26	19	12%	79%	9%	0%	
Tucannon 5 - Downstream of Fletcher Road	6.1	37	31	17%	75%	7%	1%	
Tucannon 6	7.2	30	14	5%	77%	17%	2%	
Tucannon 7 - RV Park	9.2	31	23	15%	71%	13%	1%	
Tucannon 8 - Red Roof House	11.4	31	19	4%	80%	12%	3%	
Tucannon 9 - Pataha Creek	Pataha 1.3	40	29	14%	76%	9%	1%	
Tucannon 10 - Upstream of Highway 12 Bridge	14.9	29	34	4%	94%	1%	1%	
Tucannon 11 - Upstream of Brines Bridge	18.6	44	40	14%	85%	1%	0%	
Tucannon 12	21.6	47	36	21%	74%	3%	1%	
Tucannon 13	25.1	51	65	51%	48%	1%	0%	
Tucannon 14	27.9	64	74	58%	41%	0%	0%	
Tucannon 15	30.8	54	34	20%	69%	10%	0%	
Tucannnon 16 - WDFW	34	30	33	18%	69%	12%	1%	
Tucannnon 17	37.6	47	50	38%	57%	5%	0%	
Tucannnon 18	42.1	82	62	48%	49%	2%	0%	
Tucannnon 19 - Tucannon Camp	45.8	46	36	29%	61%	9%	0%	
Tucannnon 20 - Campground Beach	49.1	68	58	41%	59%	0%	0%	
Tucannnon 21 - Panjab Creek	Panjab	45	52	20%	72%	7%	0%	
Tucannnon 22 - Upstream of Panjab	50.5	51	53	36%	58%	5%	0%	
Tucannnon 23	55	33	23	23%	64%	12%	0%	

Average		42	38	22%	70%	7%	1%
Minimum		24	14	2%	41%	0%	0%
Maximum		82	74	58%	94%	17%	3%
Standard Deviation		14.9	16.5	16%	14%	5%	1%



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
10"	10	256	100%
5"	5.0	128	100%
2-1/2"	2.5	64	78.0%
1-1/4"	1.3	32	42.0%
5/8"	0.63	16	4.00%
5/16"	0.31	8.0	0.00%
No. 5	0.16	4.0	0.00%
No. 10	0.079	2.0	0.00%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
0%	100%	0%	NA

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	52
D_{50}=	39
D_{30}=	-
D_{15}=	-
D_{10}=	-

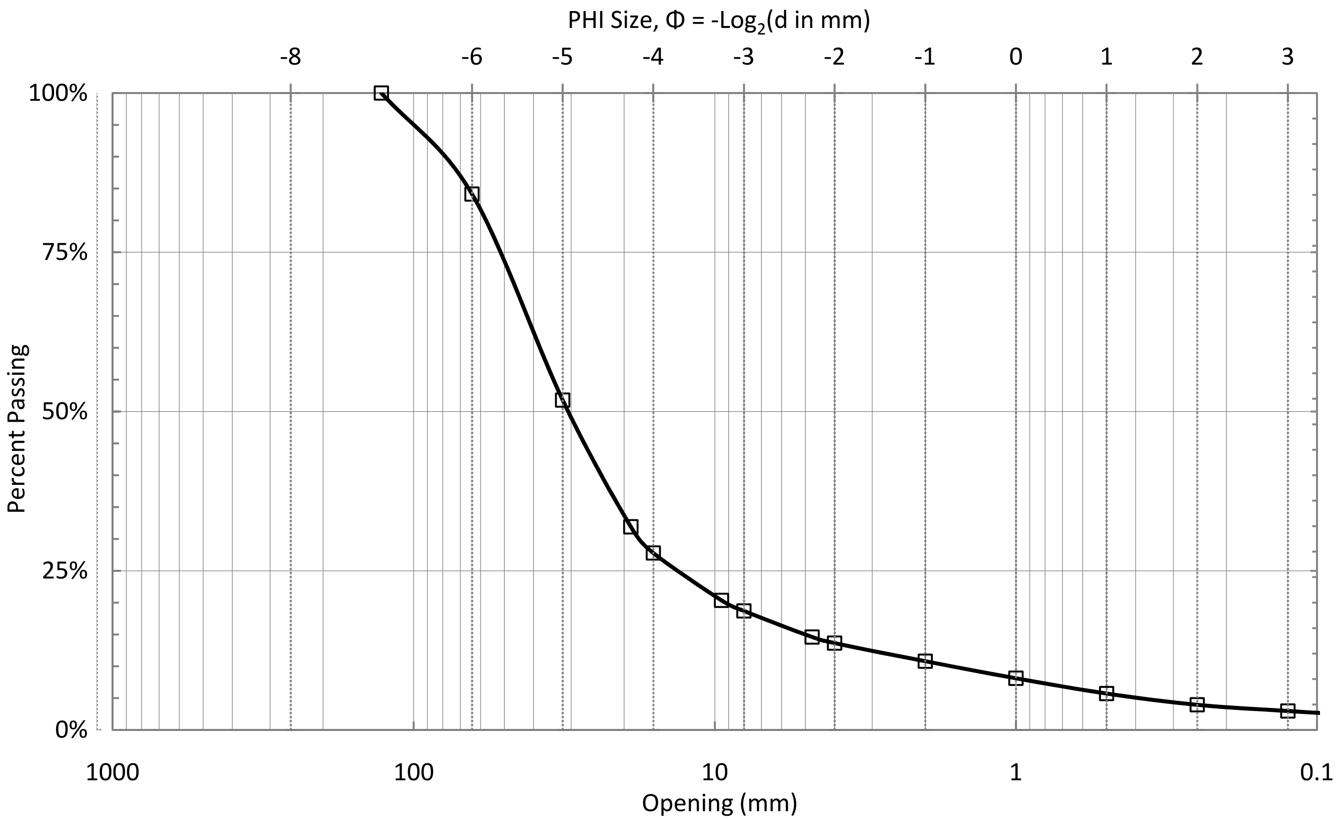
Sample Location

River Mile 1.3

Armor X

Sub-Armor

Location Notes



US Sieve Class	*Nominal Opening (in)*	*Nominal Opening (mm)*	*Percent Passing*
5"	5.0	128	100%
2-1/2"	2.5	64	84.1%
1-1/4"	1.3	32	51.8%
3/4"	0.75	19	31.9%
5/8"	0.63	16	27.8%
3/8"	0.37	9.5	20.4%
5/16"	0.31	8.0	18.7%
No. 4	0.187	4.75	14.6%
No. 5	0.16	4.0	13.6%
No. 10	0.079	2.0	10.8%
No. 18	0.039	1.0	8.13%
No. 35	0.020	0.50	5.73%
No. 60	0.010	0.25	3.96%
No. 120	0.0049	0.125	2.98%
No. 200	0.0030	0.075	2.37%
No. 230	0.0025	0.063	2.23%
No. 270	0.0021	0.053	0.00%

Pct. Cobbles	*Pct. Gravel*	*Pct. Sand*	*Pct. Fines*
16%	73%	9%	2%

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	45
D_{50}=	31
D_{30}=	-
D_{15}=	-
D_{10}=	-

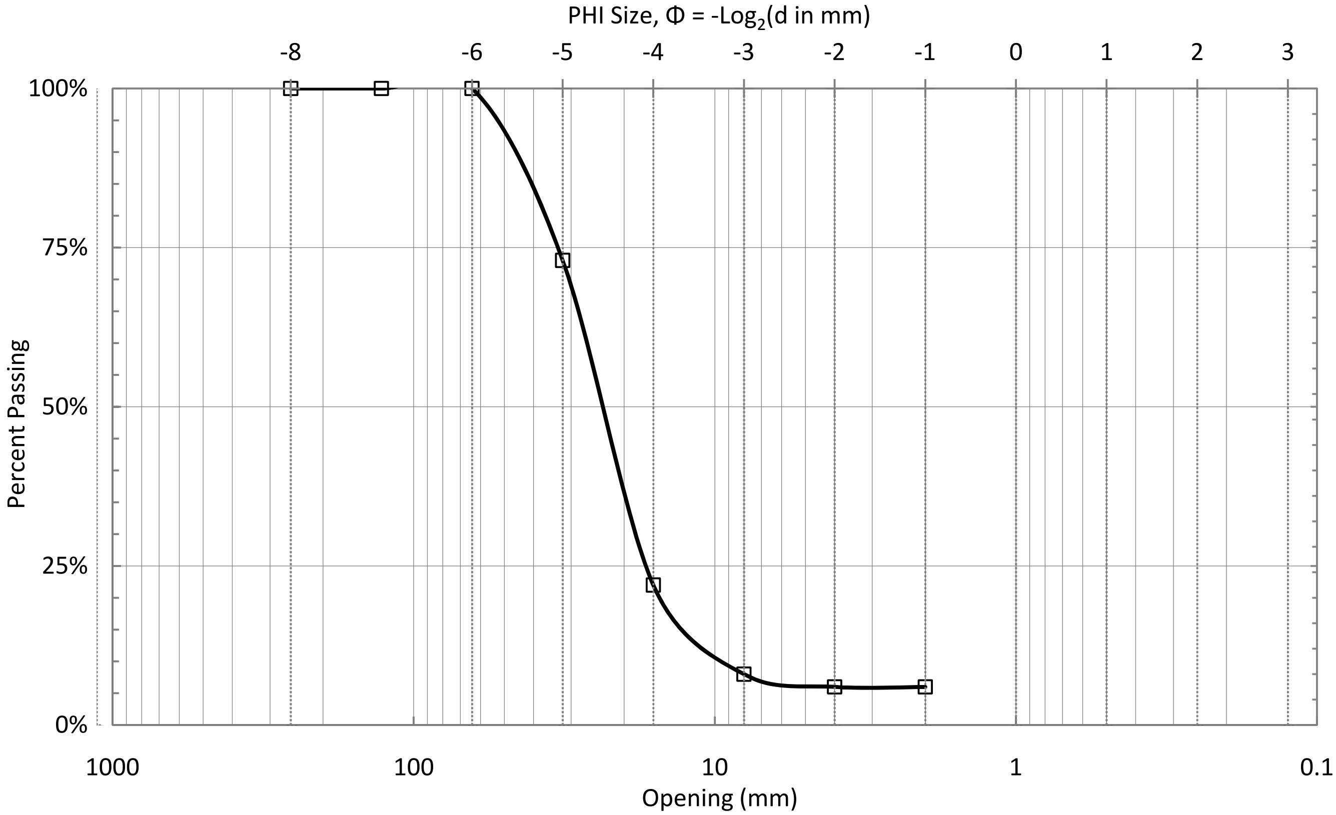
Sample Location

River Mile 1.3

Armor

Sub-Armor X

Location Notes



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
10"	10	256	100%
5"	5.0	128	100%
2-1/2"	2.5	64	100%
1-1/4"	1.3	32	73.0%
5/8"	0.63	16	22.0%
5/16"	0.31	8.0	8.00%
No. 5	0.16	4.0	6.00%
No. 10	0.079	2.0	6.00%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
0%	94%	6%	NA

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	29
D_{50}=	25
D_{30}=	-
D_{15}=	-
D_{10}=	-

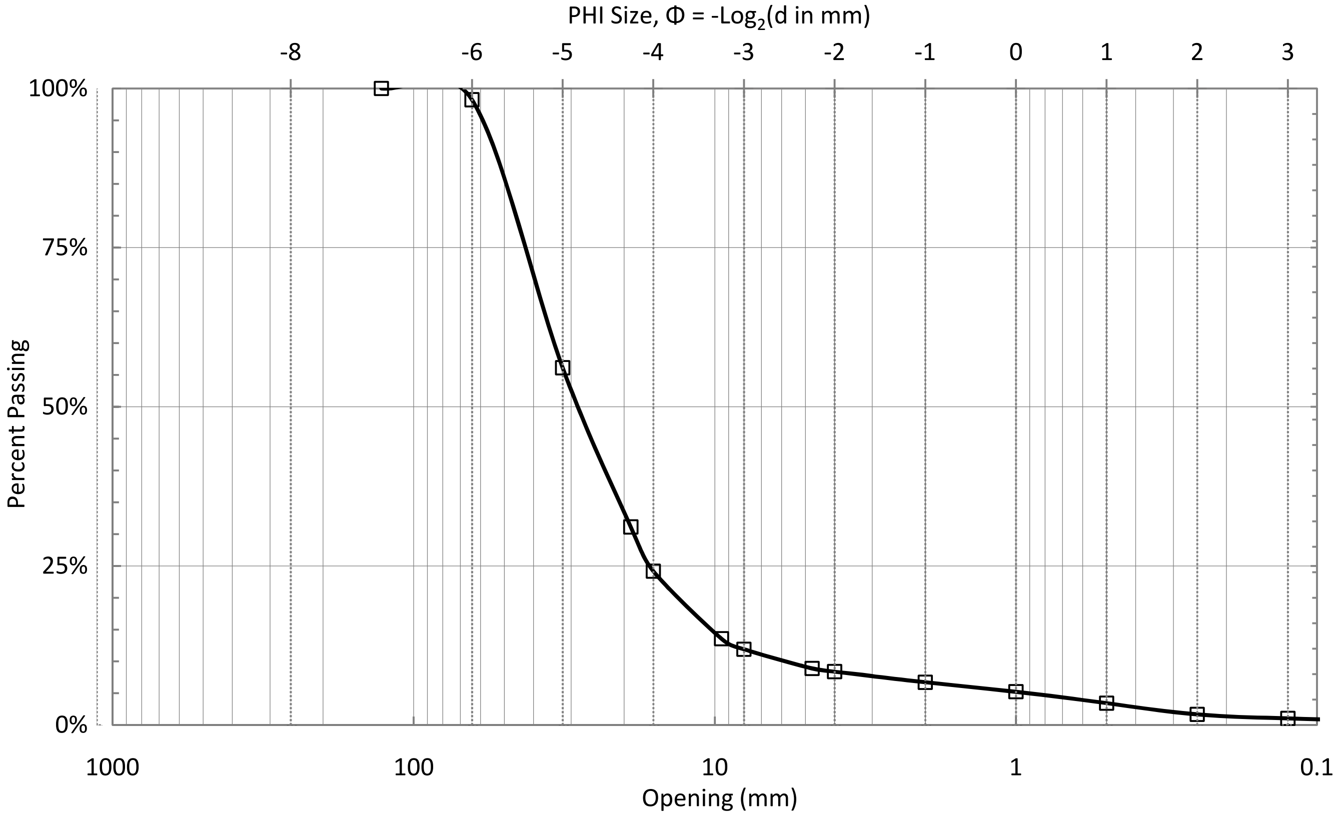
Sample Location

River Mile 2.5

Armor X

Sub-Armor

Location Notes



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
5"	5.0	128	100%
2-1/2"	2.5	64	98.2%
1-1/4"	1.3	32	56.1%
3/4"	0.75	19	31.1%
5/8"	0.63	16	24.2%
3/8"	0.37	9.5	13.6%
5/16"	0.31	8.0	11.9%
No. 4	0.187	4.75	8.90%
No. 5	0.16	4.0	8.40%
No. 10	0.079	2.0	6.72%
No. 18	0.039	1.0	5.24%
No. 35	0.020	0.50	3.44%
No. 60	0.010	0.25	1.67%
No. 120	0.0049	0.125	1.05%
No. 200	0.0030	0.075	0.774%
No. 230	0.0025	0.063	0.726%
No. 270	0.0021	0.053	0.000%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
2%	92%	6%	1%

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	39
D_{50}=	29
D_{30}=	-
D_{15}=	-
D_{10}=	-

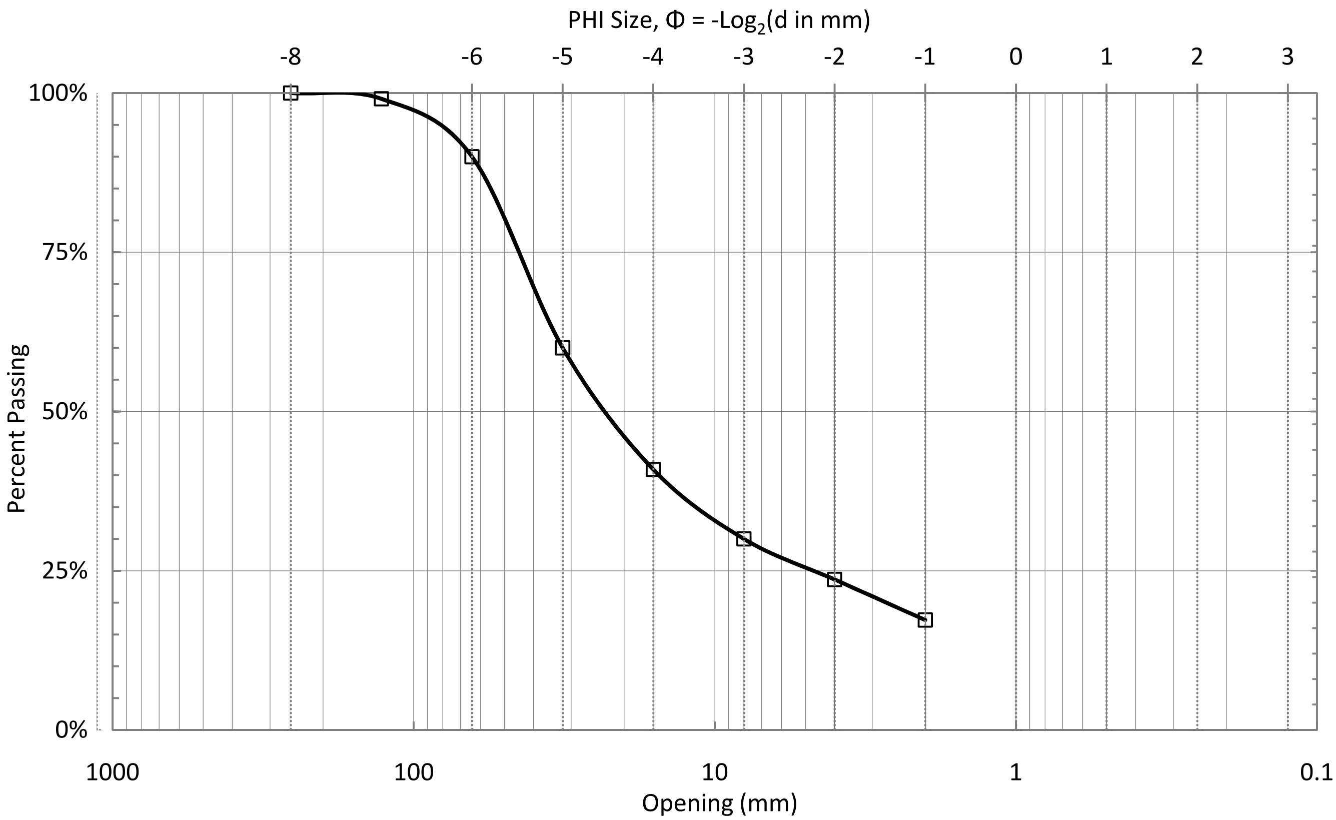
Sample Location

River Mile 2.5

Armor

Sub-Armor X

Location Notes



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
10"	10	256	100%
5"	5.0	128	99.1%
2-1/2"	2.5	64	90.0%
1-1/4"	1.3	32	60.0%
5/8"	0.63	16	40.9%
5/16"	0.31	8.0	30.0%
No. 5	0.16	4.0	23.6%
No. 10	0.079	2.0	17.3%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
1%	75%	24%	NA

Sample Location

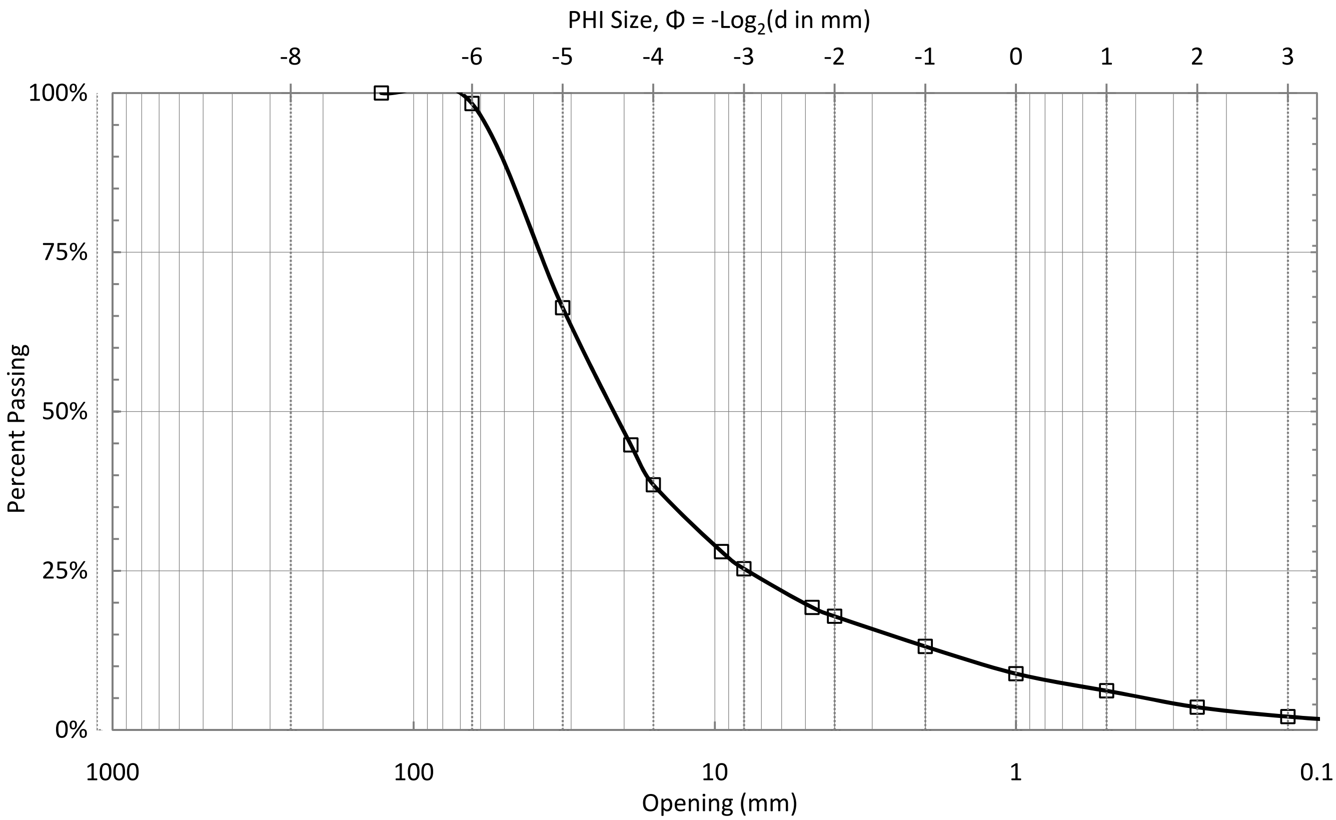
River Mile 3.1

Armor X

Sub-Armor

Location Notes

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	37
D_{50}=	24
D_{30}=	-
D_{15}=	-
D_{10}=	-



US Sieve Class	Nominal Opening (in)	(mm)	Percent Passing
5"	5.0	128	100%
2-1/2"	2.5	64	98.4%
1-1/4"	1.3	32	66.3%
3/4"	0.75	19	44.8%
5/8"	0.63	16	38.5%
3/8"	0.37	9.5	28.0%
5/16"	0.31	8.0	25.3%
No. 4	0.187	4.75	19.2%
No. 5	0.16	4.0	17.9%
No. 10	0.079	2.0	13.1%
No. 18	0.039	1.0	8.85%
No. 35	0.020	0.50	6.17%
No. 60	0.010	0.25	3.58%
No. 120	0.0049	0.125	2.10%
No. 200	0.0030	0.075	1.45%
No. 230	0.0025	0.063	1.45%
No. 270	0.0021	0.053	0.00%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
2%	85%	12%	1%

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	31
D_{50}=	22
D_{30}=	-
D_{15}=	-
D_{10}=	-

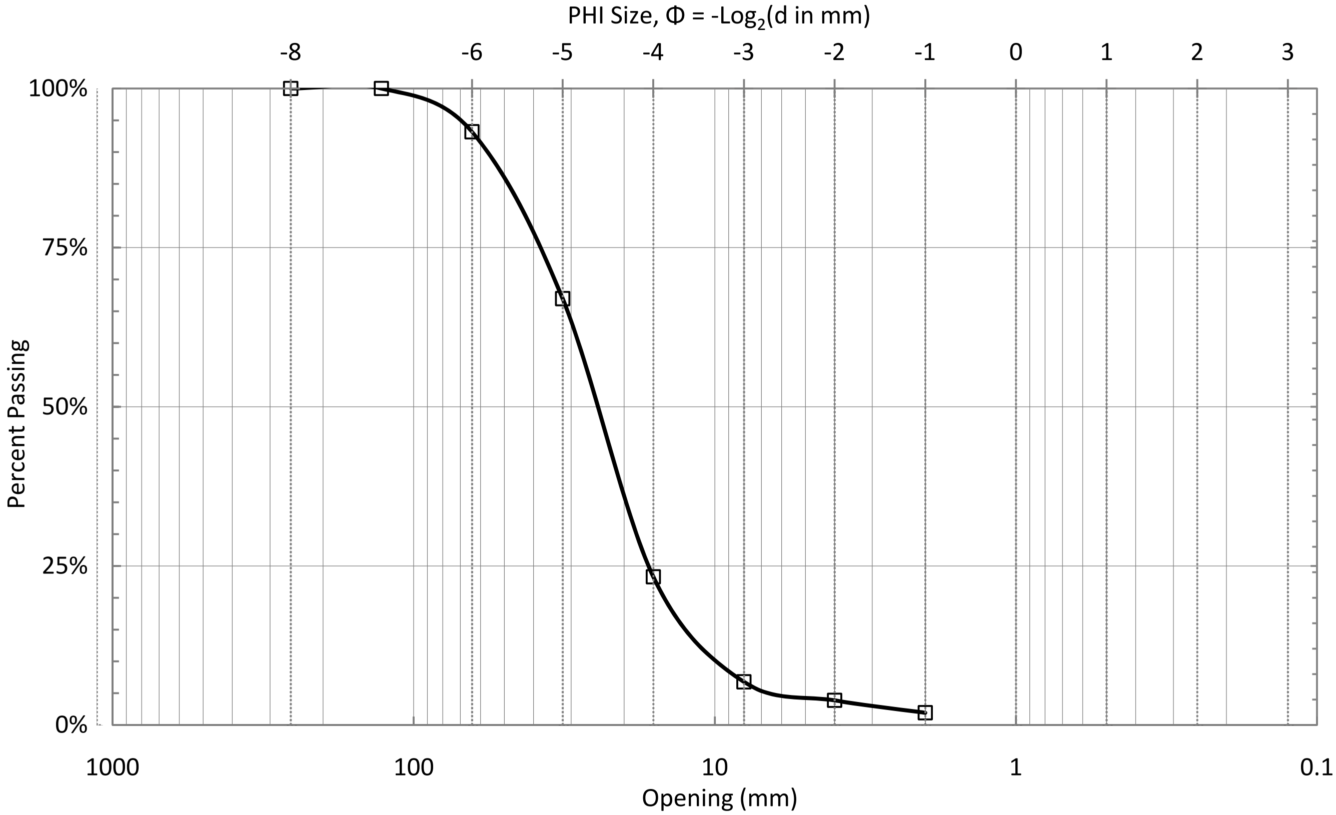
Sample Location

River Mile 3.1

Armor

Sub-Armor X

Location Notes



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
10"	10	256	100%
5"	5.0	128	100%
2-1/2"	2.5	64	93.2%
1-1/4"	1.3	32	67.0%
5/8"	0.63	16	23.3%
5/16"	0.31	8.0	6.80%
No. 5	0.16	4.0	3.88%
No. 10	0.079	2.0	1.94%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
0%	96%	4%	NA

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	31
D_{50}=	26
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

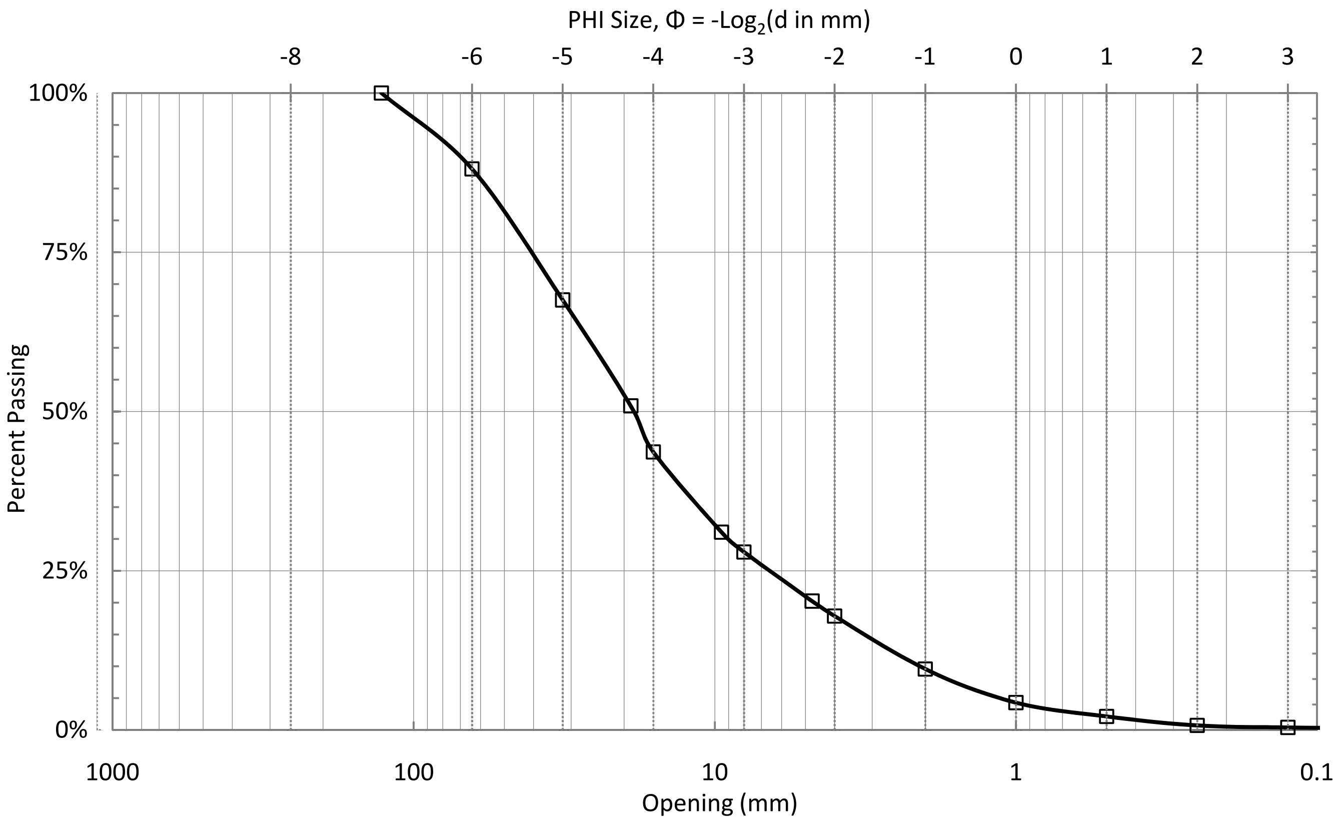
River Mile 3.9

Armor X

Sub-Armor

Location Notes

Mid-channel bar where channel splits just downstream of riprap on left bank. Gravel dug from channel.



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
5"	5.0	128	100%
2-1/2"	2.5	64	88.1%
1-1/4"	1.3	32	67.5%
3/4"	0.75	19	50.9%
5/8"	0.63	16	43.6%
3/8"	0.37	9.5	31.1%
5/16"	0.31	8.0	28.0%
No. 4	0.187	4.75	20.2%
No. 5	0.16	4.0	17.9%
No. 10	0.079	2.0	9.58%
No. 18	0.039	1.0	4.31%
No. 35	0.020	0.50	2.14%
No. 60	0.010	0.25	0.717%
No. 120	0.0049	0.125	0.408%
No. 200	0.0030	0.075	0.294%
No. 230	0.0025	0.063	0.290%
No. 270	0.0021	0.053	0.00%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
12%	79%	9%	0%

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	30
D_{50}=	19
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

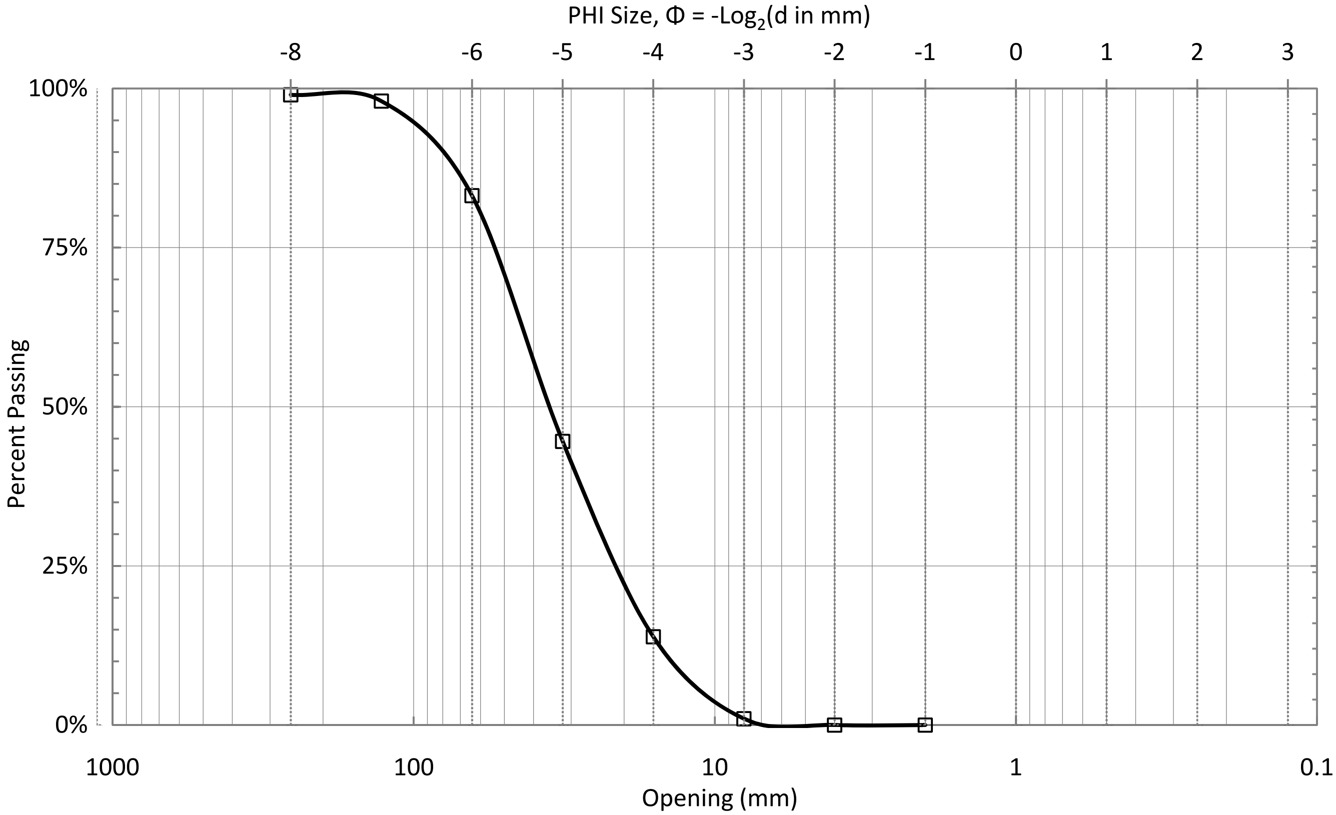
River Mile 3.9

Armor

Sub-Armor X

Location Notes

Mid-channel bar where channel splits just downstream of riprap on left bank. Gravel dug from channel.



US Sieve Class	*Nominal Opening (in)*	*(mm)*	*Percent Passing*
10"	10	256	99.0%
5"	5.0	128	98.0%
2-1/2"	2.5	64	83.2%
1-1/4"	1.3	32	44.6%
5/8"	0.63	16	13.9%
5/16"	0.31	8.0	0.990%
No. 5	0.16	4.0	0.00%
No. 10	0.079	2.0	0.00%

Pct. Cobbles	*Pct. Gravel*	*Pct. Sand*	*Pct. Fines*
2%	98%	0%	NA

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	49
D_{50}=	37
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

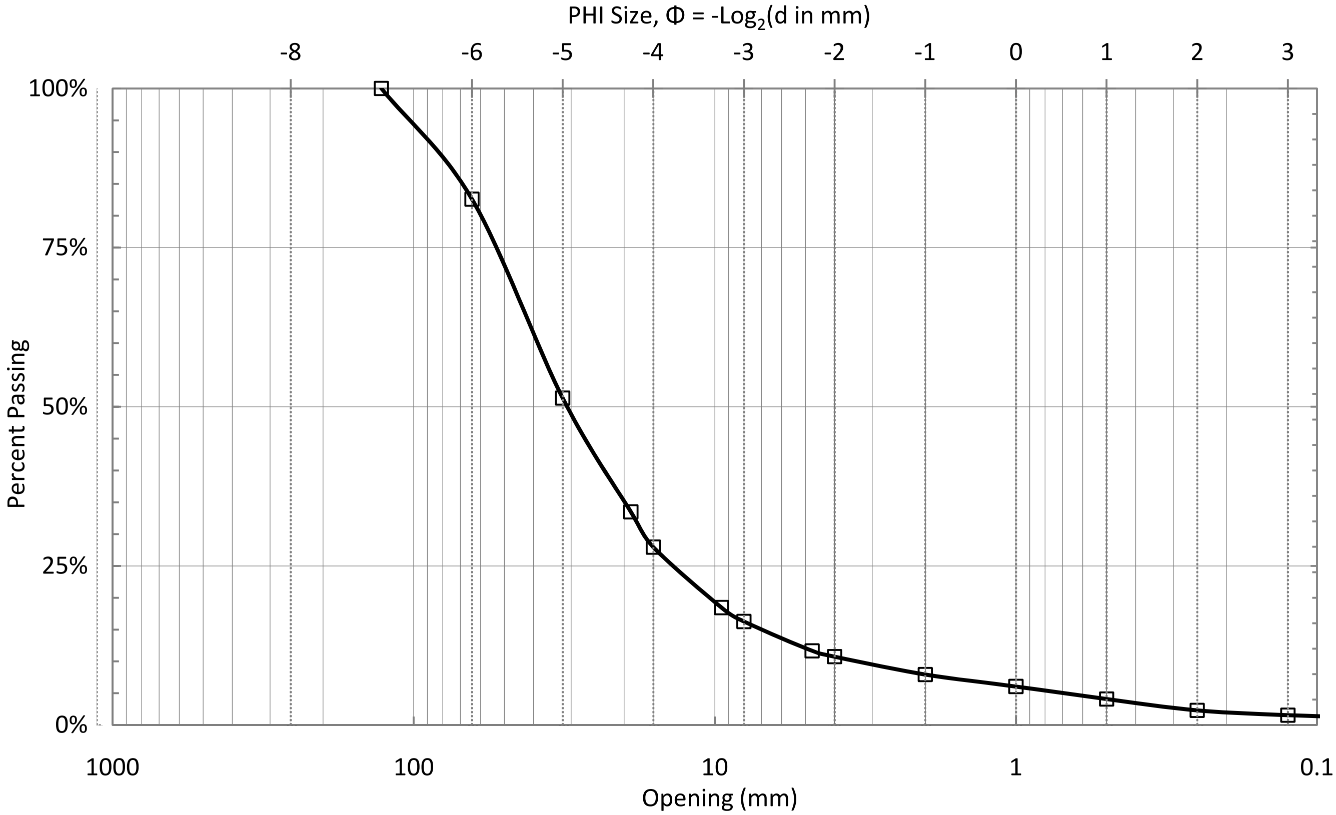
River Mile 6.1

Armor X

Sub-Armor

Location Notes

Some of the larger cobbles appear to be riprap from upstream. Sample location downstream of engineered rock weir.



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
5"	5.0	128	100%
2-1/2"	2.5	64	82.6%
1-1/4"	1.3	32	51.4%
3/4"	0.75	19	33.5%
5/8"	0.63	16	28.0%
3/8"	0.37	9.5	18.5%
5/16"	0.31	8.0	16.3%
No. 4	0.187	4.75	11.7%
No. 5	0.16	4.0	10.7%
No. 10	0.079	2.0	7.94%
No. 18	0.039	1.0	6.06%
No. 35	0.020	0.50	4.09%
No. 60	0.010	0.25	2.31%
No. 120	0.0049	0.125	1.56%
No. 200	0.0030	0.075	1.26%
No. 230	0.0025	0.063	1.21%
No. 270	0.0021	0.053	0.00%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
17%	75%	7%	1%

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	46
D_{50}=	31
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

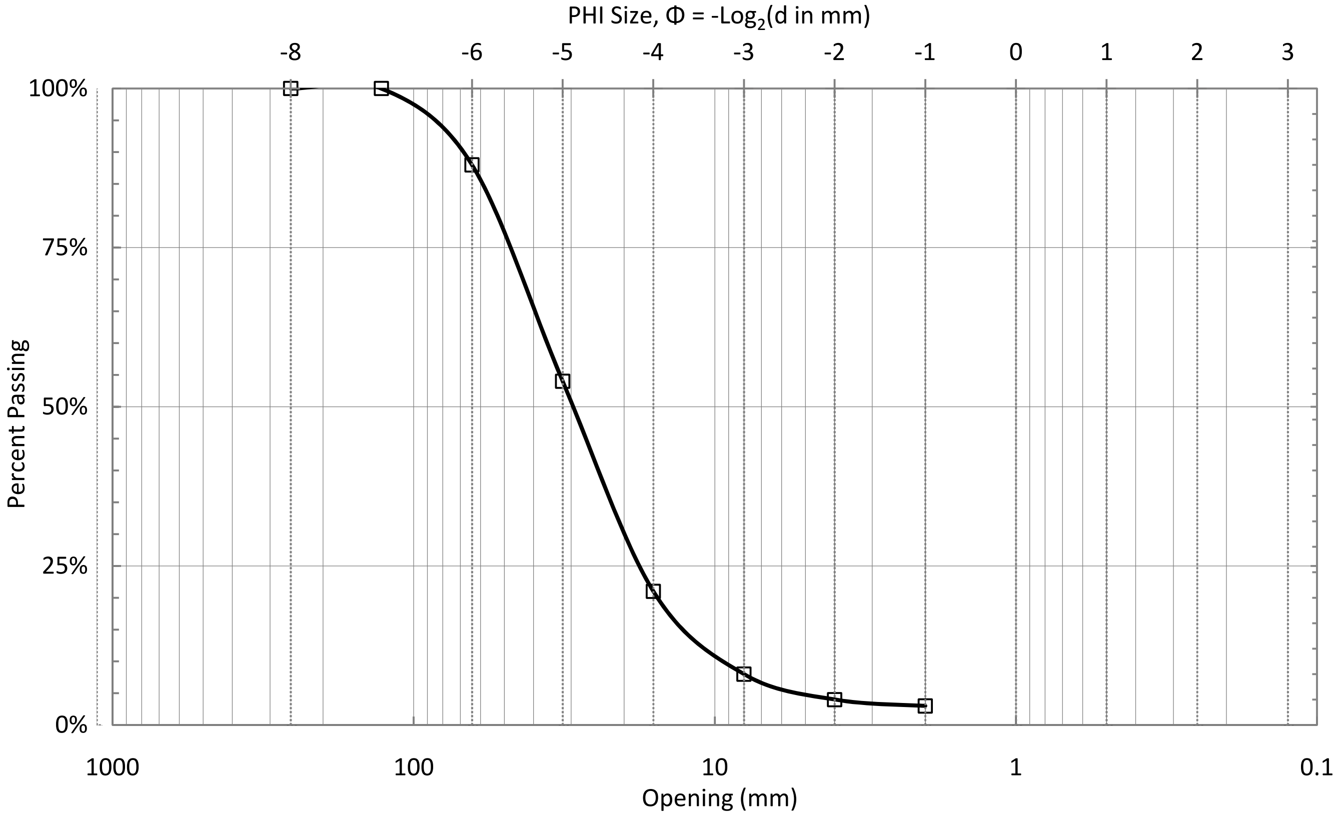
River Mile 6.1

Armor

Sub-Armor X

Location Notes

Some of the larger cobbles appear to be riprap from upstream. Sample location downstream of engineered rock weir.



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
10"	10	256	100%
5"	5.0	128	100%
2-1/2"	2.5	64	88.0%
1-1/4"	1.3	32	54.0%
5/8"	0.63	16	21.0%
5/16"	0.31	8.0	8.00%
No. 5	0.16	4.0	4.00%
No. 10	0.079	2.0	3.00%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
0%	96%	4%	NA

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	42
D_{50}=	30
D_{30}=	-
D_{15}=	-
D_{10}=	-

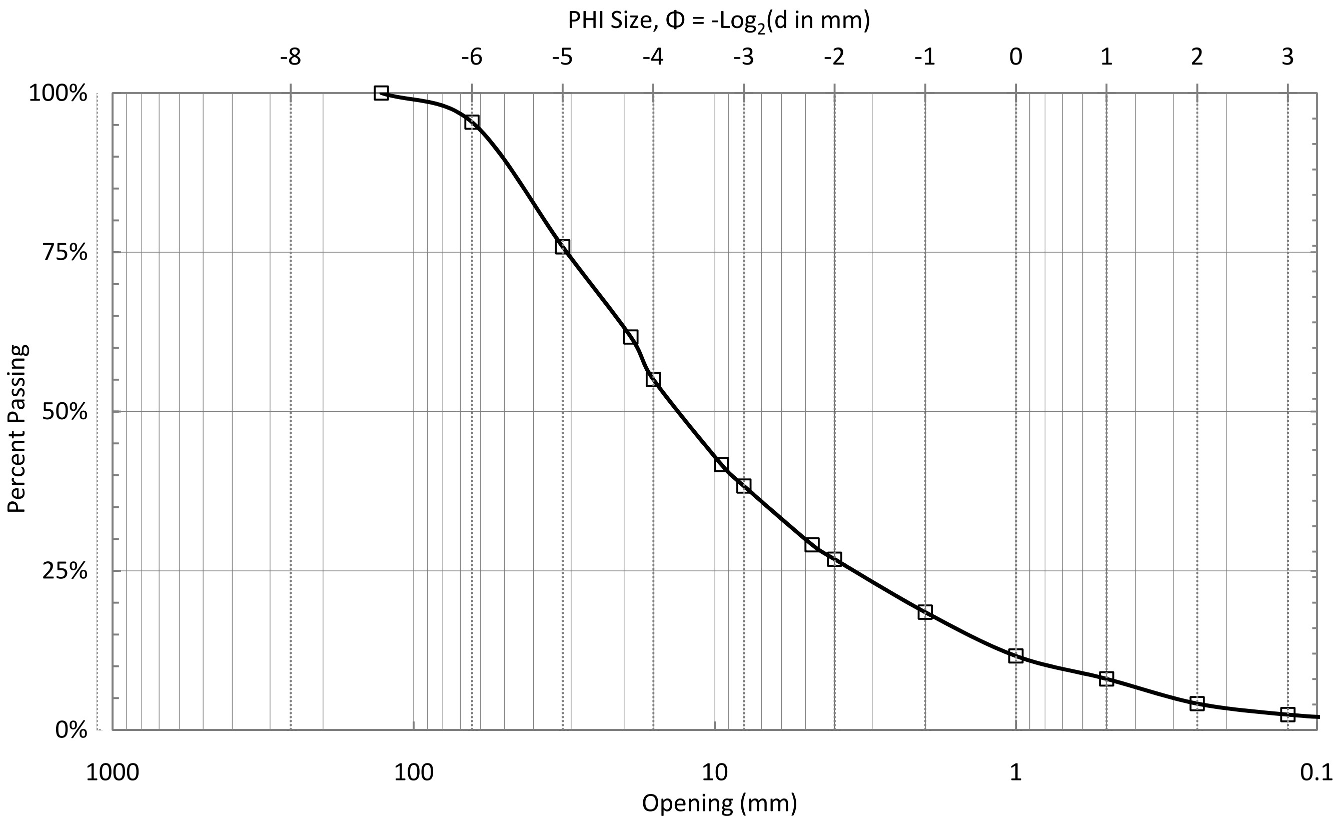
Sample Location

River Mile 7.2

Armor X

Sub-Armor

Location Notes



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
5"	5.0	128	100%
2-1/2"	2.5	64	95.4%
1-1/4"	1.3	32	75.9%
3/4"	0.75	19	61.7%
5/8"	0.63	16	55.0%
3/8"	0.37	9.5	41.7%
5/16"	0.31	8.0	38.3%
No. 4	0.187	4.75	29.1%
No. 5	0.16	4.0	26.8%
No. 10	0.079	2.0	18.5%
No. 18	0.039	1.0	11.6%
No. 35	0.020	0.50	8.03%
No. 60	0.010	0.25	4.14%
No. 120	0.0049	0.125	2.42%
No. 200	0.0030	0.075	1.79%
No. 230	0.0025	0.063	1.77%
No. 270	0.0021	0.053	0.000%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
5%	77%	17%	2%

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	22
D_{50}=	14
D_{30}=	-
D_{15}=	-
D_{10}=	-

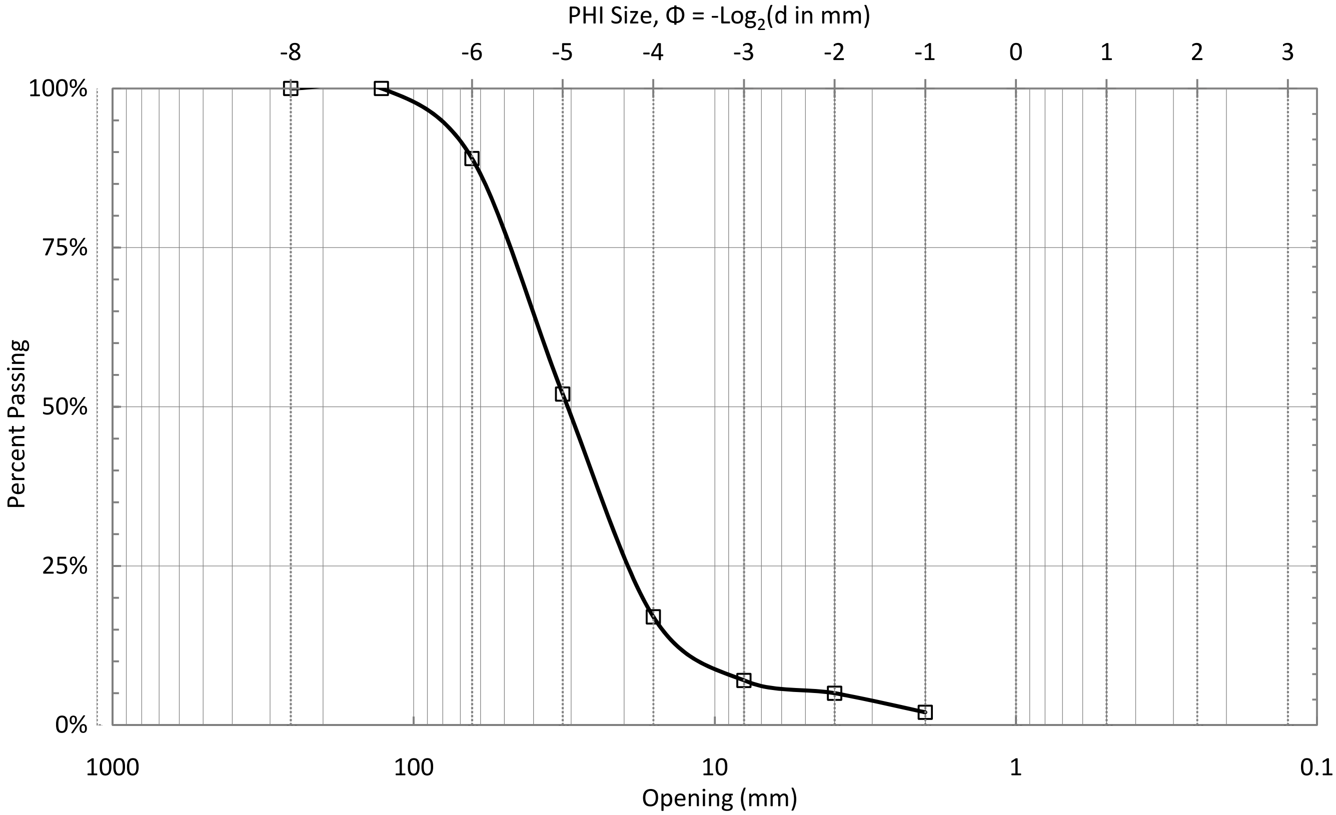
Sample Location

River Mile 7.2

Armor

Sub-Armor X

Location Notes



US Sieve Class	*Nominal Opening (in)*	*(mm)*	*Percent Passing*
10"	10	256	100%
5"	5.0	128	100%
2-1/2"	2.5	64	89.0%
1-1/4"	1.3	32	52.0%
5/8"	0.63	16	17.0%
5/16"	0.31	8.0	7.00%
No. 5	0.16	4.0	5.00%
No. 10	0.079	2.0	2.00%

Pct. Cobbles	*Pct. Gravel*	*Pct. Sand*	*Pct. Fines*
0%	95%	5%	NA

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	43
D_{50}=	31
D_{30}=	-
D_{15}=	-
D_{10}=	-

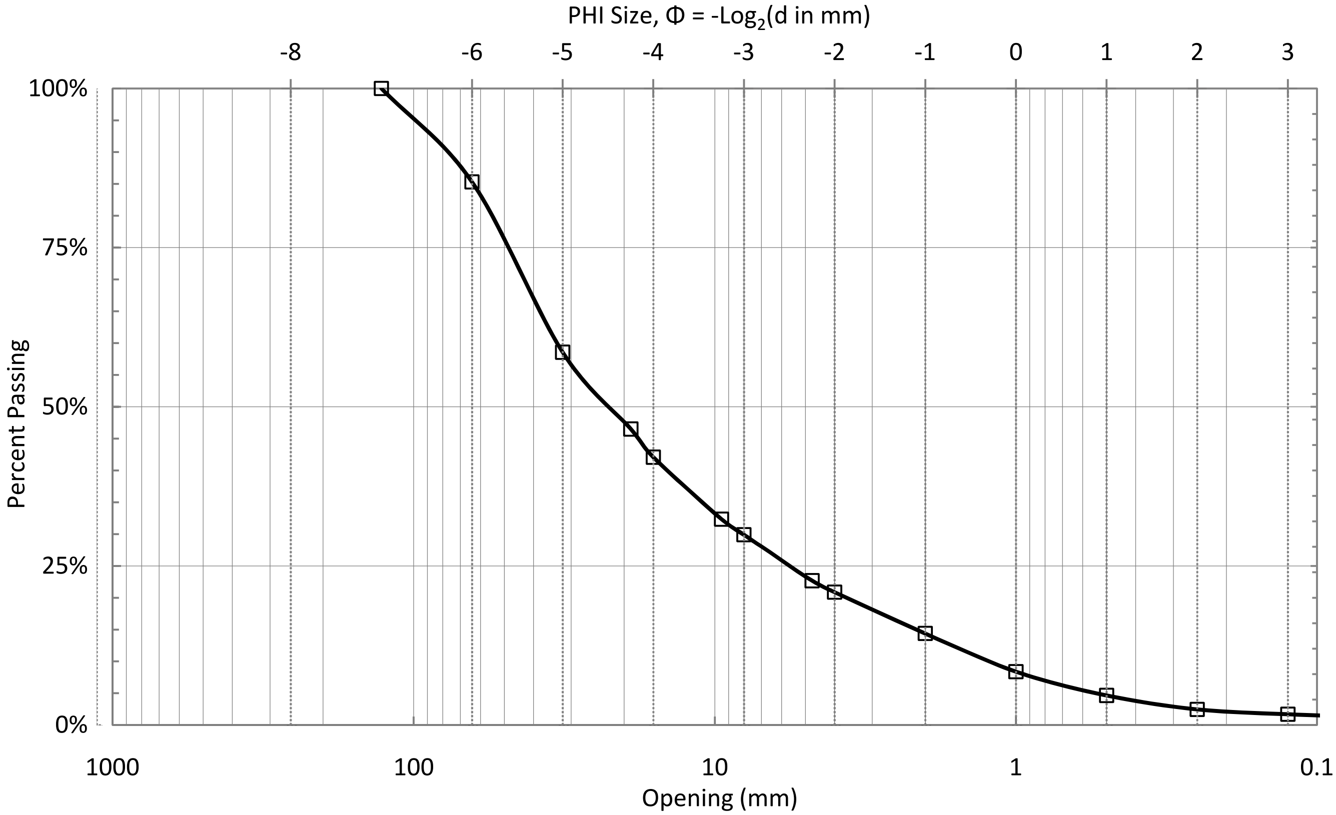
Sample Location

River Mile 9.2

Armor X

Sub-Armor

Location Notes



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
5"	5.0	128	100%
2-1/2"	2.5	64	85.3%
1-1/4"	1.3	32	58.6%
3/4"	0.75	19	46.5%
5/8"	0.63	16	42.1%
3/8"	0.37	9.5	32.4%
5/16"	0.31	8.0	29.9%
No. 4	0.187	4.75	22.7%
No. 5	0.16	4.0	20.9%
No. 10	0.079	2.0	14.4%
No. 18	0.039	1.0	8.39%
No. 35	0.020	0.50	4.66%
No. 60	0.010	0.25	2.47%
No. 120	0.0049	0.125	1.70%
No. 200	0.0030	0.075	1.36%
No. 230	0.0025	0.063	1.34%
No. 270	0.0021	0.053	0.000%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
15%	71%	13%	1%

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	40
D_{50}=	23
D_{30}=	-
D_{15}=	-
D_{10}=	-

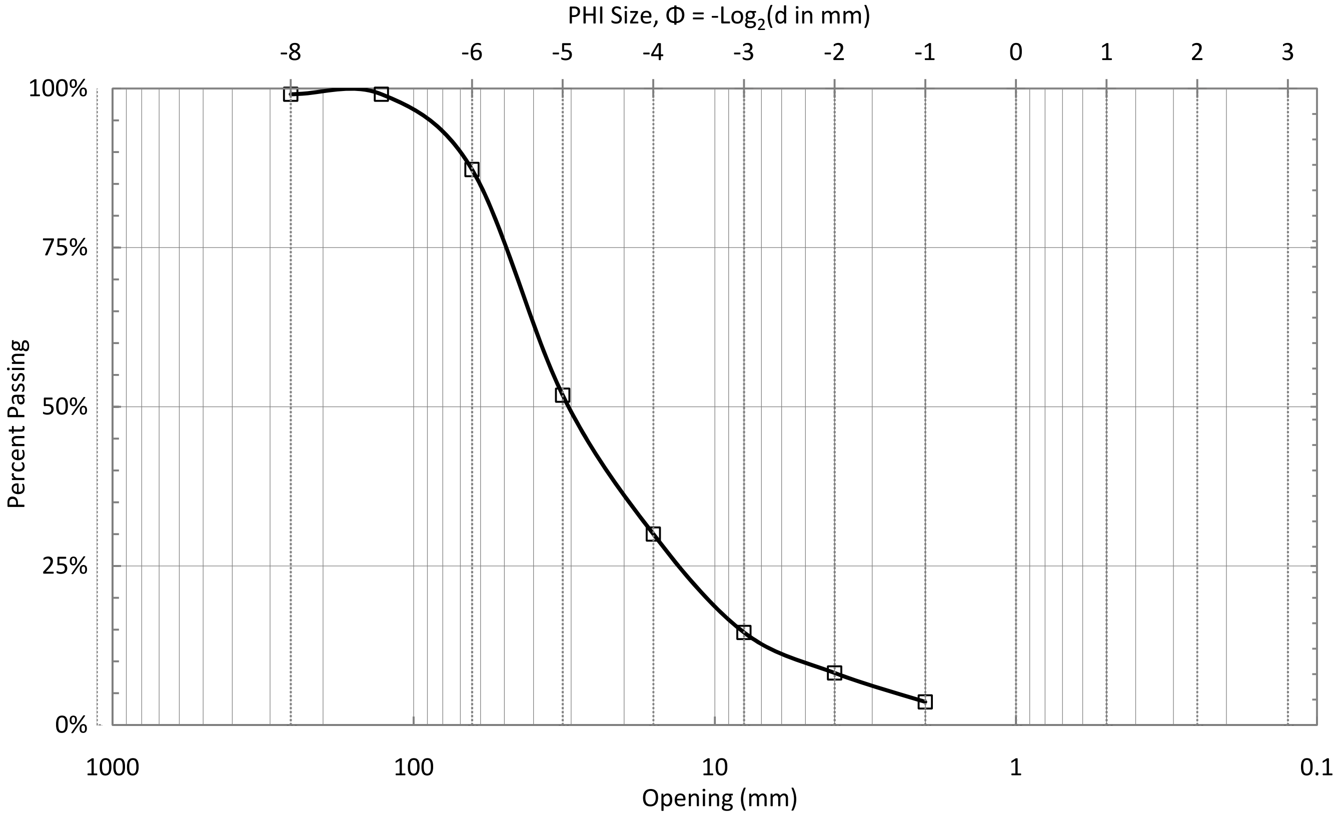
Sample Location

River Mile 9.2

Armor

Sub-Armor X

Location Notes



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
10"	10	256	99%
5"	5.0	128	99.1%
2-1/2"	2.5	64	87.3%
1-1/4"	1.3	32	51.8%
5/8"	0.63	16	30.0%
5/16"	0.31	8.0	14.5%
No. 5	0.16	4.0	8.18%
No. 10	0.079	2.0	3.64%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
1%	91%	8%	NA

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	44
D_{50}=	31
D_{30}=	-
D_{15}=	-
D_{10}=	-

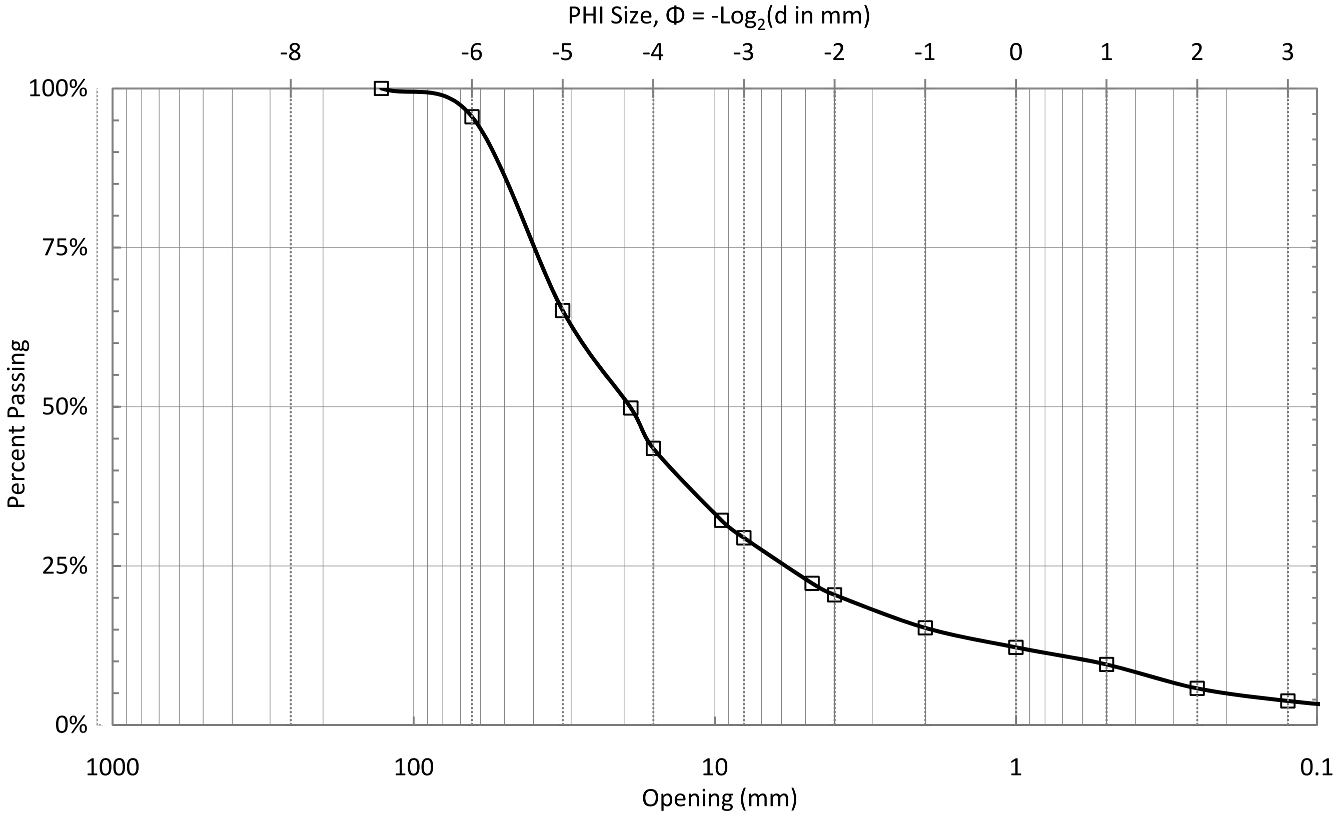
Sample Location

River Mile 11.4

Armor X

Sub-Armor

Location Notes



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
5"	5.0	128	100%
2-1/2"	2.5	64	95.6%
1-1/4"	1.3	32	65.1%
3/4"	0.75	19	49.8%
5/8"	0.63	16	43.5%
3/8"	0.37	9.5	32.2%
5/16"	0.31	8.0	29.4%
No. 4	0.187	4.75	22.3%
No. 5	0.16	4.0	20.5%
No. 10	0.079	2.0	15.3%
No. 18	0.039	1.0	12.2%
No. 35	0.020	0.50	9.52%
No. 60	0.010	0.25	5.76%
No. 120	0.0049	0.125	3.79%
No. 200	0.0030	0.075	2.90%
No. 230	0.0025	0.063	2.89%
No. 270	0.0021	0.053	0.000%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
4%	80%	12%	3%

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	32
D_{50}=	19
D_{30}=	-
D_{15}=	-
D_{10}=	-

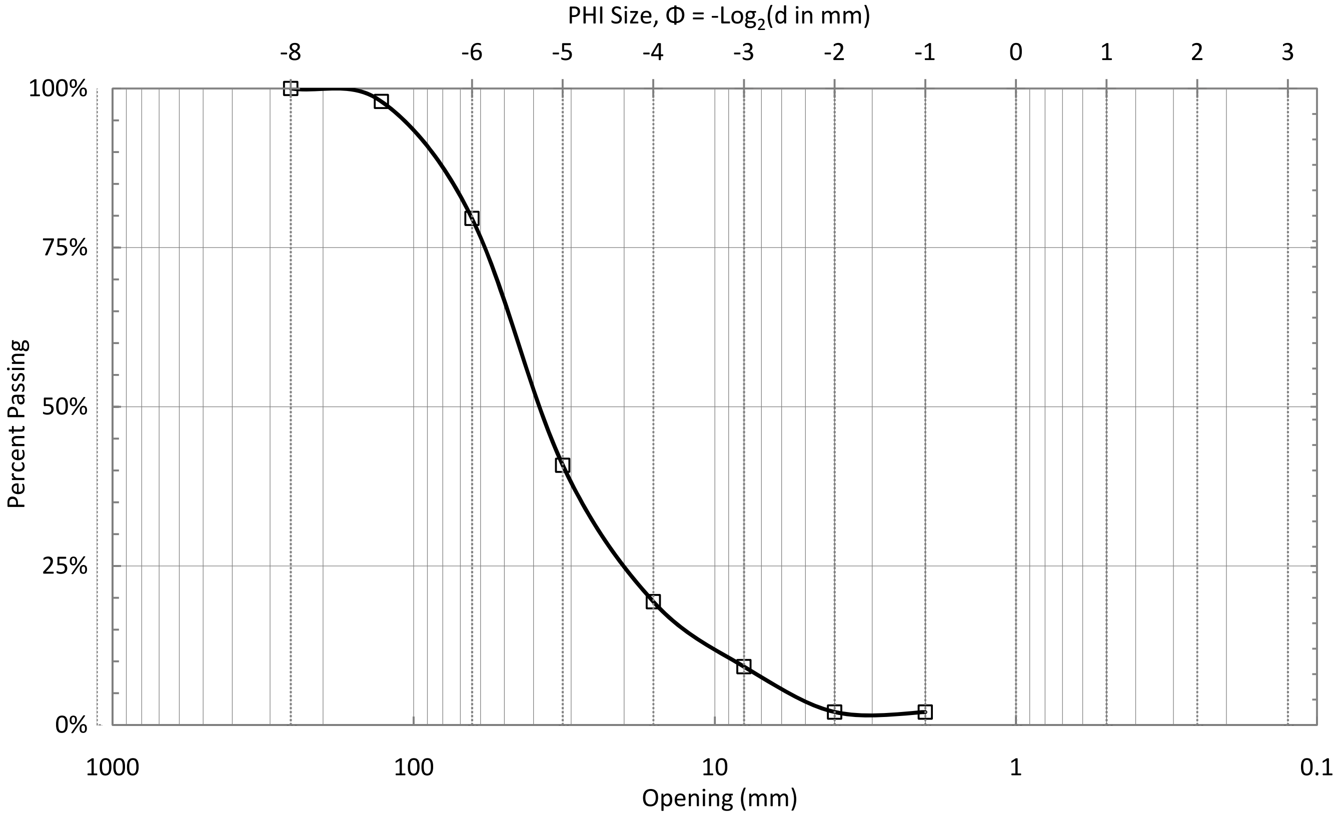
Sample Location

River Mile 11.4

Armor

Sub-Armor X

Location Notes



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
10"	10	256	100%
5"	5.0	128	98.0%
2-1/2"	2.5	64	79.6%
1-1/4"	1.3	32	40.8%
5/8"	0.63	16	19.4%
5/16"	0.31	8.0	9.18%
No. 5	0.16	4.0	2.04%
No. 10	0.079	2.0	2.04%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
2%	96%	2%	NA

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	52
D_{50}=	40
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

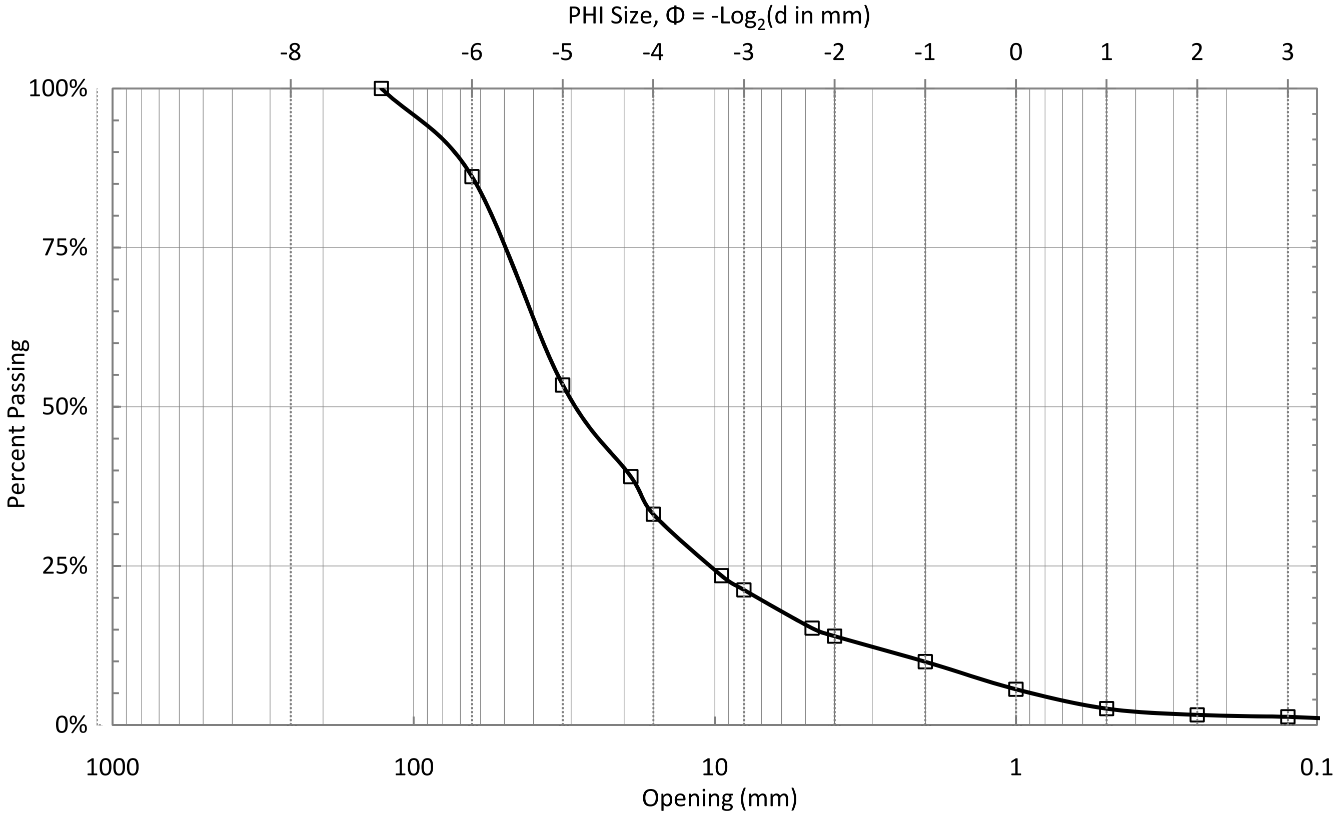
River Mile Pataha Cr.

Armor X

Sub-Armor

Location Notes

Sample taken in Pataha Creek 1.3 miles upstream of confluence with the Tucannon River. Bar overgrown with grass. Sample taken on riffle.



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
5"	5.0	128	100%
2-1/2"	2.5	64	86.2%
1-1/4"	1.3	32	53.4%
3/4"	0.75	19	39.0%
5/8"	0.63	16	33.1%
3/8"	0.37	9.5	23.5%
5/16"	0.31	8.0	21.2%
No. 4	0.187	4.75	15.2%
No. 5	0.16	4.0	14.0%
No. 10	0.079	2.0	9.96%
No. 18	0.039	1.0	5.63%
No. 35	0.020	0.50	2.59%
No. 60	0.010	0.25	1.60%
No. 120	0.0049	0.125	1.29%
No. 200	0.0030	0.075	0.832%
No. 230	0.0025	0.063	0.829%
No. 270	0.0021	0.053	0.000%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
14%	76%	9%	1%

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	43
D_{50}=	29
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

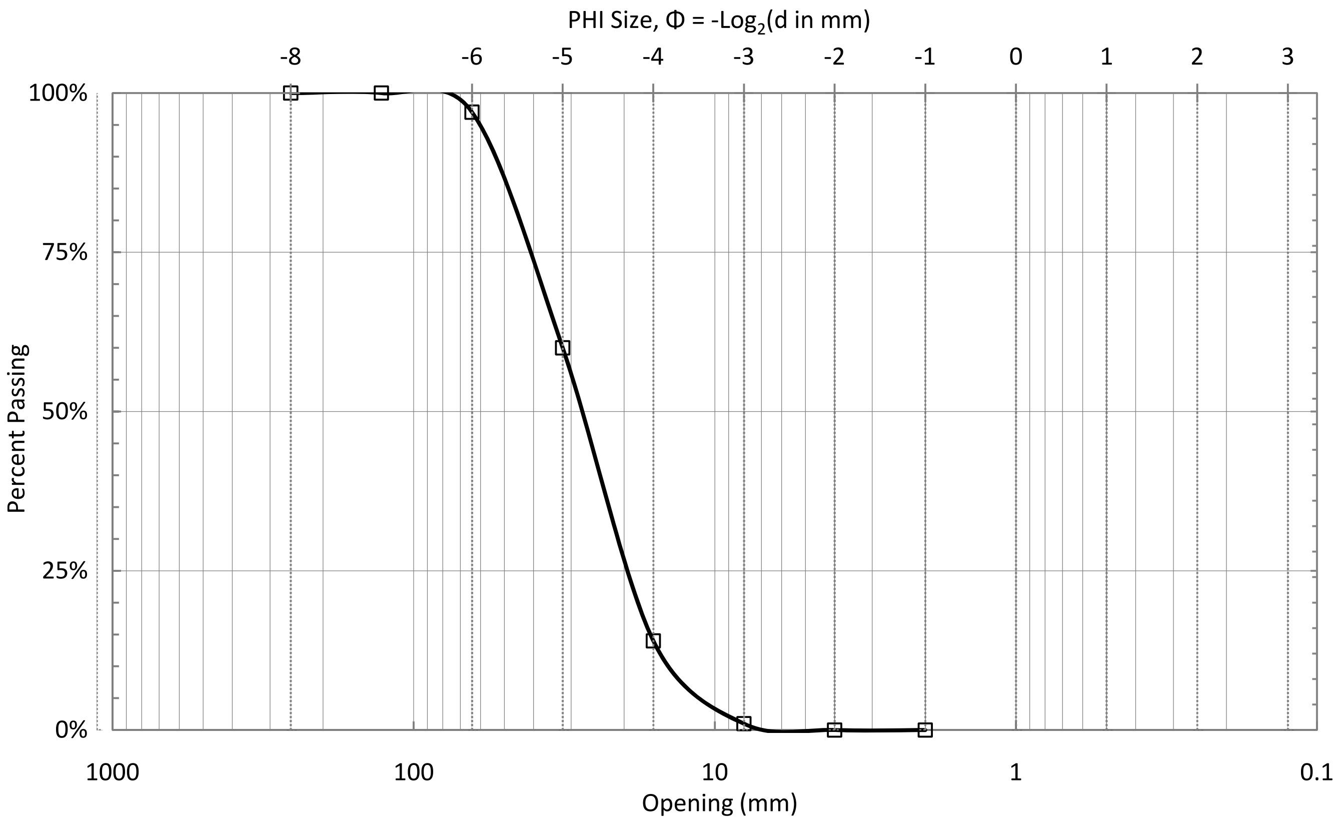
River Mile Pataha Creek

Armor

Sub-Armor X

Location Notes

Sample taken in Pataha Creek 1.3 miles upstream of confluence with the Tucannon River. Bar overgrown with grass. Sample taken on riffle.



US Sieve Class	Nominal Opening (in)	(mm)	Percent Passing
10"	10	256	100%
5"	5.0	128	100%
2-1/2"	2.5	64	97.0%
1-1/4"	1.3	32	60.0%
5/8"	0.63	16	14.0%
5/16"	0.31	8.0	1.00%
No. 5	0.16	4.0	0.00%
No. 10	0.079	2.0	0.00%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
0%	100%	0%	NA

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	36
D_{50}=	29
D_{30}=	-
D_{15}=	-
D_{10}=	-

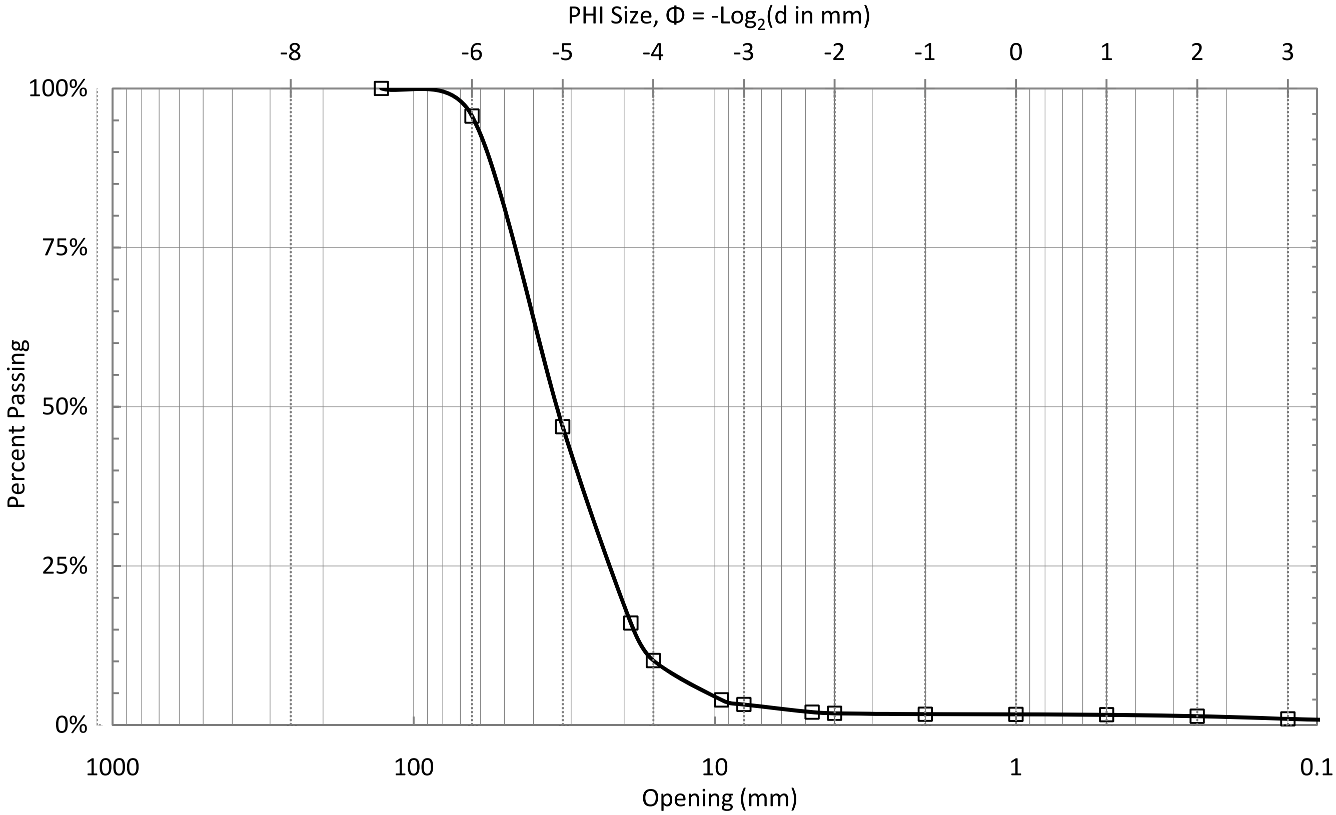
Sample Location

River Mile 14.9

Armor X

Sub-Armor

Location Notes



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
5"	5.0	128	100%
2-1/2"	2.5	64	95.7%
1-1/4"	1.3	32	46.9%
3/4"	0.75	19	16.0%
5/8"	0.63	16	10.1%
3/8"	0.37	9.5	3.95%
5/16"	0.31	8.0	3.24%
No. 4	0.187	4.75	2.03%
No. 5	0.16	4.0	1.85%
No. 10	0.079	2.0	1.70%
No. 18	0.039	1.0	1.68%
No. 35	0.020	0.50	1.64%
No. 60	0.010	0.25	1.39%
No. 120	0.0049	0.125	0.970%
No. 200	0.0030	0.075	0.720%
No. 230	0.0025	0.063	0.714%
No. 270	0.0021	0.053	0.000%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
4%	94%	1%	1%

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	44
D_{50}=	34
D_{30}=	-
D_{15}=	-
D_{10}=	-

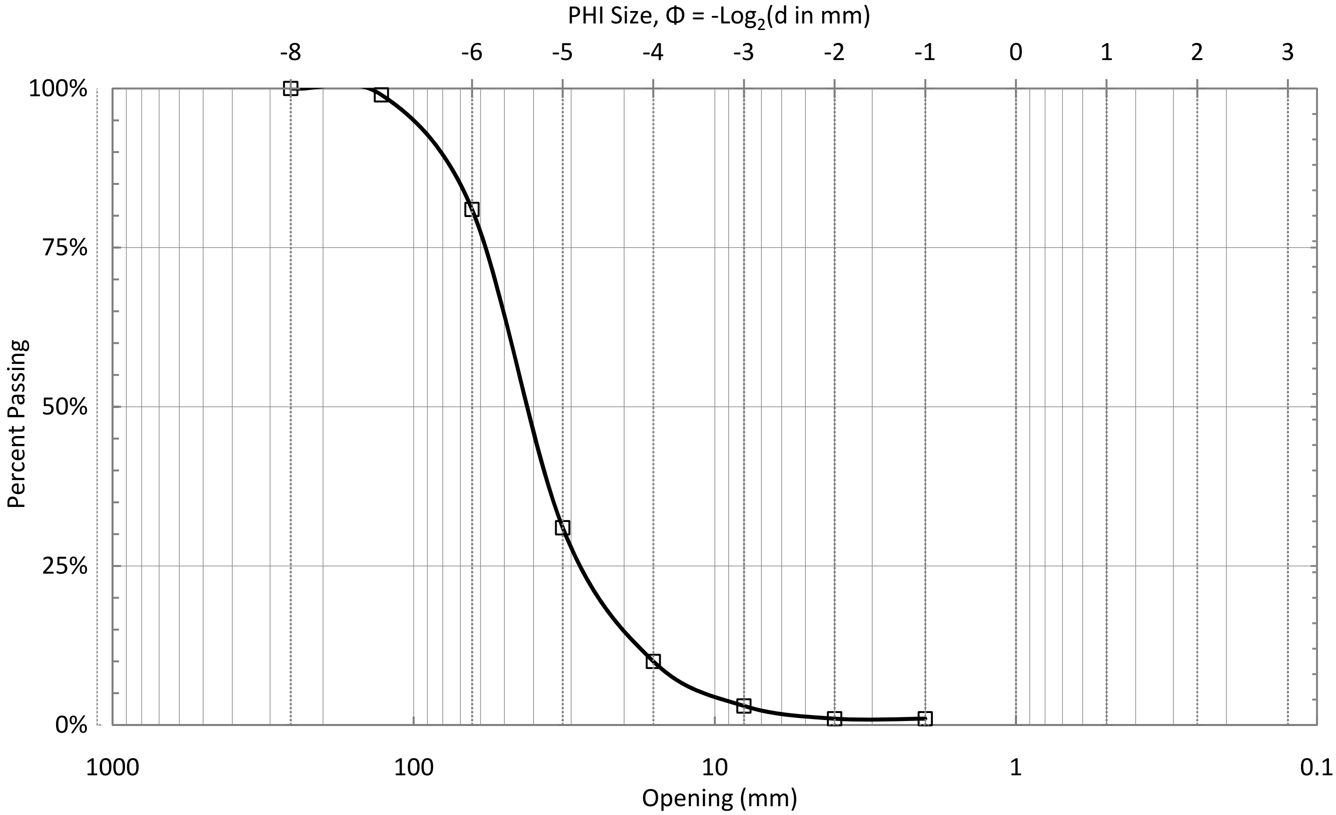
Sample Location

River Mile 14.9

Armor

Sub-Armor X

Location Notes



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
10"	10	256	100%
5"	5.0	128	99.0%
2-1/2"	2.5	64	81.0%
1-1/4"	1.3	32	31.0%
5/8"	0.63	16	10.0%
5/16"	0.31	8.0	3.00%
No. 5	0.16	4.0	1.00%
No. 10	0.079	2.0	1.00%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
1%	98%	1%	NA

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	54
D_{50}=	44
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

River Mile 18.6

Armor X

Sub-Armor

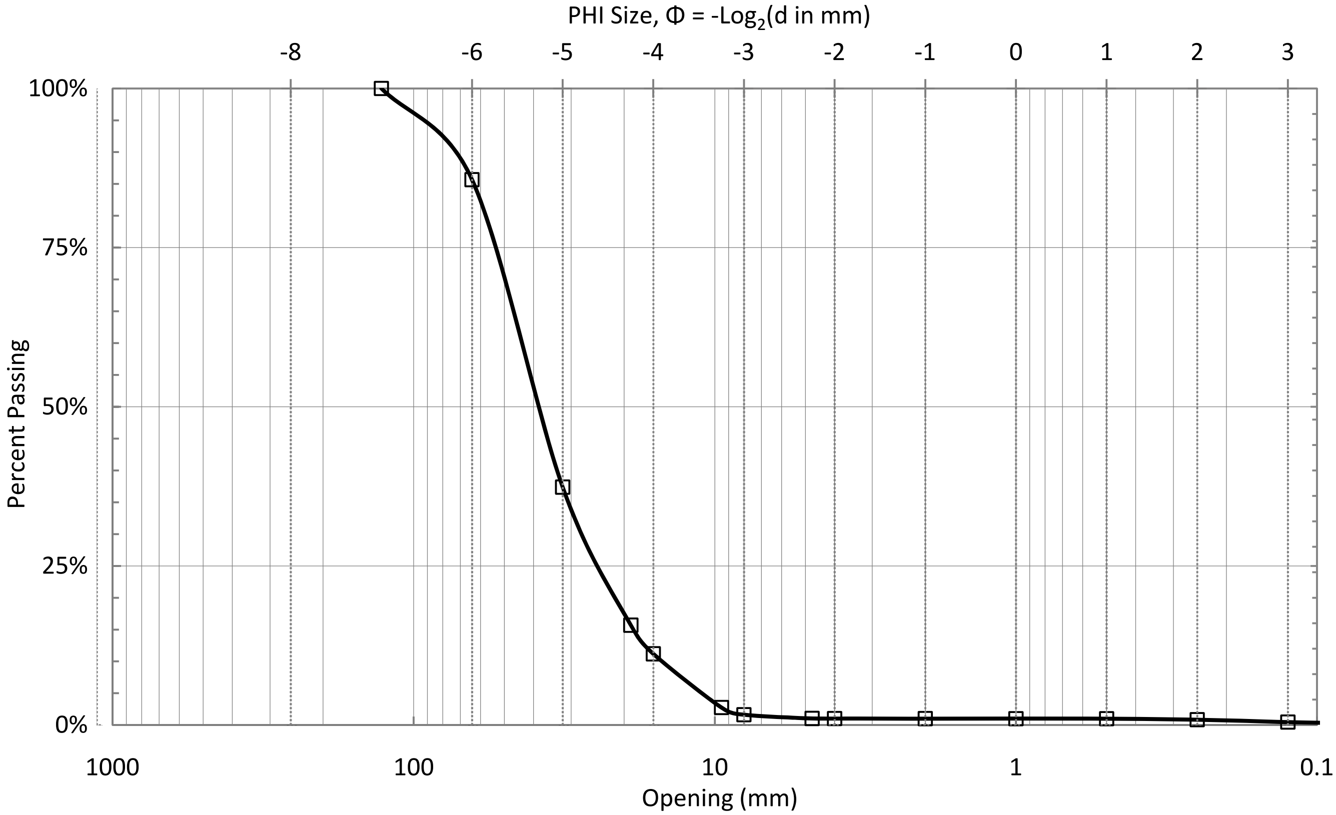
Location Notes

Thick grass on both banks.

Sediment Grain Size Distribution Report

Sample ID : TR_11_SA

Project: Tucannon River
Client: CCD



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
5"	5.0	128	100%
2-1/2"	2.5	64	85.7%
1-1/4"	1.3	32	37.4%
3/4"	0.75	19	15.7%
5/8"	0.63	16	11.2%
3/8"	0.37	9.5	2.76%
5/16"	0.31	8.0	1.63%
No. 4	0.187	4.75	1.04%
No. 5	0.16	4.0	1.03%
No. 10	0.079	2.0	1.02%
No. 18	0.039	1.0	1.01%
No. 35	0.020	0.50	1.00%
No. 60	0.010	0.25	0.855%
No. 120	0.0049	0.125	0.471%
No. 200	0.0030	0.075	0.272%
No. 230	0.0025	0.063	0.272%
No. 270	0.0021	0.053	0.000%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
14%	85%	1%	0%

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	50
D_{50}=	44
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

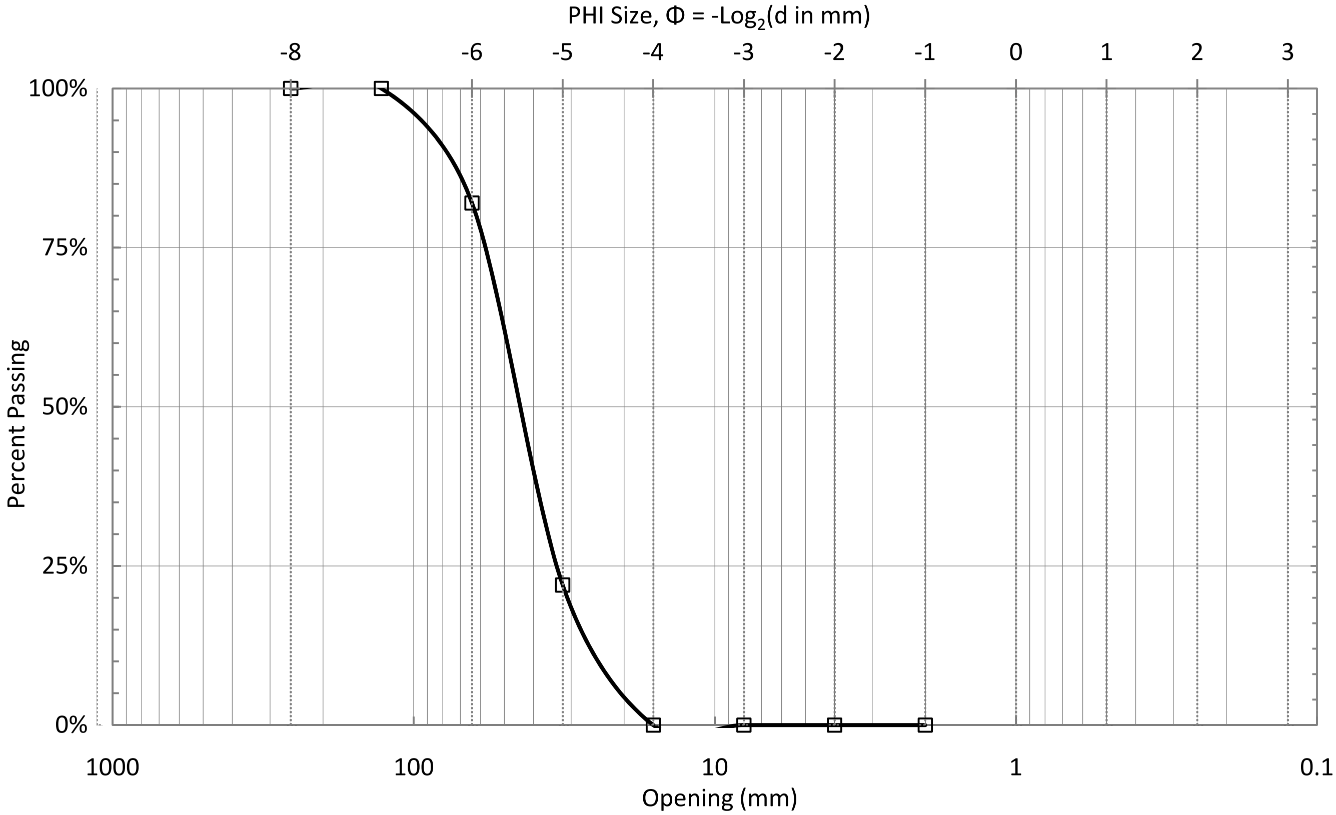
River Mile 18.6

Armor

Sub-Armor X

Location Notes

Thick grass on both banks.



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
10"	10	256	100%
5"	5.0	128	100%
2-1/2"	2.5	64	82.0%
1-1/4"	1.3	32	22.0%
5/8"	0.63	16	0.00%
5/16"	0.31	8.0	0.00%
No. 5	0.16	4.0	0.00%
No. 10	0.079	2.0	0.00%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
0%	100%	0%	NA

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	55
D_{50}=	47
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

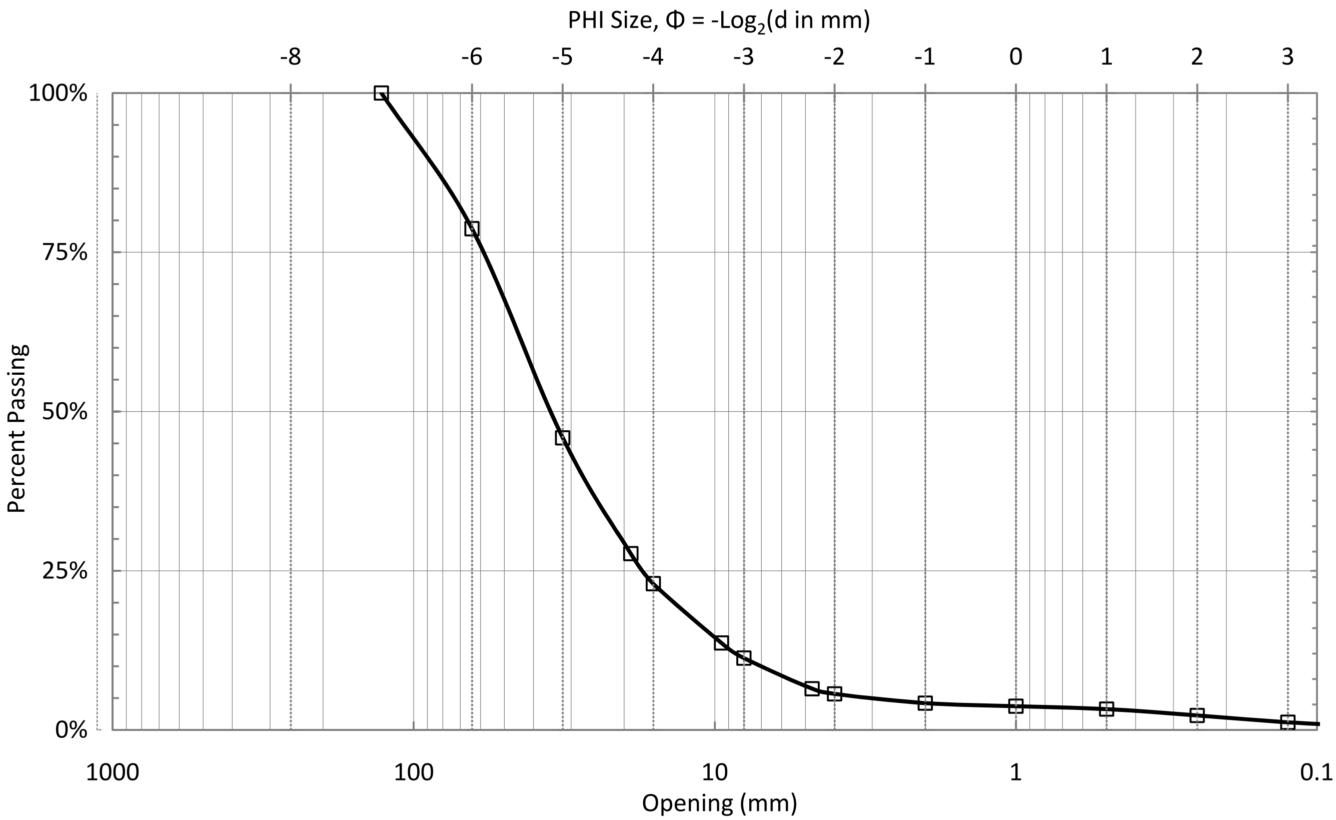
River Mile 21.6

Armor X

Sub-Armor

Location Notes

There is another small channel river left that was not sampled.



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
5"	5.0	128	100%
2-1/2"	2.5	64	78.7%
1-1/4"	1.3	32	45.9%
3/4"	0.75	19	27.7%
5/8"	0.63	16	23.0%
3/8"	0.37	9.5	13.7%
5/16"	0.31	8.0	11.3%
No. 4	0.187	4.75	6.48%
No. 5	0.16	4.0	5.68%
No. 10	0.079	2.0	4.22%
No. 18	0.039	1.0	3.74%
No. 35	0.020	0.50	3.29%
No. 60	0.010	0.25	2.29%
No. 120	0.0049	0.125	1.21%
No. 200	0.0030	0.075	0.725%
No. 230	0.0025	0.063	0.724%
No. 270	0.0021	0.053	0.000%

Pct. Cobbles	*Pct. Gravel*	*Pct. Sand*	*Pct. Fines*
21%	74%	3%	1%

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	51
D_{50}=	36
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

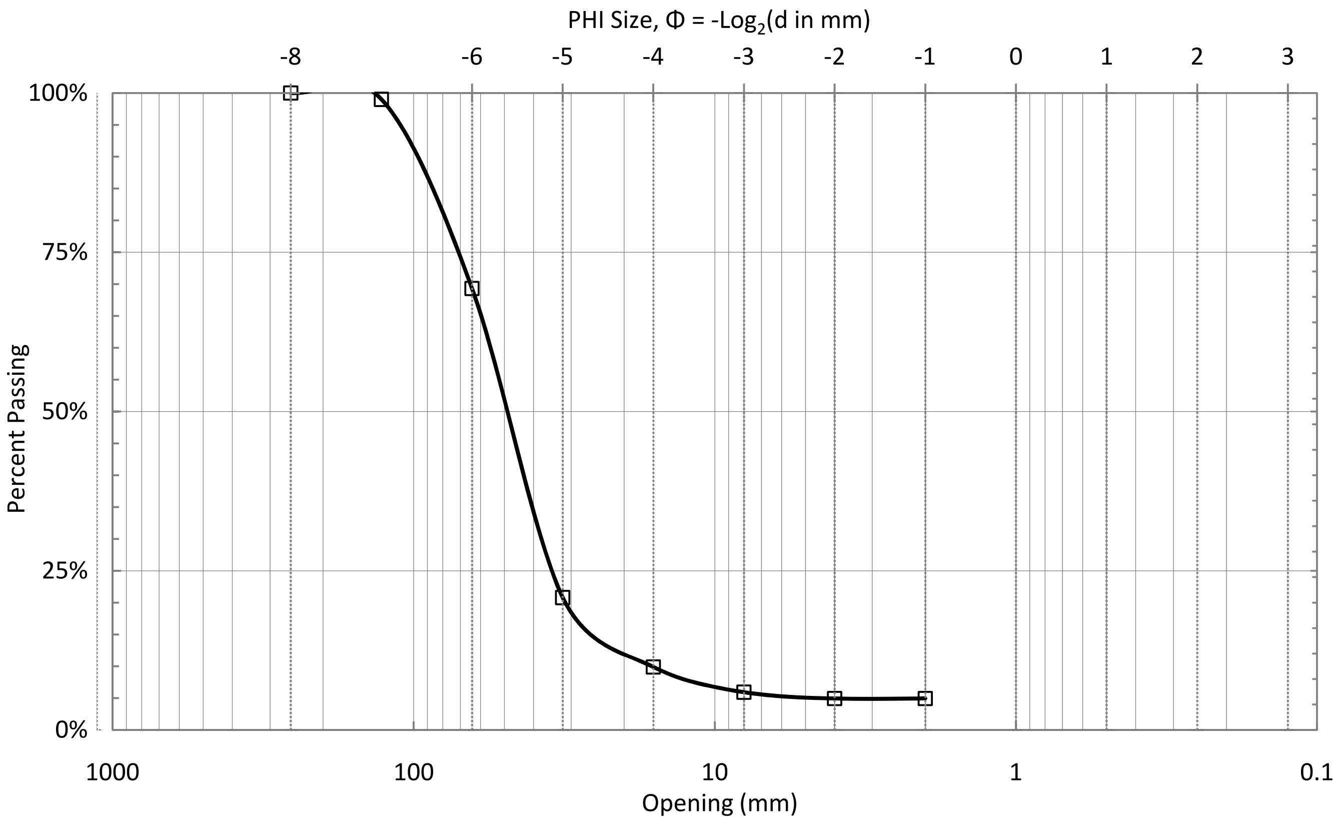
River Mile 21.6

Armor

Sub-Armor X

Location Notes

There is another small channel river left that was not sampled.



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
10"	10	256	100%
5"	5.0	128	99.0%
2-1/2"	2.5	64	69.3%
1-1/4"	1.3	32	20.8%
5/8"	0.63	16	9.90%
5/16"	0.31	8.0	5.94%
No. 5	0.16	4.0	4.95%
No. 10	0.079	2.0	4.95%

Pct. Cobbles	*Pct. Gravel*	*Pct. Sand*	*Pct. Fines*
1%	94%	5%	NA

Sample Location

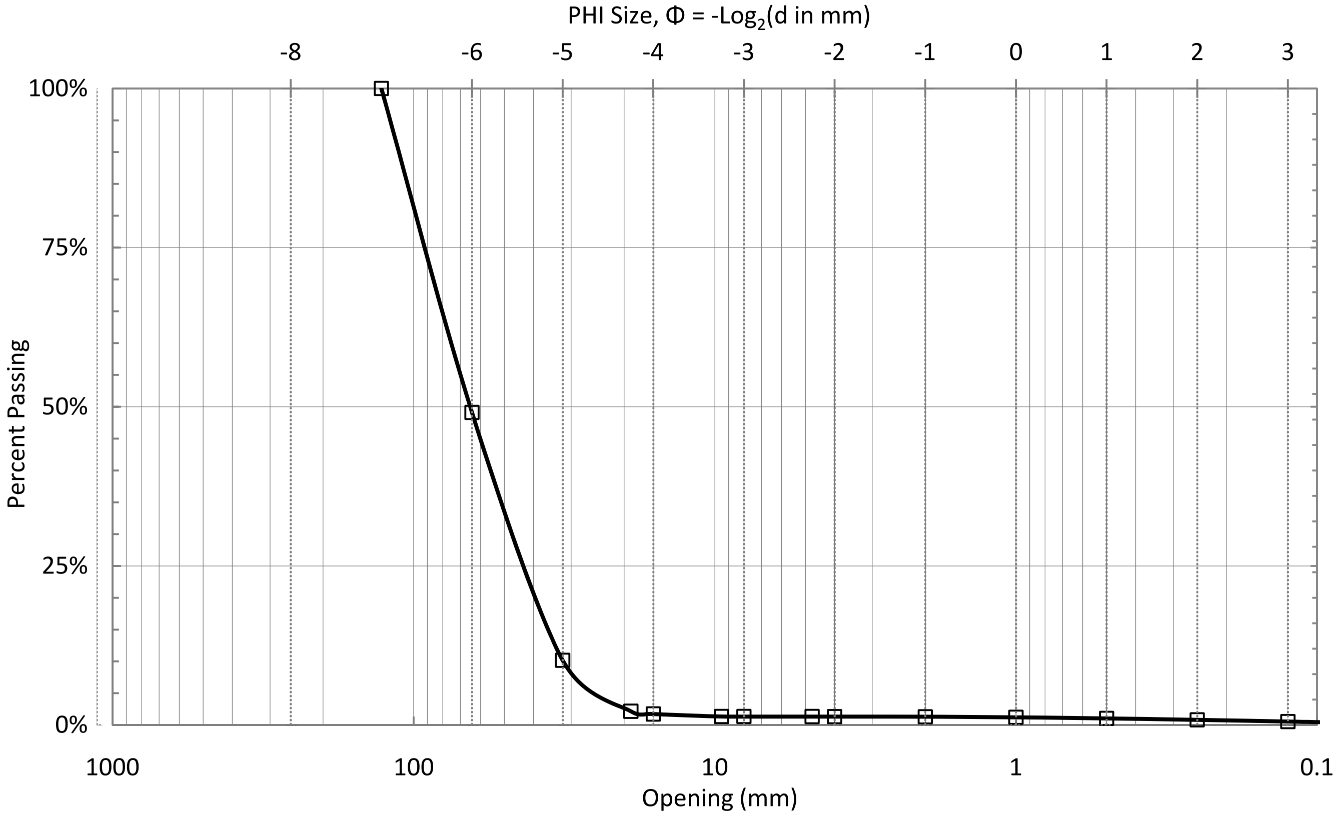
River Mile 25.1

Armor X

Sub-Armor

Location Notes

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	61
D_{50}=	51
D_{30}=	-
D_{15}=	-
D_{10}=	-



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
5"	5.0	128	100%
2-1/2"	2.5	64	49.1%
1-1/4"	1.3	32	10.2%
3/4"	0.75	19	2.17%
5/8"	0.63	16	1.75%
3/8"	0.37	9.5	1.35%
5/16"	0.31	8.0	1.35%
No. 4	0.187	4.75	1.34%
No. 5	0.16	4.0	1.33%
No. 10	0.079	2.0	1.31%
No. 18	0.039	1.0	1.24%
No. 35	0.020	0.50	1.06%
No. 60	0.010	0.25	0.828%
No. 120	0.0049	0.125	0.552%
No. 200	0.0030	0.075	0.395%
No. 230	0.0025	0.063	0.373%
No. 270	0.0021	0.053	0.000%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
51%	48%	1%	0%

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	84
D_{50}=	65
D_{30}=	-
D_{15}=	-
D_{10}=	-

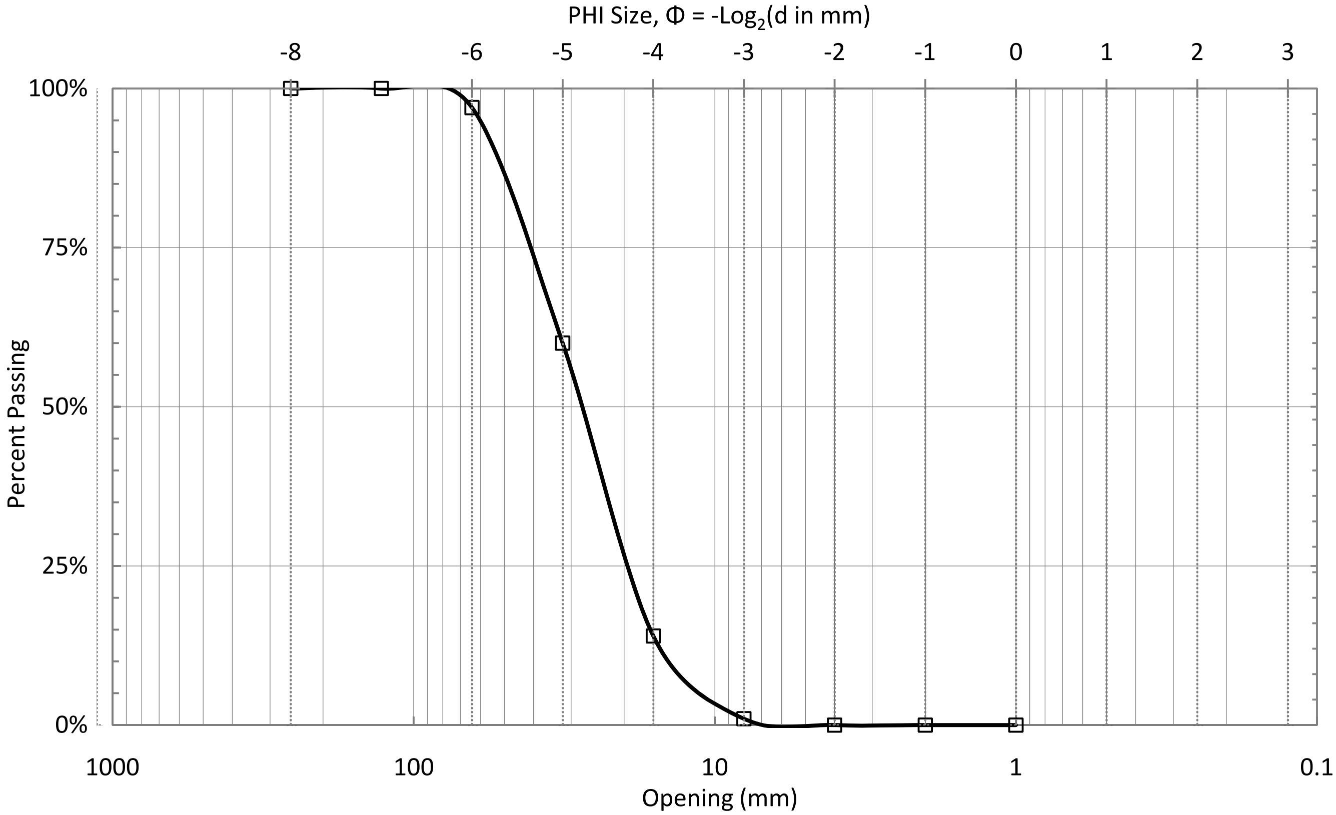
Sample Location

River Mile 25.1

Armor

Sub-Armor X

Location Notes



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
10"	10	256	100%
5"	5.0	128	100%
2-1/2"	2.5	64	97.0%
1-1/4"	1.3	32	60.0%
5/8"	0.63	16	14.0%
5/16"	0.31	8.0	1.00%
No. 5	0.16	4.0	0.00%
No. 10	0.079	2.0	0.00%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
0%	100%	0%	NA

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	84
D_{50}=	64
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

River Mile 27.9

Armor X

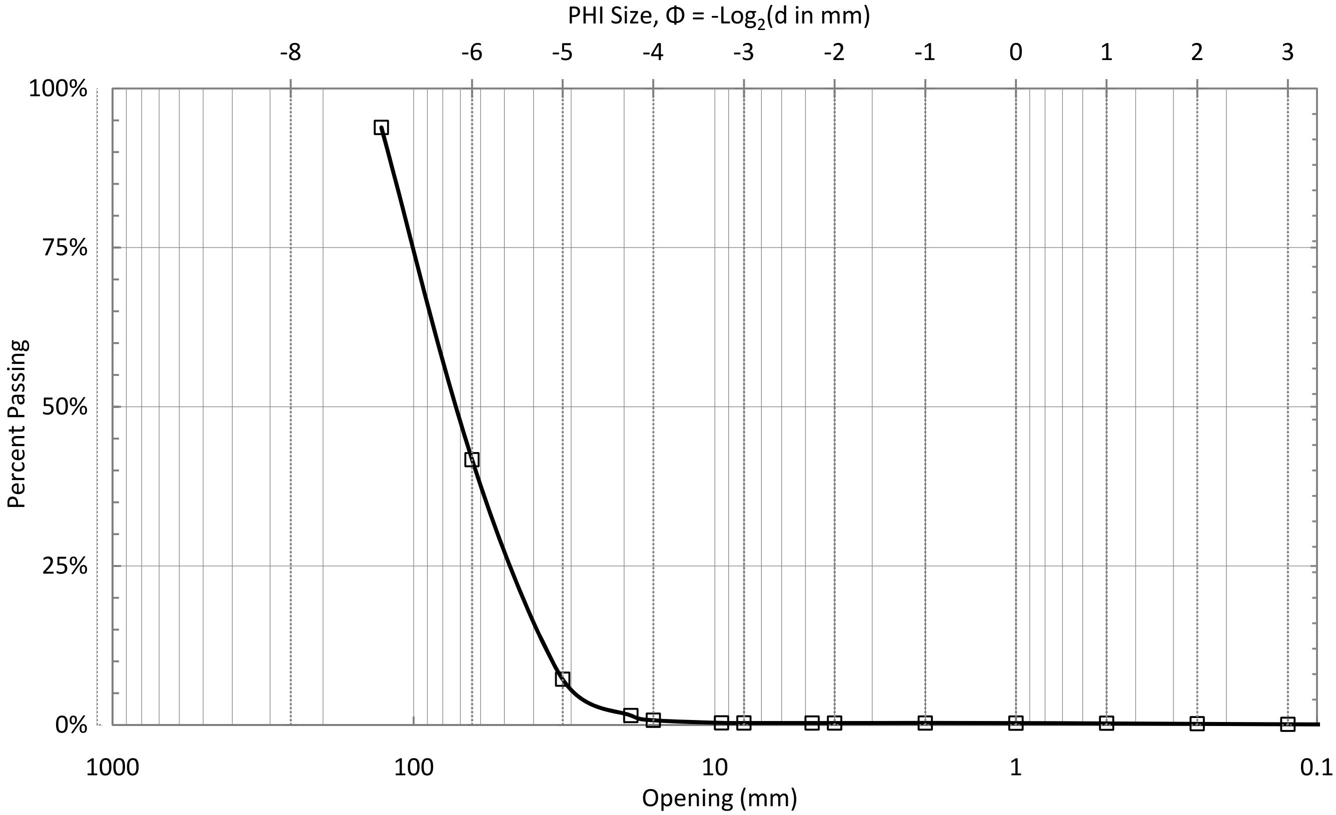
Sub-Armor

Location Notes

Sediment Grain Size Distribution Report

Sample ID : TR_14_SA

Project: Tucannon River
Client: CCD



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
5"	5.0	128	0.939%
2-1/2"	2.5	64	41.7%
1-1/4"	1.3	32	7.21%
3/4"	0.75	19	1.51%
5/8"	0.63	16	0.761%
3/8"	0.37	9.5	0.348%
5/16"	0.31	8.0	0.333%
No. 4	0.187	4.75	0.323%
No. 5	0.16	4.0	0.319%
No. 10	0.079	2.0	0.315%
No. 18	0.039	1.0	0.311%
No. 35	0.020	0.50	0.299%
No. 60	0.010	0.25	0.214%
No. 120	0.0049	0.125	0.117%
No. 200	0.0030	0.075	0.0745%
No. 230	0.0025	0.063	0.0742%
No. 270	0.0021	0.053	0.000%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
58%	41%	0%	0%

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	93
D_{50}=	74
D_{30}=	-
D_{15}=	-
D_{10}=	-

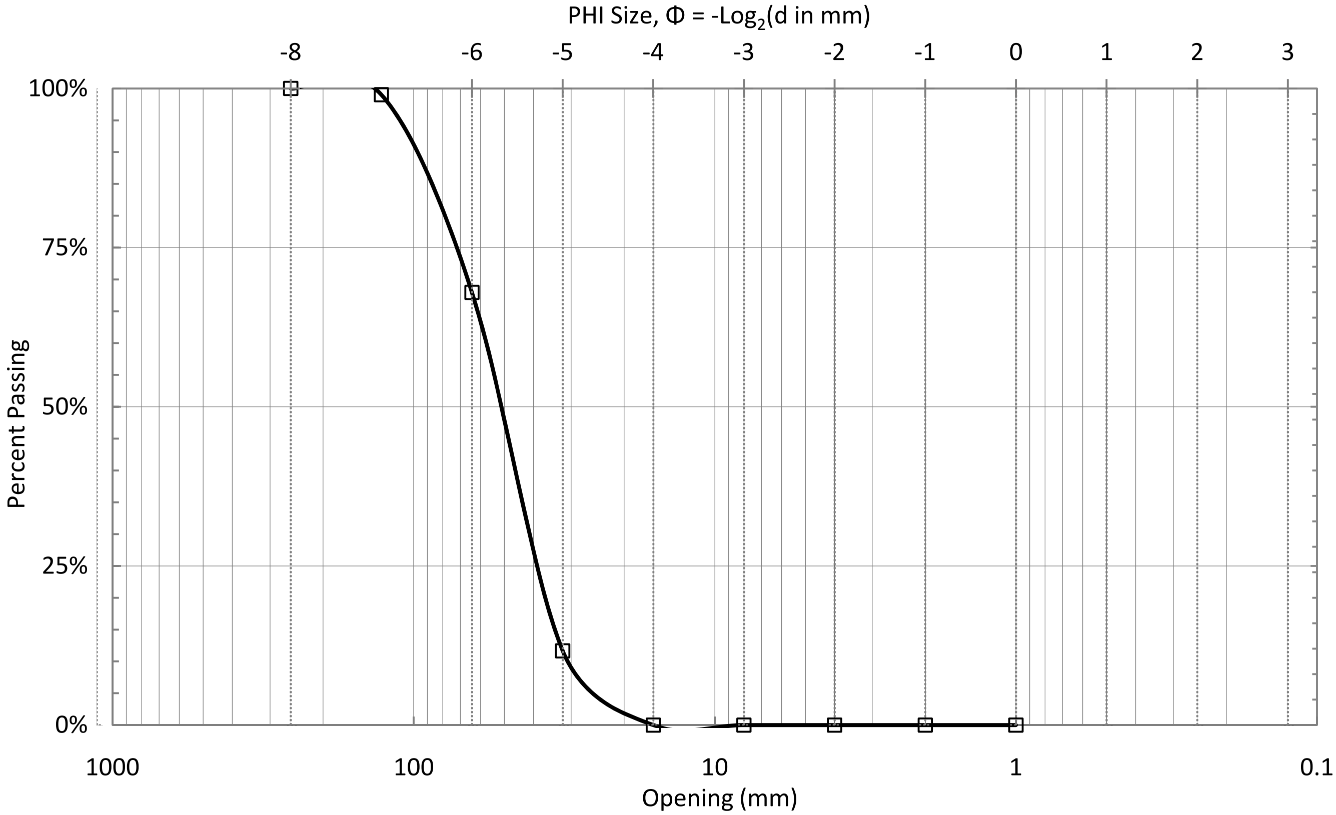
Sample Location

River Mile 27.9

Armor

Sub-Armor X

Location Notes



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
10"	10	256	100%
5"	5.0	128	99.0%
2-1/2"	2.5	64	68.0%
1-1/4"	1.3	32	11.7%
5/8"	0.63	16	0.00%
5/16"	0.31	8.0	0.00%
No. 5	0.16	4.0	0.00%
No. 10	0.079	2.0	0.00%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
1%	99%	0%	NA

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	62
D_{50}=	54
D_{30}=	-
D_{15}=	-
D_{10}=	-

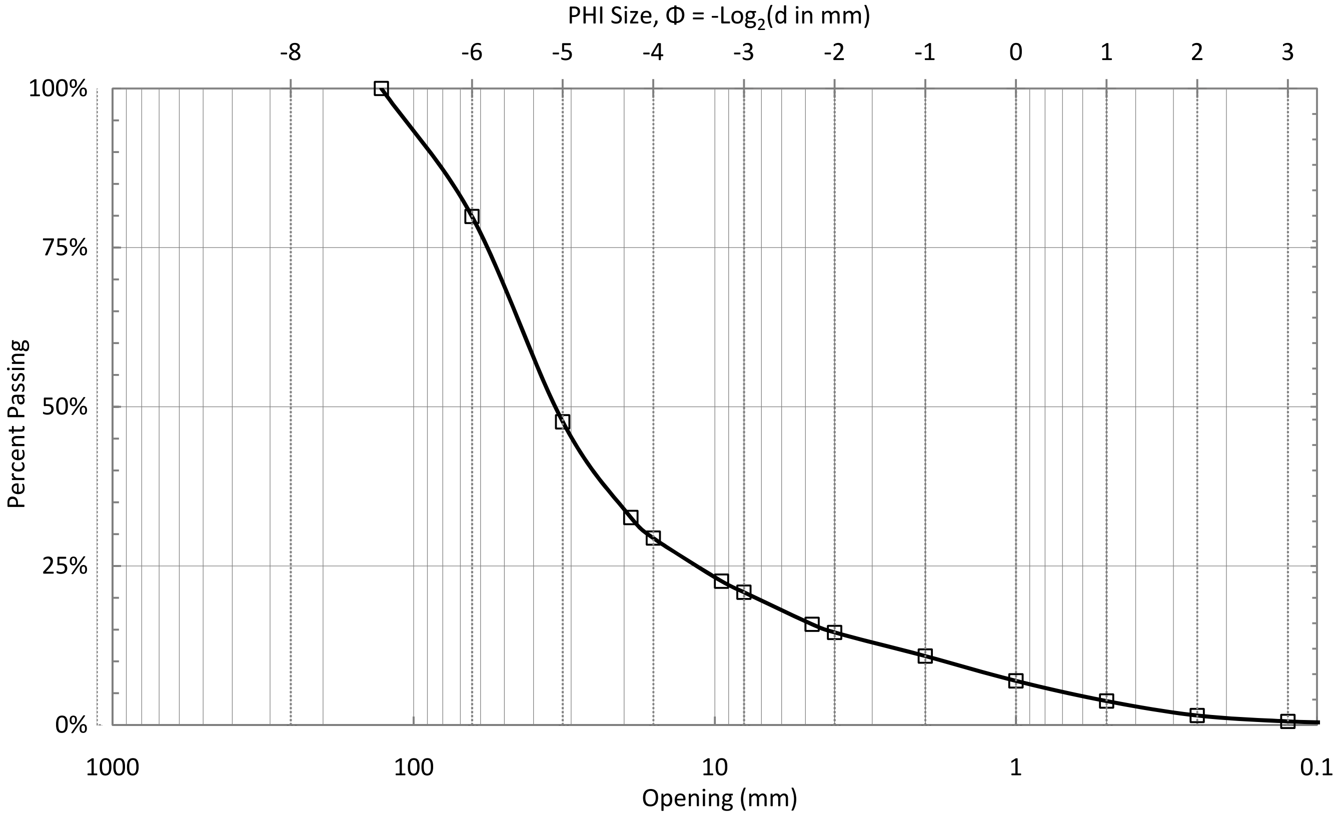
Sample Location

River Mile 30.8

Armor X

Sub-Armor

Location Notes



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
5"	5.0	128	100%
2-1/2"	2.5	64	79.9%
1-1/4"	1.3	32	47.6%
3/4"	0.75	19	32.6%
5/8"	0.63	16	29.4%
3/8"	0.37	9.5	22.6%
5/16"	0.31	8.0	20.9%
No. 4	0.187	4.75	15.8%
No. 5	0.16	4.0	14.5%
No. 10	0.079	2.0	10.8%
No. 18	0.039	1.0	6.95%
No. 35	0.020	0.50	3.78%
No. 60	0.010	0.25	1.51%
No. 120	0.0049	0.125	0.582%
No. 200	0.0030	0.075	0.356%
No. 230	0.0025	0.063	0.353%
No. 270	0.0021	0.053	0.000%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
20%	69%	10%	0%

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	49
D_{50}=	34
D_{30}=	-
D_{15}=	-
D_{10}=	-

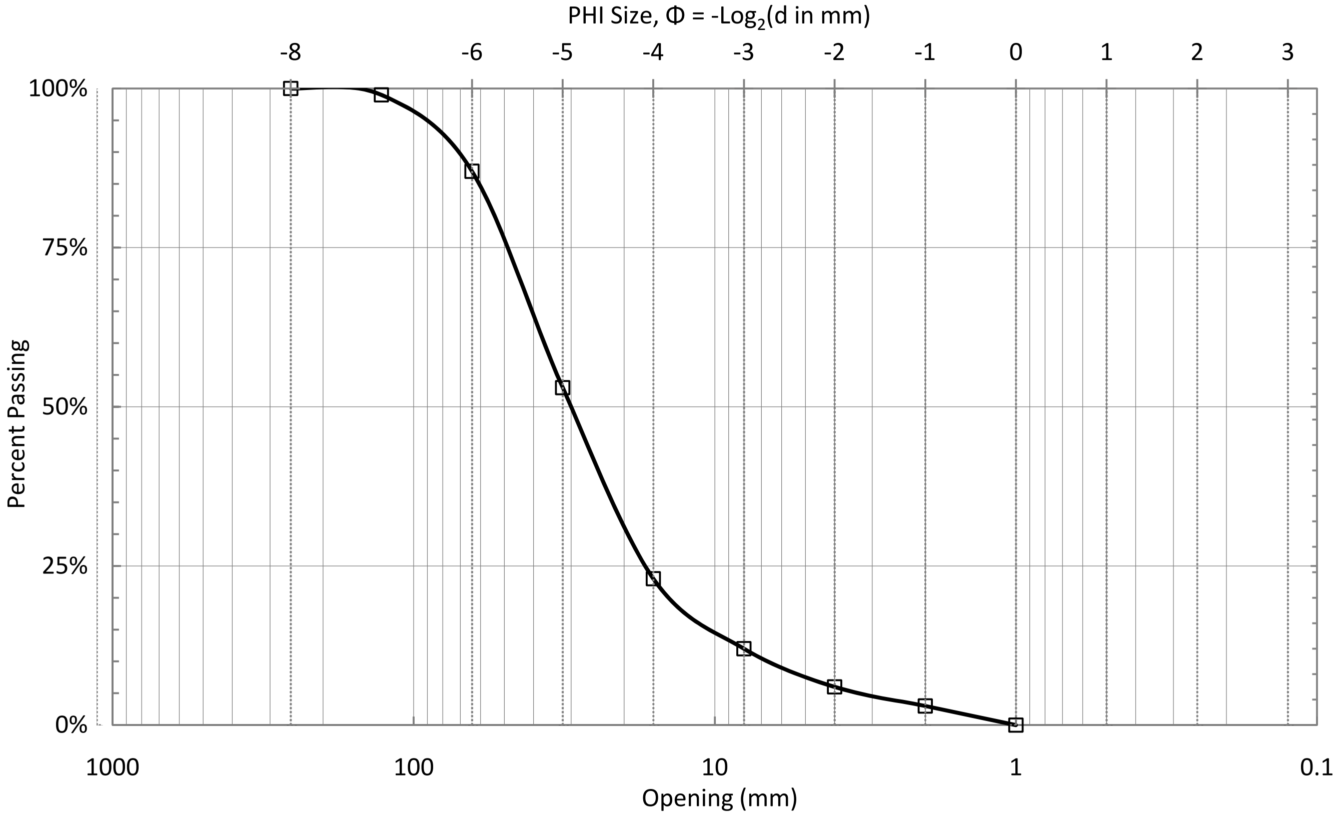
Sample Location

River Mile 30.8

Armor

Sub-Armor X

Location Notes



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
10"	10	256	100%
5"	5.0	128	99.0%
2-1/2"	2.5	64	87.0%
1-1/4"	1.3	32	53.0%
5/8"	0.63	16	23.0%
5/16"	0.31	8.0	12.0%
No. 5	0.16	4.0	6.00%
No. 10	0.079	2.0	3.00%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
1%	93%	6%	NA

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	43
D_{50}=	30
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

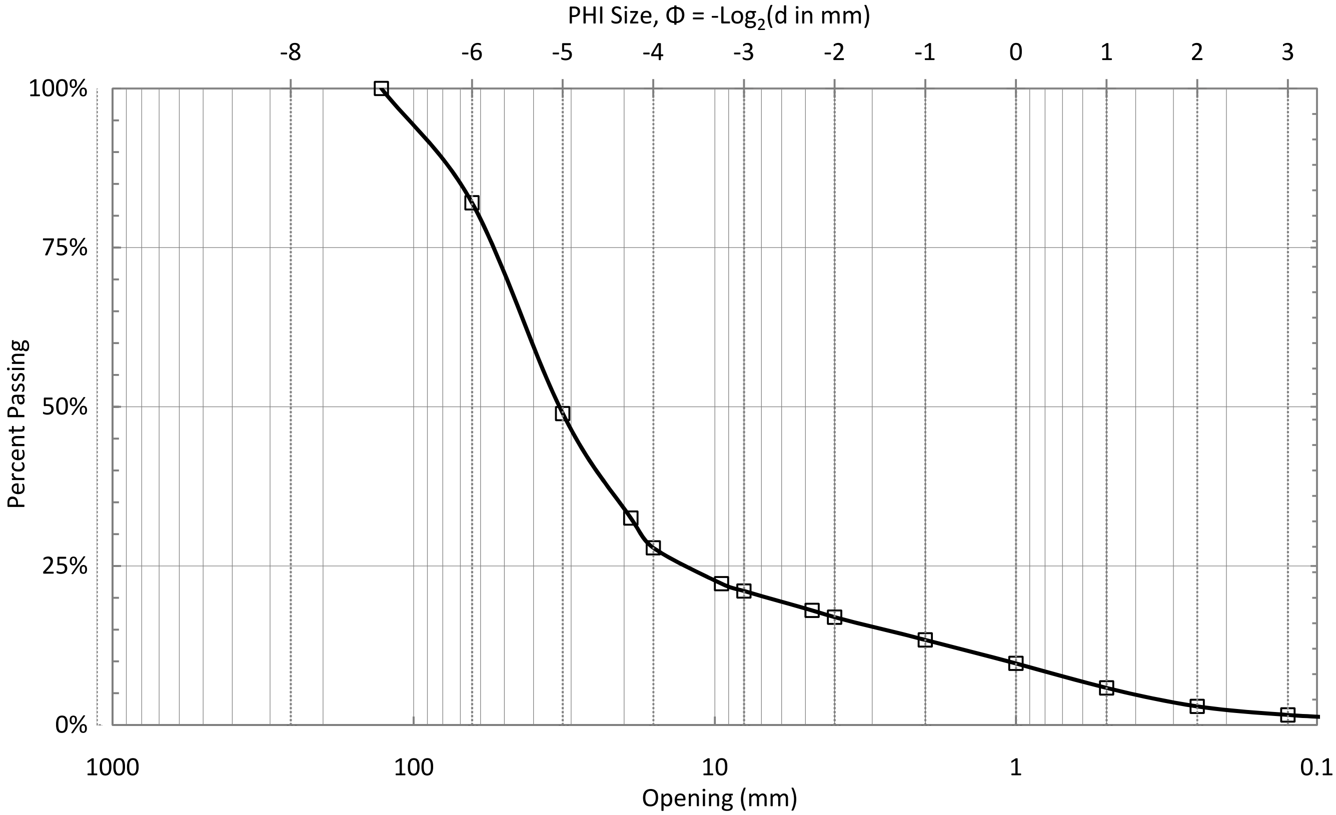
River Mile 34

Armor X

Sub-Armor

Location Notes

Just downstream of braided section with engineered log jams. Agrading in braided section cobble layer.



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
5"	5.0	128	100%
2-1/2"	2.5	64	82.0%
1-1/4"	1.3	32	48.9%
3/4"	0.75	19	32.5%
5/8"	0.63	16	27.8%
3/8"	0.37	9.5	22.2%
5/16"	0.31	8.0	21.1%
No. 4	0.187	4.75	18.0%
No. 5	0.16	4.0	16.9%
No. 10	0.079	2.0	13.4%
No. 18	0.039	1.0	9.70%
No. 35	0.020	0.50	5.84%
No. 60	0.010	0.25	2.93%
No. 120	0.0049	0.125	1.59%
No. 200	0.0030	0.075	1.08%
No. 230	0.0025	0.063	1.06%
No. 270	0.0021	0.053	0.000%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
18%	69%	12%	1%

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	48
D_{50}=	33
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

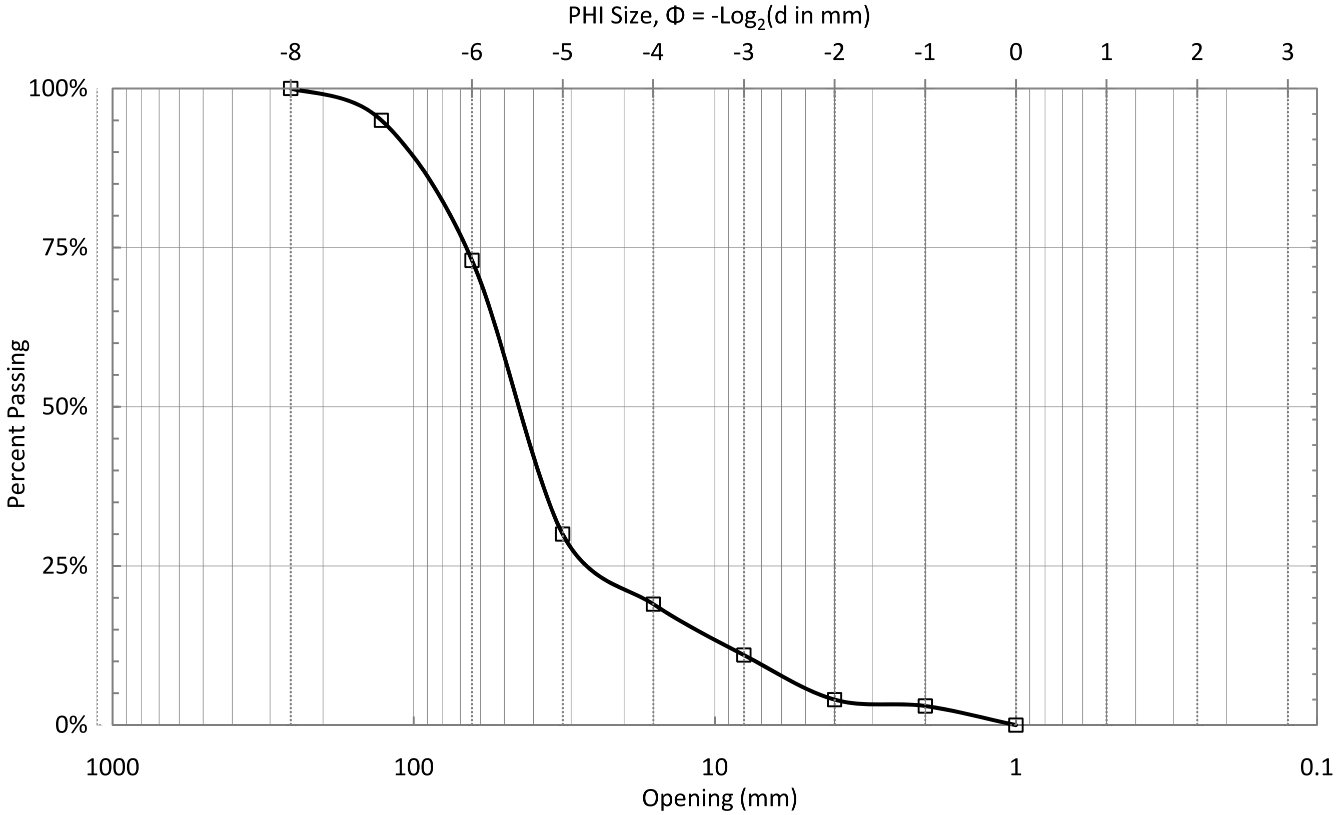
River Mile 34

Armor

Sub-Armor X

Location Notes

Just downstream of braided section with engineered log jams. Agrading in braided section cobble layer.



US Sieve Class	Nominal Opening (in)	(mm)	Percent Passing
10"	10	256	100%
5"	5.0	128	95.0%
2-1/2"	2.5	64	73.0%
1-1/4"	1.3	32	30.0%
5/8"	0.63	16	19.0%
5/16"	0.31	8.0	11.0%
No. 5	0.16	4.0	4.00%
No. 10	0.079	2.0	3.00%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
5%	91%	4%	NA

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	58
D_{50}=	47
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

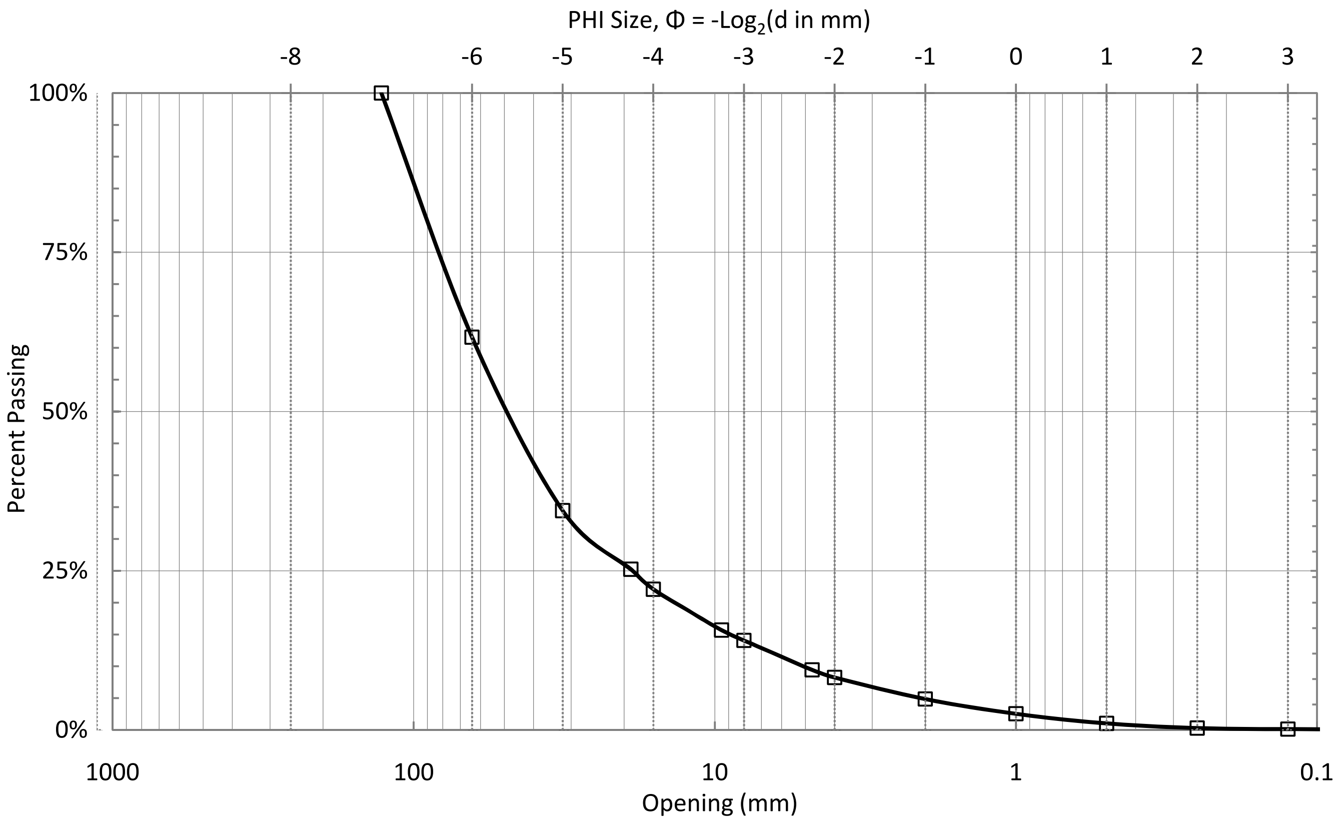
River Mile 37.6

Armor X

Sub-Armor

Location Notes

Taken on left bank point bar.



US Sieve Class	*Nominal Opening* (in)	(mm)	Percent Passing
5"	5.0	128	100%
2-1/2"	2.5	64	61.7%
1-1/4"	1.3	32	34.4%
3/4"	0.75	19	25.2%
5/8"	0.63	16	22.1%
3/8"	0.37	9.5	15.7%
5/16"	0.31	8.0	14.1%
No. 4	0.187	4.75	9.44%
No. 5	0.16	4.0	8.25%
No. 10	0.079	2.0	4.86%
No. 18	0.039	1.0	2.56%
No. 35	0.020	0.50	1.04%
No. 60	0.010	0.25	0.311%
No. 120	0.0049	0.125	0.150%
No. 200	0.0030	0.075	0.105%
No. 230	0.0025	0.063	0.104%
No. 270	0.0021	0.053	0.000%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
38%	57%	5%	0%

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	70
D_{50}=	50
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

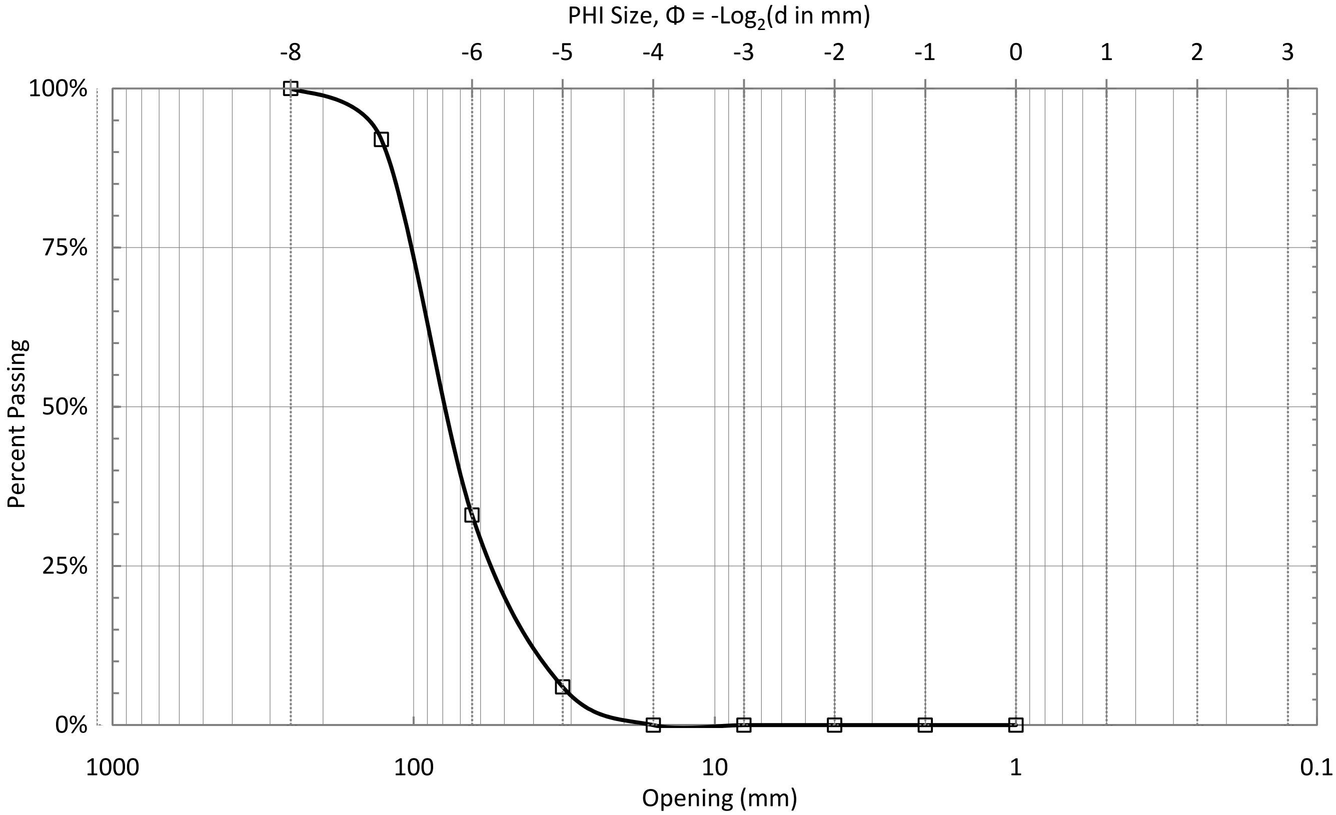
River Mile 37.6

Armor

Sub-Armor X

Location Notes

Taken on left bank point bar.



US Sieve Class	Nominal Opening (in)	(mm)	Percent Passing
10"	10	256	100%
5"	5.0	128	92.0%
2-1/2"	2.5	64	33.0%
1-1/4"	1.3	32	6.00%
5/8"	0.63	16	0.00%
5/16"	0.31	8.0	0.00%
No. 5	0.16	4.0	0.00%
No. 10	0.079	2.0	0.00%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
8%	92%	0%	NA

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	99
D_{50}=	82
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

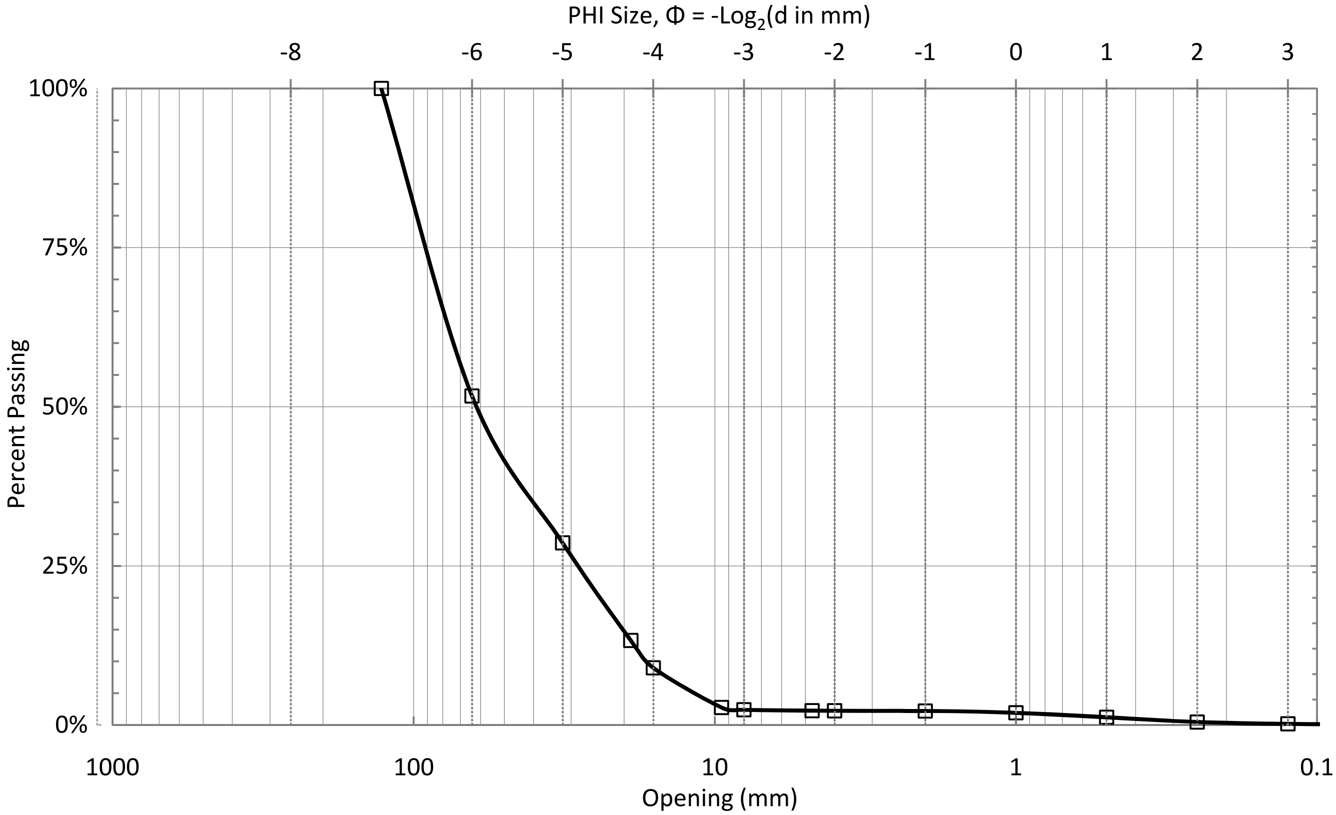
River Mile 42.1

Armor X

Sub-Armor

Location Notes

Bedrock on river left 30 ft upstream of site with deep pool.



US Sieve Class	Nominal Opening (in)	(mm)	Percent Passing
5"	5.0	128	0.939%
2-1/2"	2.5	64	51.7%
1-1/4"	1.3	32	28.6%
3/4"	0.75	19	13.3%
5/8"	0.63	16	8.99%
3/8"	0.37	9.5	2.76%
5/16"	0.31	8.0	2.41%
No. 4	0.187	4.75	2.26%
No. 5	0.16	4.0	2.25%
No. 10	0.079	2.0	2.20%
No. 18	0.039	1.0	1.93%
No. 35	0.020	0.50	1.23%
No. 60	0.010	0.25	0.475%
No. 120	0.0049	0.125	0.190%
No. 200	0.0030	0.075	0.110%
No. 230	0.0025	0.063	0.110%
No. 270	0.0021	0.053	0.000%

Pct. Cobbles	*Pct. Gravel*	*Pct. Sand*	*Pct. Fines*
48%	49%	2%	0%

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	82
D_{50}=	62
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

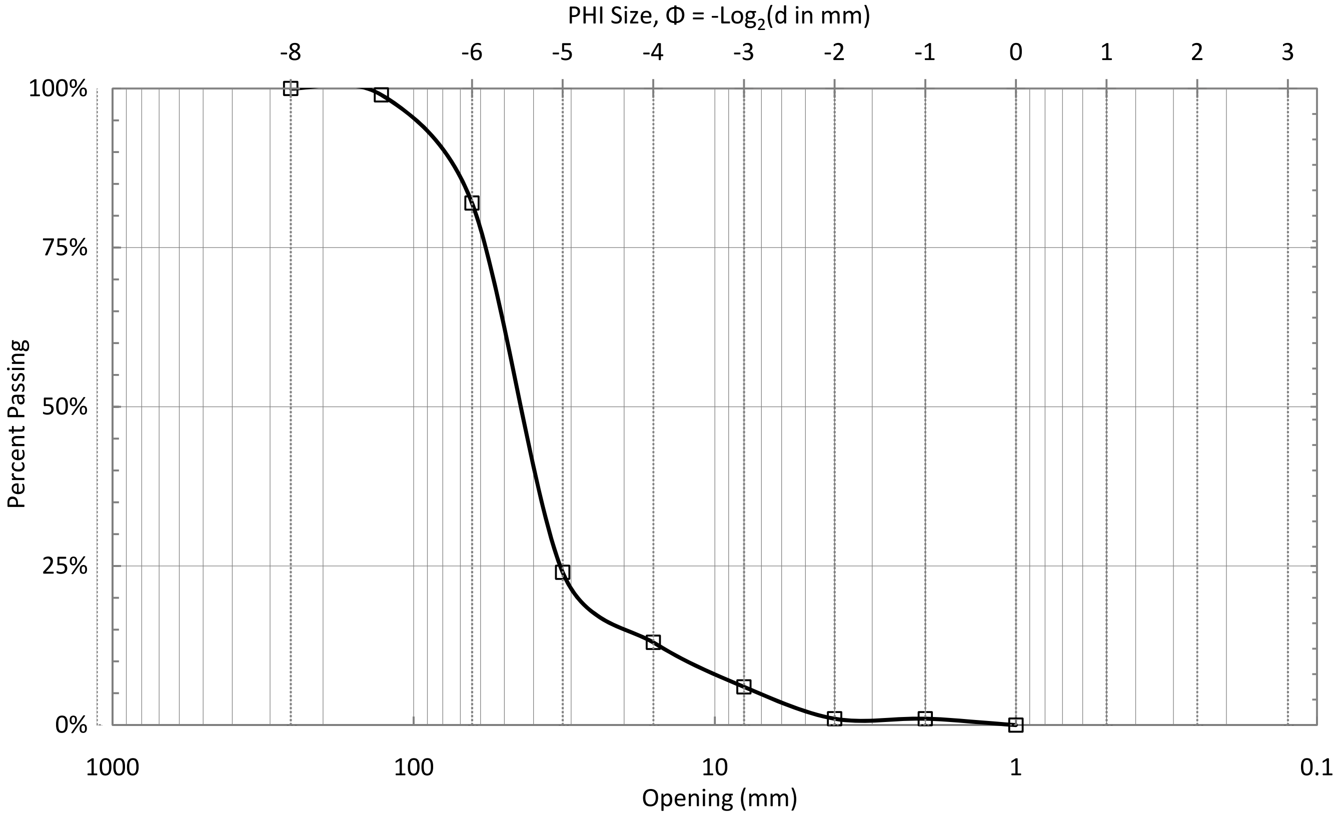
River Mile 42.1

Armor

Sub-Armor X

Location Notes

Bedrock on river left 30 ft upstream of site with deep pool.



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
10"	10	256	100%
5"	5.0	128	99.0%
2-1/2"	2.5	64	82.0%
1-1/4"	1.3	32	24.0%
5/8"	0.63	16	13.0%
5/16"	0.31	8.0	1.00%
No. 5	0.16	4.0	1.00%
No. 10	0.079	2.0	1.00%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
1%	98%	1%	NA

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	55
D_{50}=	46
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

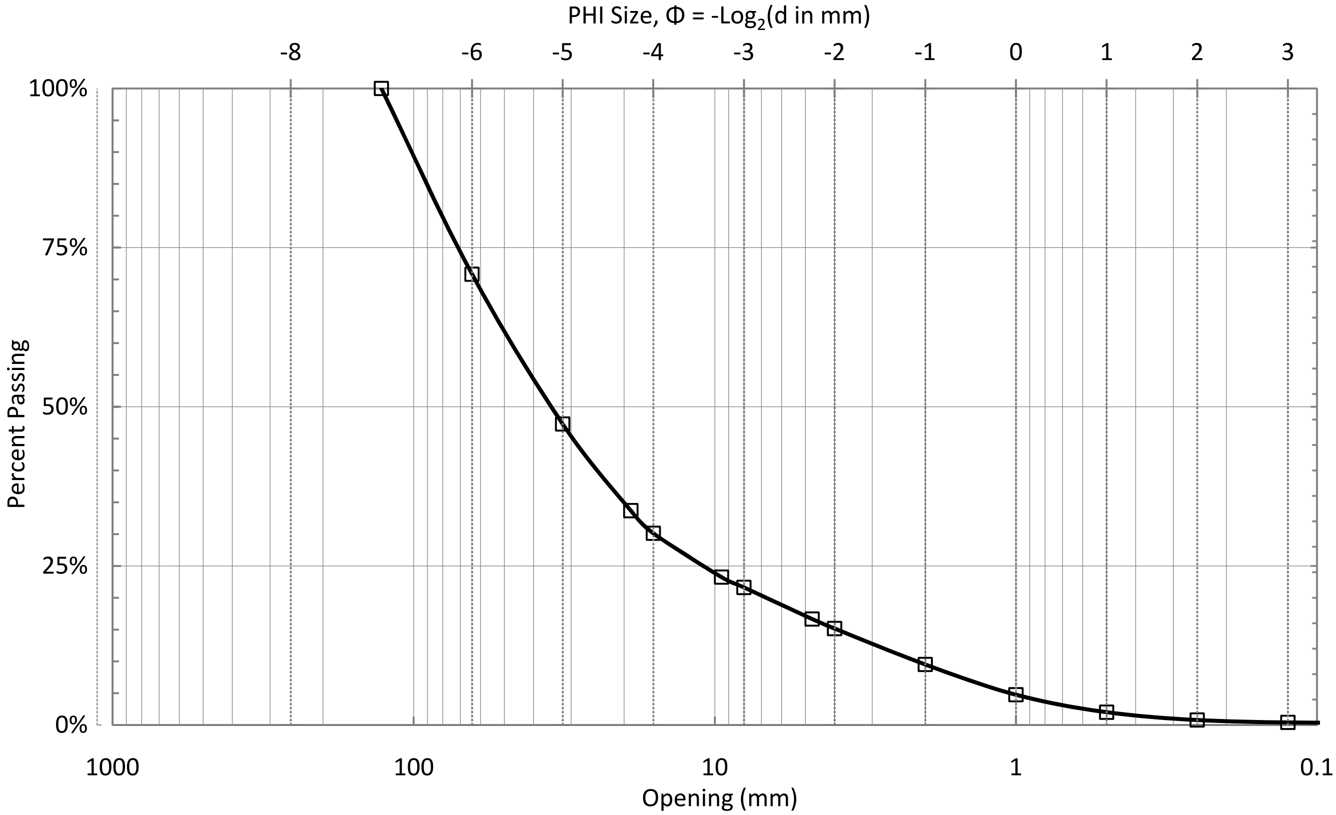
River Mile 45.8

Armor X

Sub-Armor

Location Notes

Mid-channel bar just downstream of Tucannon Campground.



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
5"	5.0	128	100%
2-1/2"	2.5	64	70.8%
1-1/4"	1.3	32	47.3%
3/4"	0.75	19	33.7%
5/8"	0.63	16	30.1%
3/8"	0.37	9.5	23.2%
5/16"	0.31	8.0	21.6%
No. 4	0.187	4.75	16.7%
No. 5	0.16	4.0	15.2%
No. 10	0.079	2.0	9.52%
No. 18	0.039	1.0	4.77%
No. 35	0.020	0.50	2.02%
No. 60	0.010	0.25	0.795%
No. 120	0.0049	0.125	0.425%
No. 200	0.0030	0.075	0.296%
No. 230	0.0025	0.063	0.293%
No. 270	0.0021	0.053	0.000%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
29%	61%	9%	0%

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	56
D_{50}=	36
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

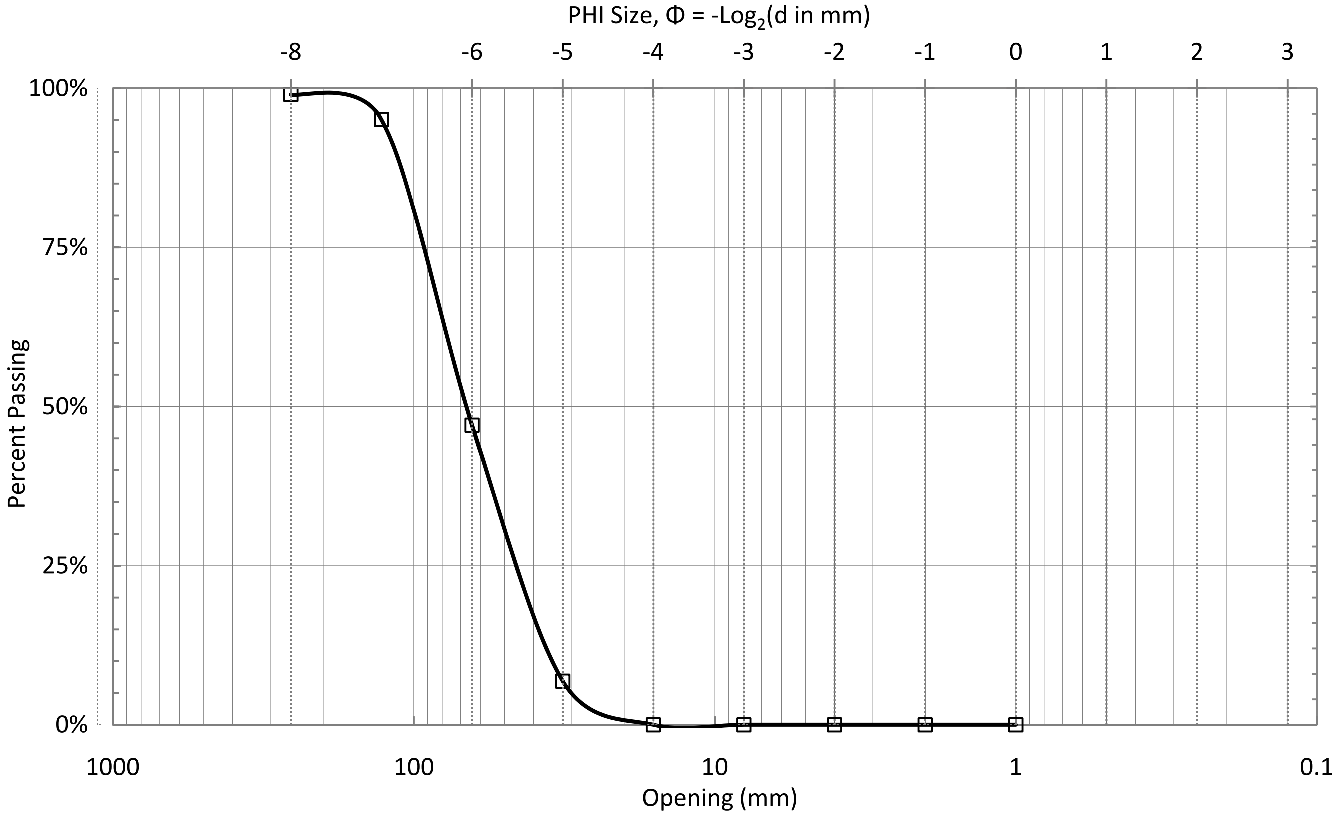
River Mile 45.8

Armor

Sub-Armor X

Location Notes

Mid-channel bar just downstream of Tucannon Campground.



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
10"	10	256	99.0%
5"	5.0	128	95.1%
2-1/2"	2.5	64	47.1%
1-1/4"	1.3	32	6.86%
5/8"	0.63	16	0.00%
5/16"	0.31	8.0	0.00%
No. 5	0.16	4.0	0.00%
No. 10	0.079	2.0	0.00%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
5%	95%	0%	NA

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	88
D_{50}=	68
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

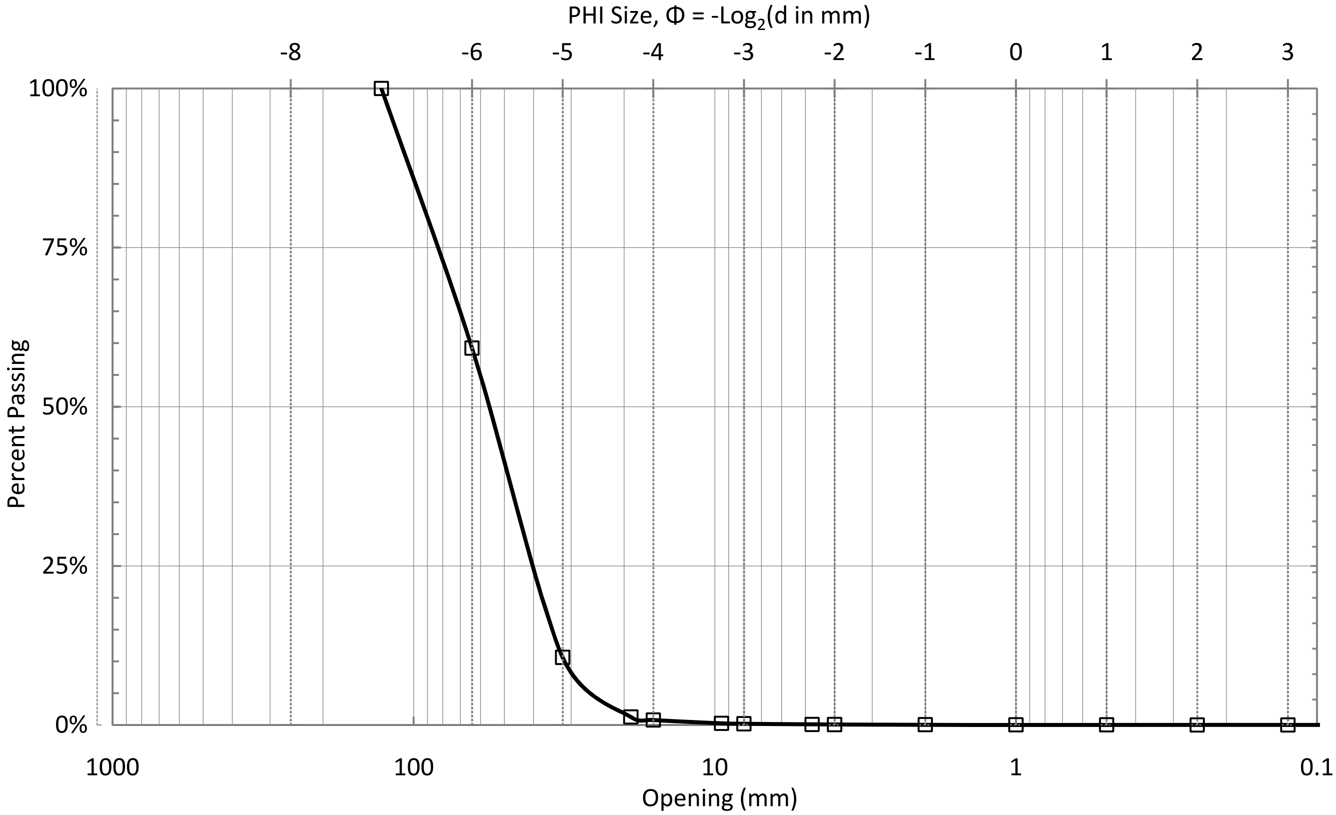
River Mile 49.1

Armor X

Sub-Armor

Location Notes

Right bank bar adjacent to campsite.



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
5"	5.0	128	100%
2-1/2"	2.5	64	59.2%
1-1/4"	1.3	32	10.6%
3/4"	0.75	19	1.27%
5/8"	0.63	16	0.803%
3/8"	0.37	9.5	0.274%
5/16"	0.31	8.0	0.208%
No. 4	0.187	4.75	0.101%
No. 5	0.16	4.0	0.0864%
No. 10	0.079	2.0	0.0640%
No. 18	0.039	1.0	0.0530%
No. 35	0.020	0.50	0.0392%
No. 60	0.010	0.25	0.0248%
No. 120	0.0049	0.125	0.0175%
No. 200	0.0030	0.075	0.0144%
No. 230	0.0025	0.063	0.0141%
No. 270	0.0021	0.053	0.000%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
41%	59%	0%	0%

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	73
D_{50}=	58
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

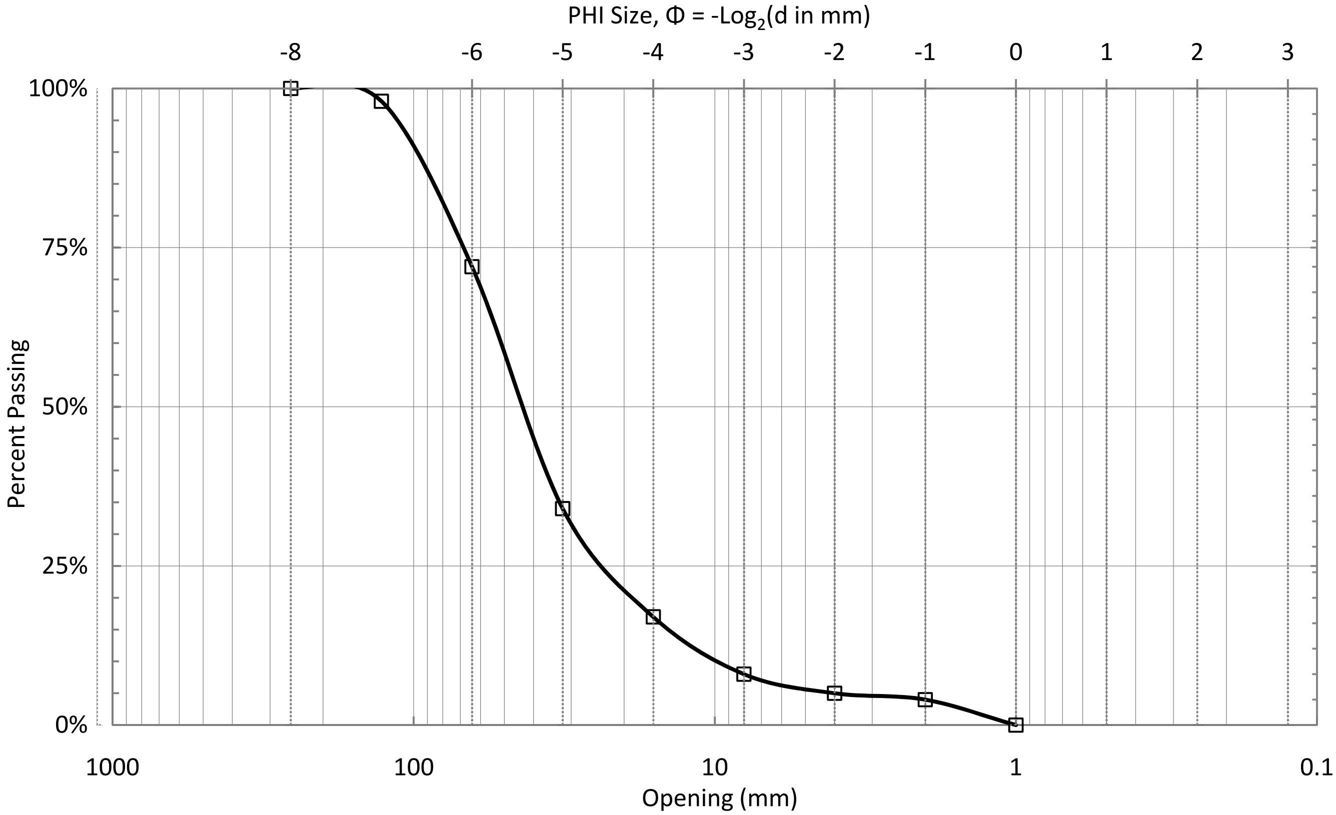
River Mile 49.1

Armor

Sub-Armor X

Location Notes

Right bank bar adjacent to campsite.



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
10"	10	256	100%
5"	5.0	128	98.0%
2-1/2"	2.5	64	72.0%
1-1/4"	1.3	32	34.0%
5/8"	0.63	16	17.0%
5/16"	0.31	8.0	8.00%
No. 5	0.16	4.0	5.00%
No. 10	0.079	2.0	4.00%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
2%	93%	5%	NA

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	58
D_{50}=	45
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

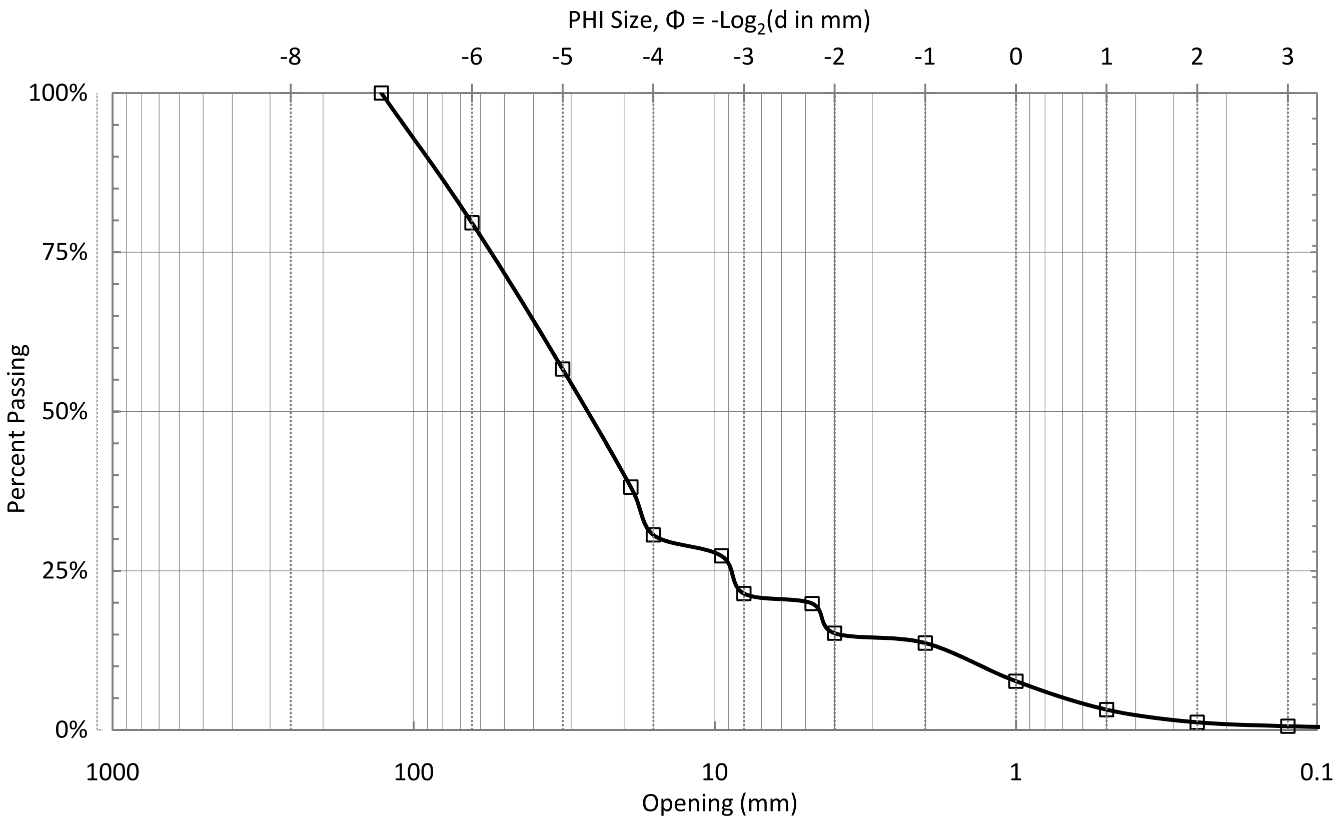
River Mile 50.3

Armor X

Sub-Armor

Location Notes

Sample taken in Panjab Creek near the confluence with the Tucannon River at river mile 50.3. Lots of large wood in stream. Side channel bar upstream.



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
5"	5.0	128	100%
2-1/2"	2.5	64	79.6%
1-1/4"	1.3	32	56.7%
3/4"	0.75	19	38.1%
5/8"	0.63	16	30.6%
3/8"	0.37	9.5	27.3%
5/16"	0.31	8.0	21.4%
No. 4	0.187	4.75	19.9%
No. 5	0.16	4.0	15.2%
No. 10	0.079	2.0	13.7%
No. 18	0.039	1.0	7.67%
No. 35	0.020	0.50	3.20%
No. 60	0.010	0.25	1.21%
No. 120	0.0049	0.125	0.602%
No. 200	0.0030	0.075	0.392%
No. 230	0.0025	0.063	0.291%
No. 270	0.0021	0.053	0.000%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
20%	72%	7%	0%

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	87
D_{50}=	52
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

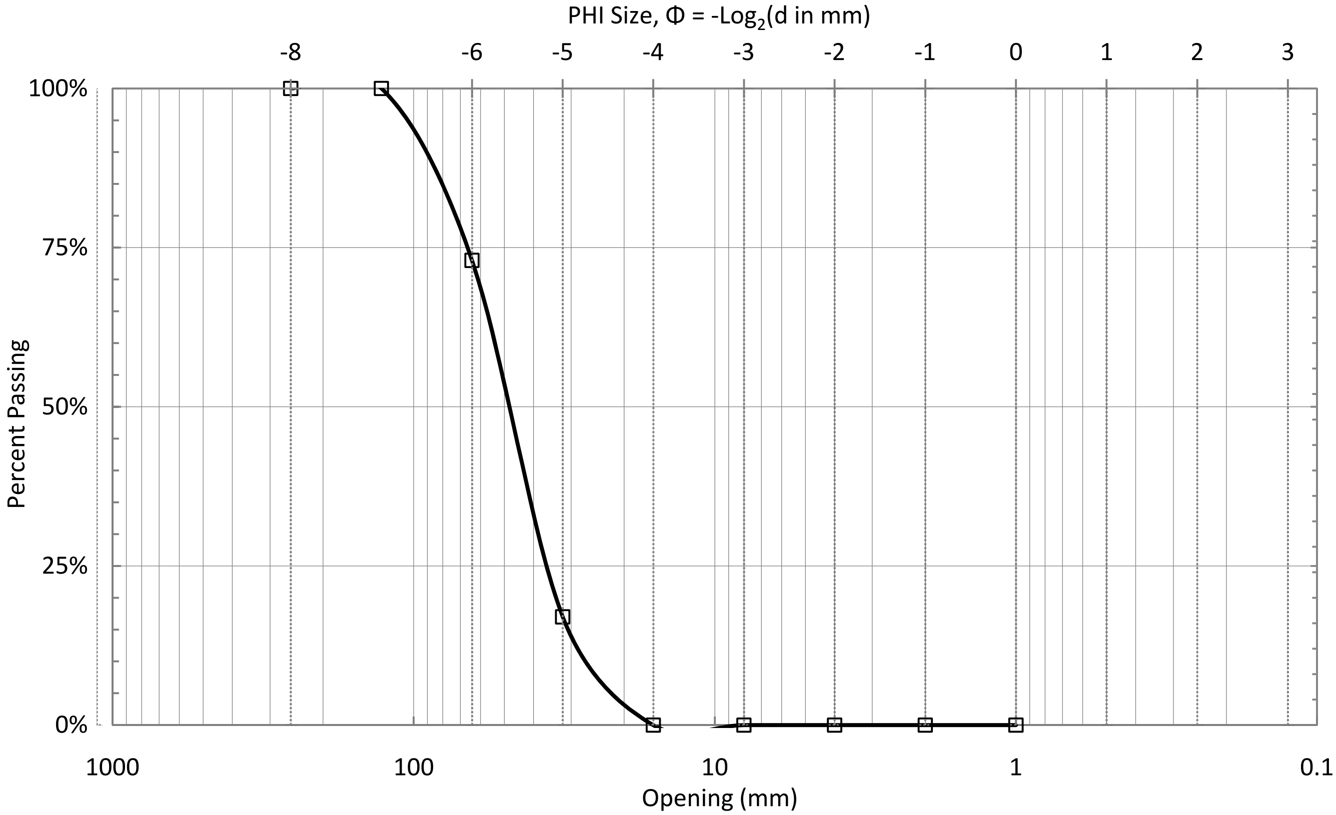
River Mile 50.3

Armor

Sub-Armor X

Location Notes

Sample taken in Panjab Creek near the confluence with the Tucannon River at river mile 50.3. Lots of large wood in stream. Side channel bar upstream.



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
10"	10	256	100%
5"	5.0	128	100%
2-1/2"	2.5	64	73.0%
1-1/4"	1.3	32	17.0%
5/8"	0.63	16	0.00%
5/16"	0.31	8.0	0.00%
No. 5	0.16	4.0	0.00%
No. 10	0.079	2.0	0.00%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
0%	100%	0%	NA

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	59
D_{50}=	51
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

River Mile 50.5

Armor X

Sub-Armor

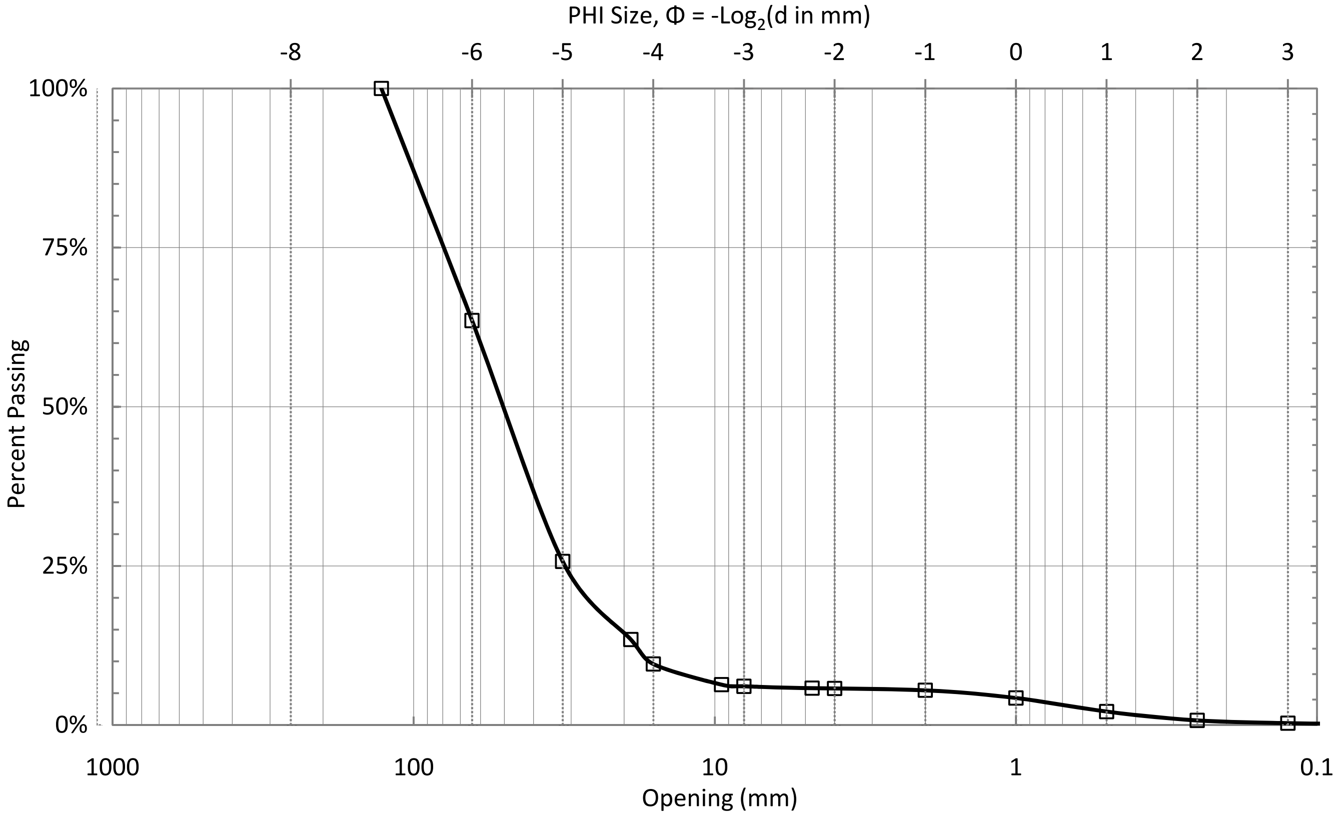
Location Notes

Mid-channel bar.

Sediment Grain Size Distribution Report

Sample ID : TR_22_SA

Project: Tucannon River
Client: CCD



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
5"	5.0	128	0.939%
2-1/2"	2.5	64	63.5%
1-1/4"	1.3	32	25.7%
3/4"	0.75	19	13.4%
5/8"	0.63	16	9.59%
3/8"	0.37	9.5	6.35%
5/16"	0.31	8.0	6.09%
No. 4	0.187	4.75	5.80%
No. 5	0.16	4.0	5.74%
No. 10	0.079	2.0	5.47%
No. 18	0.039	1.0	4.26%
No. 35	0.020	0.50	2.12%
No. 60	0.010	0.25	0.738%
No. 120	0.0049	0.125	0.305%
No. 200	0.0030	0.075	0.188%
No. 230	0.0025	0.063	0.186%
No. 270	0.0021	0.053	0.000%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
36%	58%	5%	0%

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	67
D_{50}=	53
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

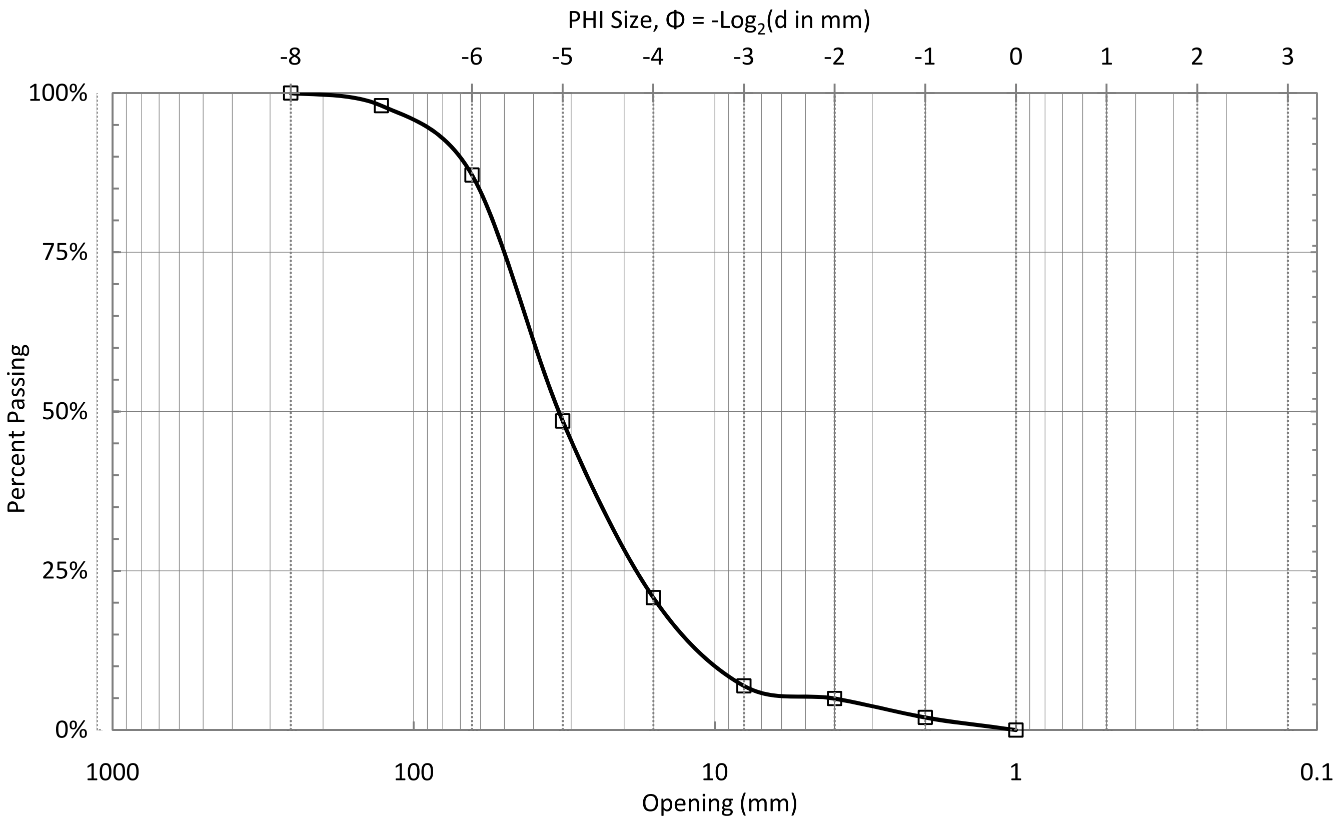
River Mile 50.5

Armor

Sub-Armor X

Location Notes

Mid-channel bar.



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
10"	10	256	100%
5"	5.0	128	98.0%
2-1/2"	2.5	64	87.1%
1-1/4"	1.3	32	48.5%
5/8"	0.63	16	20.8%
5/16"	0.31	8.0	1.98%
No. 5	0.16	4.0	4.95%
No. 10	0.079	2.0	1.98%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
2%	93%	5%	NA

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	46
D_{50}=	33
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

River Mile 55

Armor X

Sub-Armor

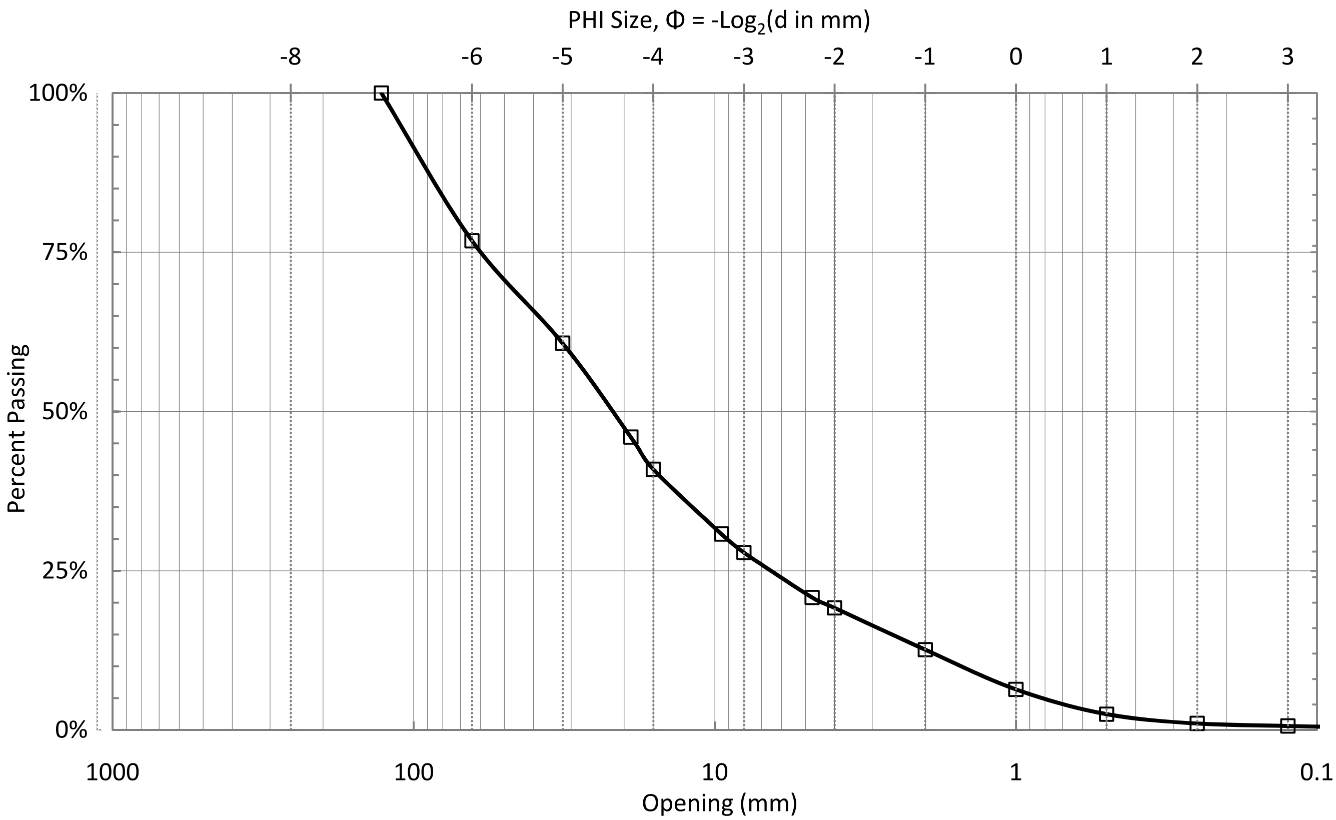
Location Notes

Just downstream of tributary with alluvial fan. Sample taken in lee of rootwad. No other bars in vicinity.

Sediment Grain Size Distribution Report

Sample ID : TR_23_SA

Project: Tucannon River
Client: CCD



US Sieve Class	Nominal Opening (in)	Nominal Opening (mm)	Percent Passing
5"	5.0	128	100%
2-1/2"	2.5	64	76.8%
1-1/4"	1.3	32	60.7%
3/4"	0.75	19	46.0%
5/8"	0.63	16	40.9%
3/8"	0.37	9.5	30.8%
5/16"	0.31	8.0	27.9%
No. 4	0.187	4.75	20.8%
No. 5	0.16	4.0	19.2%
No. 10	0.079	2.0	12.6%
No. 18	0.039	1.0	6.38%
No. 35	0.020	0.50	2.49%
No. 60	0.010	0.25	1.04%
No. 120	0.0049	0.125	0.639%
No. 200	0.0030	0.075	0.457%
No. 230	0.0025	0.063	0.453%
No. 270	0.0021	0.053	0.000%

Pct. Cobbles	Pct. Gravel	Pct. Sand	Pct. Fines
23%	64%	12%	0%

Coefficients (mm)	
D_{90}=	-
D_{85}=	-
D_{65}=	40
D_{50}=	23
D_{30}=	-
D_{15}=	-
D_{10}=	-

Sample Location

River Mile 55

Armor

Sub-Armor X

Location Notes

Just downstream of tributary with alluvial fan. Sample taken in lee of rootwad. No other bars in vicinity.

APPENDIX C
SEDIMENT BUDGET REPORT

Prepared by: Kathy Dubé
Watershed GeoDynamics

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C.1 INTRODUCTION

A sediment budget for the Tucannon River watershed was developed to provide data on the input and transport of bedload and fines in the river system. Understanding the amount and timing of both bedload and suspended sediment movement through the proposed habitat restoration areas is an important aspect to ensuring the long-term success of enhancement projects.

Bedload, the coarse-grained portion of the sediment load that moves along the bed of the river, is the basis for channel geomorphology and channel substrate that provides spawning, rearing, and hiding habitat for fish and aquatic organisms. In the Tucannon River, bedload consists of cobble, gravel, and sand-sized particles. Suspended load, the fine-grained portion of the sediment load that moves in suspension, affects turbidity (water clarity). High levels of fine-grained sediment (sand, silt, and clay) can also degrade aquatic habitat by filling the pore spaces between cobble and gravel particles on the bed and reducing the oxygen flow to incubating fish eggs and reducing macroinvertebrate habitat.

The sediment input budget considers the amount and timing of sediment delivered to the channel from different erosion processes and sediment sources. Based on a review of past studies in the watershed and field and aerial photograph analysis, the following erosion processes appear to be dominant in the basin:

- Surface and rill erosion on unvegetated soil.
- Streambank erosion due to channel migration of the mainstem Tucannon River.
- Stream entrenchment (incision) in some tributaries, particularly Pataha Creek and Smith Hollow.
- Periodic gullying of some swales during extreme rainfall events. Mass wasting (landsliding) does not appear to be a dominant erosion process (USFS 2002).

Sediment inputs related to these processes were categorized for each of the following sources of sediment:

- Land Use – surface and rill erosion
  - Agricultural and range land
  - Timber harvest

- Wildfire – surface and rill erosion
- Road Erosion – surface erosion from un-surfaced (gravel/dirt) roads
- Streambank erosion – channel migration along the mainstem Tucannon
- Colluvial erosion and debris flows – Gullying in steep, bedrock-lined swales
- Channel incision – entrenchment along Pataha Creek and Smith Hollow

C.1.1 Past Studies

A number of past studies pertaining to sediment input and transport have been conducted in the Tucannon watershed. Comprehensive basin studies are summarized below; other process-specific studies are discussed in the appropriate sections.

The most comprehensive study was conducted for the National Resource Conservation Service (NRCS) in 1982 and included monitoring of water quality, suspended load, and bedload sediment at six locations in the Tucannon watershed as well as channel scour, inter-gravel flow, a study of changes to river form, and an aquatic habitat inventory (Hecht et al. 1982). Major findings of the 1982 study included the following points that are pertinent to this analysis:

- Hydrology – Relative to total average annual flow at the Starbuck gage, Pataha Creek contributed approximately 11% of the average annual flow, while the Tucannon basin upstream of Pataha Creek contributed approximately 85% of the flow during the 1980 water year. This is consistent with the partitioning of flow estimated by comparing U.S. Geologic Service (USGS) gaging records (see Appendix A).
- Channel change – The character of the mainstem Tucannon channel changed from a single, meandering thread in 1937 (aerial photographs) to a more braided pattern in 1978, with fewer large trees in the riparian zone. The change in planform resulted in an overall decrease in channel length and resulting increase in slope. The authors suggested that the channel changes were likely the result of increased peak runoff, removal of riparian forests, and a large flood that occurred in 1964.
- Sediment load – Suspended sediment load and bedload during 1980 were measured at several locations in the watershed. The 1980 annual suspended load and bedload at the Starbuck gage were 138, 270, and 565 tons, respectively. The majority of the suspended load came from Pataha Creek and the lower mainstem; there was little bedload movement in the Pataha drainage. Annual suspended sediment load from

other studies at the Starbuck gage was summarized; it varied greatly from over 3,000,000 tons/year to less than 10,000 tons/year (1963 to 1970 time period).

- **Scour and fill** – Scour and fill was measured at five locations in the mainstem Tucannon; maximum observed scour was 1.47 feet and maximum fill was 1.27 feet.

The USDA Forest Service (USFS) conducted an ecosystem analysis of the Tucannon watershed in 2002, concentrating on the upper Forest Service lands (USFS 2002). They found that the primary erosion process in the watershed is surface erosion (sheet and gully erosion), which is highest when rainfall events occur during times that the ground is frozen or saturated. The USFS inventoried landslides following the 1996 storm and found a total of only 21 slides on Forest Service land, supporting their conclusion that mass wasting is not a major sediment source in the watershed. They also investigated channel changes and found that the mainstem responded to the major flood by becoming more braided, wider, and shallower due to bank erosion and channel migration. The USFS has also been monitoring erosion following the School Fire in 2005. These results are discussed in Section C.2.4 – Wildfire.

C.2 METHODS AND RESULTS

The methods to estimate sediment inputs in this report were based on a field reconnaissance and historical aerial photograph analysis to help identify site-specific locations of past and current sediment sources and to provide information on erosion rates and delivery to streams. Erosion modeling was also used to extrapolate observations and measurements to other parts of the watershed. Estimates of sediment sources under current (2010) watershed conditions were made, as well as quantitative or qualitative estimates of sediment sources under historical conditions. Legacy sources of sediment, particularly coarse sediment (gravel and cobble), can continue to have an influence on stream conditions for decades or centuries as they are processed by the stream. Sediment inputs were calculated for each of 18 subbasins in the watershed to allow for analysis of sediment related to potential future habitat enhancement projects in different parts of the river. Due to uncertainties inherent in sediment budgeting techniques, the numerical results should be regarded as estimates of the relative magnitude of sediment from different sources, rather than a precise measurement of sediment inputs.

Figure 3 shows subbasins, roads, and stream gage/sediment sampling locations that are used in this report.

C.2.1 Aerial Photograph Analysis

A series of historic aerial photographs were viewed to look for past and current sediment sources and trends of disturbance through time. Table C-1 lists the photographs reviewed along with intervening large floods/storm events.

Table C-1
Aerial Photographs Reviewed for Sediment Source Analysis and Peak Flow Events

Date	Type	Scale	Source (Photo Set)
2/10/16	High flow (5,740 cfs) at Starbuck gage		
2/2/30	High flow (6,000 cfs) at Starbuck gage		
1937	B&W air photos, missing lower mainstem	Unknown, but large scale (24" x 24" prints)	NRCS (AAV)
8/18/54	B&W air photos	Unknown	NRCS (AAV)
12/22/64	High flow (7,980 cfs) at Starbuck gage		
7/24/74	B&W air photos, lower watershed and Pataha Creek	1:76,000	USGS (GS-VDPG)
8/30/76	B&W air photos, upper watershed	1: 80,000	USFS (41061)
1987	B&W air photos, WDNR transferred to orthophotos	1:24,000 (original scale 1:63,360)	WDNR
6/27/95	B&W air photos, parts of upper mainstem	1:12,000	WDNR (SE-P-95)
2/9/96	High flow (5,580 cfs) at Starbuck gage		
1996	B&W air photos, mainstem Tucannon	1:550 (est.)	CCD (BPA-TUCA)
2010	Color air photos, mainstem Tucannon	Electronic	CCD

Notes:
cfs = cubic feet per second
NRCS = National Resource Conservation Service
USFS = U.S. Forest Service
WDNR = Washington Department of Natural Resources
CCD = Columbia Conservation District
USGS = U.S. Geological Service

All photos were reviewed to look for sediment sources and land use patterns. Photos covering the mainstem Tucannon River from 1954, 1974, 1976, and 1996 were scanned and geo-referenced in ArcGIS for analysis of channel migration patterns. The 1937 photos were not scanned because they were too large to fit in the portable scanner (photos could not be removed from the NRCS office). The resolution of the 1987 orthophoto sheets was inadequate to accurately determine the channel position.

C.2.2 Grain Size Sampling

Sediment sources were partitioned into three size classes for analysis: cobble and gravel (greater than 2 mm), sand (0.0625 to 2 mm), and fines (less than 0.0625 mm). Partitioning was based on riverbed samples taken during the summer of 2010 (described in Section 6.1 of the main report), grab samples of fine-grained bank material in the Pataha Creek watershed, and soil sample characteristics reported by the NRCS on their Web Soil Survey (NRCS 2009). Partitioning was different for each erosion process based on soil properties as well as the size of particles that could be eroded by that process. Table C-2 shows how total input from each sediment source was partitioned.

Table C-2
Partitioning of Sediment Sources by Grain Size Class

Sediment Source	Percent Cobble/Gravel	Percent Sand	Percent Fines
Land Use – sheet and rill erosion	10%	45%	455
Road surface erosion	5%	50%	45%
Wildfire – surface erosion	0%	50%	50%
Streambank erosion – Hartsock Grade subbasin	90%	9%	1%
Streambank erosion – lower subbasin	90%	9%	1%
Streambank erosion – Marengo subbasin	98%	1%	0%
Streambank erosion – Smith Hollow subbasin	85%	13%	2%
Streambank erosion – Starbuck subbasin	87%	12%	1%
Streambank erosion – gully/swale channels in loess	0%	70%	30%
Streambank erosion - gully/swale channels in volcanic bedrock	25%	15%	65%
Channel Incision – Pataha Creek and Smith Hollow	0%	70%	30%

C.2.3 Land Use – Surface and Rill Erosion

Land use activities that expose bare soil may increase the potential for erosion. In the Tucannon River watershed, agriculture and timber harvest are important economic activities that result in ground disturbance. The 2001 National Land Cover Database (NLCD 2001) data were used to represent land use for this analysis (Figure 2, main report). Primary land use types include: forested land in the upper watershed (24% of basin area); cultivated crops, primarily wheat and barley on the flat hilltops in the middle and lower watershed (32% of area); shrub/scrub on the drier slopes in the lower basin (20% of area); and grassland used for grazing on the side slopes in the middle basin (19% of area).

The fine-grained Palouse loess soils that provide such good agricultural lands and cover much of the lower watershed are extremely susceptible to erosion (Figure 4, main report). Erosion rates of fine-grained soils are particularly high if intense rainfall occurs on exposed soils when the soil is frozen or saturated. Many studies have been conducted to determine erosion rates on Palouse soils, as well as conservation methods that can reduce erosion rates.

The NRCS completed a cooperative river basin study in 1984 that concluded that soil erosion was a serious problem on croplands in southeastern Washington (NRCS 2004). They estimated erosion from cropland, rangeland, and forested areas for the Tucannon watershed and found surface erosion rates for cropland averaged 7 tons/acre/year; gully erosion from croplands was 0.1 tons/acre/year; erosion from rangeland was 0.5 tons/acre/year; 0.3 tons/acre/year from forested areas; and an average of 16% of eroded soil was delivered to streams. The NRCS concluded that changes to cropping systems could significantly reduce erosion; for example, converting to no-till farming could reduce erosion up to 95%.

Fu et al. (2006) developed a GIS-based version of the Revised Universal Soil Loss Equation (RUSLE) and a sediment delivery algorithm to estimate the effects of no-till farming practices in the Pataha Creek watershed. Their model results suggested that cropland erosion rates decreased 78% under the no-till system compared to conventional tillage systems.

Williams et al. (2010) measured erosion from conventional tillage and no-till dry land crop areas in northeastern Oregon from 2001 to 2005. They found an average of 67.5

kilograms/hectare/year (0.03 tons/acre/year) from conventional tilled lands and 2.5 kilograms/hectare/year (0.001 tons/acre/year) from no-till lands under below-normal precipitation levels. These values compared reasonably well with calibrated Water Erosion Prediction Project (WEPP) simulations they ran for the areas. They also report a range of erosion measurements from previous studies, including 0.05 tons/acre/year from traditional tillage land (Williams et. al 2009) and a long-term average of 1.11 tons/acre/year since 1963 on 5% sloped croplands on the Columbia Plateau (Nagel and Ritchie 2004).

In order to estimate surface and rill erosion resulting from land use in different parts of the Tucannon watershed, the WEPP model was used to calculate erosion for a series of land use/slope gradient combinations. These results were applied to the GIS gridded land use and slope gradient coverages to determine average annual erosion from each grid cell. Delivery of eroded sediment to streams was estimated based on the distance from each grid cell to the stream as follows: 100% delivery within 100 feet of a stream, 35% delivery for land between 100 to 300 feet from a stream, 10% delivery for land 300 to 1,000 feet from a stream, and no delivery for land more than 1,000 feet from a mapped stream (WDNR 1997).

The following parameters were used in the WEPP model. Table C-3 shows the WEPP modeling results:

- **Climate:** Pomeroy
- **Soil:** Walla Walla silt loam
- **Hillslope length:** 100 feet planar slope
- **Hillslope gradient:** varied from 2 to 80%
- **Treatments applied as appropriate for disturbance type:** winter wheat conventional till, winter wheat no-till, short grass 60% cover (rangeland), Rome or cattle grazing (pasture land), 20-year-old forest

Table C-3
WEPP Model Runs Used for Analysis

WEPP Model Condition	Applied to Land Cover	Average Annual Erosion Rate (tons/acre/yr) for Slope Category					
		0-5%	5-15%	15-30%	30-45%	5-65%	>65%
20-year-old forest	All forest types (deciduous, evergreen, mixed)	0	0	0	0	0	0
Short grass, 60% cover	Shrub/scrub, Grassland	0.004	0.022	0.102	0.165	0.218	0.258
Cattle grazing	Pasture/hay	0.009	0.032	0.278	0.619	1.05	1.511
Winter wheat conventional till	Cultivated crops	0.077	0.274	1.918	3.951	5.617	7.289
Winter wheat no till	Cultivated crops	0.018	0.028	0.061	.014	0.237	0.342

Two different tillage scenarios were run to represent conditions in the early- to mid-part of the 1900s, which assumes all conventional till, and the change to farming and stream buffer conservation practices that reduce erosion from croplands, which assumes 50% conventional till and 50% no till. Table C-4 shows the estimated sediment input from all land uses under the conventional till, no till, and 50/50 conventional/no till scenarios. Total sediment under the no-till scenario is approximately 11% of the conventional till scenario, consistent with reductions reported elsewhere.

Table C-4
Estimated Sediment Input from Land Use

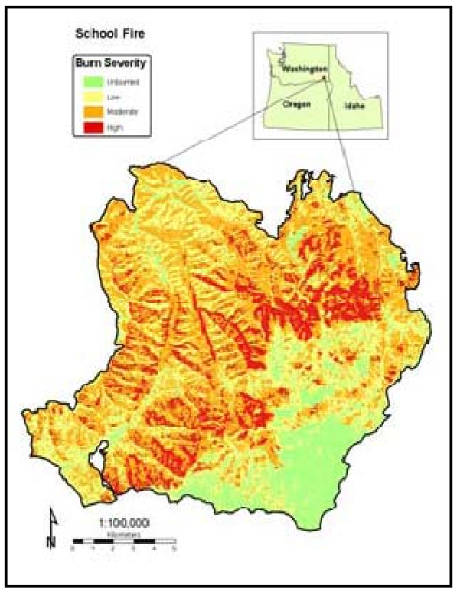
Subbasin	Land Use, Conventional (t/yr)			Land Use, No-Till (t/yr)			Land Use 50% conv. till, 50% no-till (t/yr)		
	Cobble/ Gravel	Sand	Fines	Cobble/ Gravel	Sand	Fines	Cobble/ Gravel	Sand	Fines
Headwaters Tucannon River	7	30	30	3	14	14	5	22	22
Panjab Creek	4	18	18	2	11	11	3	15	15
Little Tucannon River	44	198	198	20	92	92	32	145	145
Cummings Creek	21	94	94	7	31	31	14	63	63
Tumalum Creek	26	119	119	8	34	34	17	76	76
Hartsock Grade-Tucannon River	141	634	634	18	82	82	80	358	358
Town of Marengo-Tucannon River	64	289	289	18	83	83	41	186	186
Willow Creek	161	726	726	9	42	42	85	384	384

Subbasin	Land Use, Conventional (t/yr)			Land Use, No-Till (t/yr)			Land Use 50% conv. till, 50% no-till (t/yr)		
	Cobble/ Gravel	Sand	Fines	Cobble/ Gravel	Sand	Fines	Cobble/ Gravel	Sand	Fines
Upper Tucannon Total	**468**	**2,108**	**2,108**	**86**	**388**	**388**	**277**	**1,248**	**1,248**
Headwaters Pataha Creek	18	83	83	4	18	18	11	50	50
Bihmaier Gulch-Pataha Creek	173	777	777	19	87	87	96	432	432
Benjamin Gulch-Pataha Creek	106	475	475	13	58	58	59	267	267
Linville Gulch	290	1,305	1,305	22	99	99	156	702	702
Chard Gulch-Pataha Creek	103	464	464	19	83	83	61	274	274
Dry Hollow-Pataha Creek	66	298	298	11	52	52	39	175	175
Pataha Creek Total	**756**	**3,402**	**3,402**	**88**	**397**	**397**	**422**	**1,900**	**1,900**
Smith Hollow-Tucannon River	148	665	665	7	33	33	78	349	349
Town of Starbuck-Tucannon River	84	379	379	4	20	20	44	200	200
Kellogg Creek	266	1,197	1,197	14	64	64	140	631	631
Tucannon River	16	72	72	1	5	5	9	39	39
Watershed Total	**1,739**	**7,824**	**7,824**	**202**	**909**	**909**	**970**	**4,366**	**4,366**

C.2.4 Wildfire

In many areas of the western United States, wildfires are a natural component of the ecosystem and a mechanism for disturbance. Intense fires can burn vegetation and duff layers that protect the underlying mineral soil from erosion. In some cases this produces hydrophobic soil conditions that reduce infiltration and increase runoff and erosion. Less intense fires do not burn all vegetation or the duff layer, typically resulting in little surface erosion. Most fires result in patches of high, moderate, and low intensity fire within the burned area. Revegetation following natural fires is often rapid, especially in riparian areas where adequate moisture exists and in areas that are not intensely burned. The USFS analyzed the fire regime of USFS lands in the upper Tucannon watershed and characterized them as a mix of Fire Regime I (low severity, 0 to 35-year recurrence interval) and Fire Regime III (mixed high/low severity, 35 to 100+ year recurrence interval (USFS 2002).

In 2005, the School Fire burned approximately 50,000 acres in the upper Tucannon and Pataha drainages. As is typical with many wildfires, the School Fire left a mosaic of intensely, moderately, and lightly burned areas (Figure C-1). Based on observations made in the field and from the 2010 aerial photographs, the lasting effects of the School Fire from a sedimentation and geomorphology standpoint include a short-term input of sediment from erosion of the burned areas and a longer lasting effect of reduced canopy cover, bank stability, and long-term large wood inputs in areas of the mainstem Tucannon where there were more intense burns of the riparian zone (e.g., in patches between river mile [RM] 40 and 43). A smaller fire in the summer of 2010 in the upper Tucannon watershed in the vicinity of Hartsock Grade Road covered approximately 11,500 acres.



Source: USFS 2008

Figure C-1
Areas Burned in School Fire

The USFS has been measuring erosion and revegetation rates at several locations that were burned during the School Fire since 2006. Erosion data provided by the USFS reported an average of 0.05 tons/acre from untreated burned areas in 2008 and 0.04 tons/acre in 2008 (Clifton 2010). Based on an assumed exponential decrease in erosion rates with time after disturbance, the following erosion rates were applied to the area of the School Fire: 0.5 tons/acre in 2006, 0.05 tons/acre in 2007, 0.04 tons/acre in 2008, 0.03 tons/acre in 2009, and 0.02 tons/acre in 2010. Delivery rates used were the same as described for other land use sources based on distance from streams: 100% delivery within 100 feet of a stream, 35% delivery for land between100 to 300 feet from a stream, and 10% delivery for land 300 to

1,000 feet from a stream. Table C-5 shows the estimated average annual sediment input (2005 to 2010) from the School Fire.

Table C-5
Estimated Sediment Input from the School Fire

Subbasin	School Fire (t/yr)		
	Cobble/ Gravel	Sand	Fines
Headwaters Tucannon River	-	-	-
Panjab Creek	-	-	-
Little Tucannon River-Tucannon River	-	485	485
Cummings Creek	-	309	309
Tumalum Creek	-	123	123
Hartsock Grade-Tucannon River	-	40	40
Town of Marengo-Tucannon River	-	-	-
Willow Creek	-	-	-
Upper Tucannon Total	**0**	**957**	**957**
Headwaters Pataha Creek	-	167	167
Bihmaier Gulch-Pataha Creek	-	-	-
Benjamin Gulch-Pataha Creek	-	-	-
Linville Gulch	-	-	-
Chard Gulch-Pataha Creek	-	-	-
Dry Hollow-Pataha Creek	-	-	-
Pataha Creek Total	**0**	**167**	**167**
Smith Hollow-Tucannon River	-	-	-
Town of Starbuck-Tucannon River	-	-	-
Kellogg Creek	-	-	-
Tucannon River	-	-	-
Watershed Total	**0**	**1,124**	**1,124**

C.2.5 Road Erosion

A field reconnaissance of approximately 100 miles of roads within the watershed was conducted to determine hydrologic connectivity, road surfacing, width, cut-slope, and fill-slope characteristics. Roads visited included paved highways, graveled county roads, and smaller, unsurfaced forest roads.

The GIS stream delivery buffer layer (100, 200, and 1,000 feet) and Columbia and Garfield County road layers obtained from the Washington Department of Natural Resources (WDNR) website (see Figure 2, main report) were overlain to determine the lengths of road within each buffer boundary. Paved roads were excluded from the analysis because they have little erosion potential. For unpaved roads, the average road characteristics observed during the field reconnaissance were determined, and the data were entered into the Washington State Road Surface Erosion Model (WARSEM, Dubé et al. 2008) to estimate the average annual contribution of sediment to streams from roads in the watershed. Table C-6 shows the average annual sediment input from road surface erosion.

Table C-6
Estimated Sediment Input from Road Surface Erosion

	Road Surface Erosion (t/yr)		
Subbasin	**Cobble/ Gravel**	**Sand**	**Fines**
Headwaters Tucannon River	4	41	37
Panjab Creek	17	174	156
Little Tucannon River-Tucannon River	14	139	125
Cummings Creek	6	57	51
Tumalum Creek	3	29	26
Hartsock Grade-Tucannon River	2	21	19
Town of Marengo-Tucannon River	2	18	16
Willow Creek	4	39	35
Upper Tucannon Total	**52**	**517**	**465**
Headwaters Pataha Creek	22	215	194
Bihmaier Gulch-Pataha Creek	2	21	19
Benjamin Gulch-Pataha Creek	3	26	23
Linville Gulch	4	40	36
Chard Gulch-Pataha Creek	2	24	22
Dry Hollow-Pataha Creek	2	20	18
Pataha Creek Total	**35**	**346**	**312**

Subbasin	Road Surface Erosion (t/yr)		
	Cobble/ Gravel	Sand	Fines
Smith Hollow-Tucannon River	2	17	16
Town of Starbuck-Tucannon River	1	12	11
Kellogg Creek	3	31	28
Tucannon River	1	8	7
Watershed Total	**93**	**931**	**838**

C.2.6 Channel Erosion

Erosional processes associated with bedrock-lined swales and mainstem channel migration within the valley provide sediment directly to the stream channel. These sources are episodic; large quantities of sediment are added during major storms and peak flow events, with little sediment input during low or moderate flows. Field observations in the Tucannon watershed suggest that localized erosion and gullying of ephemeral, bedrock-lined channels located in steep, narrow swales occurs during major storms. This process has been documented by the USFS in a study of the effects of the 1996 flood event on forest land (Fitzgerald and Clifton 2007). In addition, analysis of historical aerial photographs shows that the mainstem Tucannon River actively migrates and erodes streambanks within its alluvial floodplain. A large amount of channel migration indeed occurs during large floods; however, observations by local residents suggest that channel migration is actively occurring in many locations throughout the study area during frequent flood events such as the 2-year event.

In order to estimate sediment input from these two types of channel processes, the GIS stream layer was overlain with the WDNR geology layer (WDNR 1997) to separate stream segments that are and are not underlain by alluvium. The alluvial stream segments are located in valley bottoms and are subject to channel migration. The non-alluvial stream segments are located in small, confined bedrock-lined valleys and on hillsides, and are subject to localized erosion and gullying.

C.2.6.1 Mainstem Channel Migration

An estimate of bank erosion along the alluvial channel lengths was made based on migration of the active Tucannon River mainstem channel observed on a series of historic aerial photographs. The photos used for this analysis were the 1954, 1974, 1976, 1996, and 2010 series. The active channel area was digitized on each photo series and overlaid to result in a series of polygons that represented unique areas of active channel on each set of photos. The area of each of these polygons thus represented new valley bottom areas that the active channel occupied between the previous and current photo years (i.e., the 1954 to 1974, 1976; 1974, 1976 to 1996; and 1996 to 2010 periods). The aerial photographs covered the mainstem Tucannon River between the mouth (RM 0) and just upstream of Cummings Creek (RM 38). Channel migration was evident along the mainstem between RM 38 and approximately RM 48 in the Little Tucannon River-Tucannon River subbasin, but could not be quantified due to the lack of complete aerial photograph coverage in this area. Therefore, estimates for sediment input from channel migration in this subbasin are unknown, but are likely of similar or smaller magnitude as the estimated amounts in the downstream Hartsock Grade-Tucannon River subbasin. A smaller amount of channel migration likely occurs in the Headwaters subbasin upstream of Panjab Creek, although the volume of contributed sediment is expected to be minor in comparison.

The unique active channel area for each photo period was multiplied by an average bank height of 3 feet (observed in the field) to yield the estimated volume of sediment added to the channel from channel migration. The total volume of eroded streambank for each photo period was divided by the number of years between photos to obtain an average annual sediment input rate. Figures D-1 and 2a through D-11a in Appendix D show the mapped active channel areas for the three photo periods.

C.2.6.2 Erosion in Bedrock Swales

Due to the small size of the bedrock-lined channels, they are not easily seen on aerial photographs and little information is available on the rates of erosional processes associated with these features. The two main sources of sediment to these drainages are colluvial erosion of soils that accumulate in the swales over time, and debris flows that remove these soils and carry them into the main river valley. Erosion from bedrock swale channels was estimated using a soil creep calculation and the assumption that the soil that gradually moves downhill via soil creep will enter the stream channel at the base of the hill by either bank erosion or gullying. Soil creep was calculated using the following formula (WDNR 1997):

Annual Sediment Yield from Soil Creep = Length of Stream Channel x 2 Banks x Soil Depth x Average Creep Rate x Soil Bulk Density

A creep rate of 1.5 millimeter/year (0.06 inches/year) and a soil depth of 1 meter (rounded to 3.25 feet) was used in the calculation. A bulk density value of 1.09 tons/cubic yard was used based on soil bulk density reported in the NRCS Web Soil Survey (NRCS 2009).

Table C-7 shows the estimated average annual sediment input from bedrock swales, as well as estimated input from channel migration in the mainstem for the three different aerial photograph periods studied. The inputs from migration of the mainstem channel vary greatly between photograph periods depending on whether a major flood occurred or not (e.g., 1954 to 1974 included the 1964 flood, and 1974 to 1996 included the 1996 flood).

Table C-7
Estimated Average Annual Sediment Input from Mainstem Channel Migration and Bedrock Swales

	Colluvial Erosion from bedrock swales (t/yr)			Channel migration 1954-1974/76 (t/yr)			Channel migration 1974-1996 (t/yr)			Channel migration 1996-2010 (t/yr)		
Subbasin	**Cobble/ Gravel**	**Sand**	**Fines**	**Cobble/ Gravel**	**Sand**	**Fines**	**Cobble/ Gravel**	**Sand**	**Fines**	**Cobble/ Gravel**	**Sand**	
Headwaters Tucannon River	132	99	429	U	U	U	U	U	U	U	U	U
Panjab Creek	109	82	356	-	-	-	-	-	-	-	-	-
Little Tucannon River-Tucannon River	342	259	1,113	U	U	U	U	U	U	U	U	U
Cummings Creek	163	122	529	-	-	-	-	-	-	-	-	-
Tumalum Creek	92	70	299	-	-	-	-	-	-	-	-	-
Hartsock Grade-Tucannon River	68	121	250	18,699	1,903	105	12,417	1,264	69	2,414	246	13
Town of Marengo-Tucannon River	50	81	182	58,231	760	256	24,852	324	109	9,262	121	41
Willow Creek	10	233	128	-	-	-	-	-	-	-	-	-
Upper Tucannon Total (see note below)	966	1,066	3,285	76,930	2,663	360	37,270	1,588	179	11,676	367	54
Headwaters Pataha Creek	181	136	590	-	-	-	-	-	-	-	-	-
Bihmaier Gulch-Pataha Creek	72	144	272	-	-	-	-	-	-	-	-	-

Subbasin	Colluvial Erosion from bedrock swales (t/yr)			Channel migration 1954-1974/76 (t/yr)			Channel migration 1974-1996 (t/yr)			Channel migration 1996-2010 (t/yr)		
	Cobble/ Gravel	Sand	Fines	Cobble/ Gravel	Sand	Fines	Cobble/ Gravel	Sand	Fines	Cobble/ Gravel	Sand	
Benjamin Gulch-Pataha Creek	37	74	141	-	-	-	-	-	-	-	-	-
Linville Gulch	63	162	256	-	-	-	-	-	-	-	-	-
Chard Gulch-Pataha Creek	44	113	178	-	-	-	-	-	-	-	-	-
Dry Hollow-Pataha Creek	42	138	181	-	-	-	-	-	-	-	-	-
Pataha Creek Total	440	767	1,617	0	0	0	0	0	0	0	0	0
Smith Hollow-Tucannon River	30	158	156	9,387	1,402	233	4,026	601	100	2,288	342	57
Town of Starbuck-Tucannon River	47	149	201	7,775	1,051	134	3,156	427	54	1,140	154	20
Kellogg Creek	51	248	256	-	-	-	-	-	-	-	-	-
Tucannon River	22	73	96	15,795	1,560	206	5,585	552	73	2,181	215	28
Watershed Total	1,556	2,461	5,612	109,887	6,676	934	50,036	3,167	406	17,286	1,078	159

Notes:
U= unknown; mainstem channel migration was observed in the Little Tucannon-Tucannon River subbasin, as well as a minor amount in the Headwaters subbasin, but the magnitude of sediment input in these areas could not be quantified due to the lack of complete aerial photograph coverage.

C.2.7 Channel Incision

Major areas of channel incision were observed along Pataha Creek and Smith Hollow. These streams flow through valleys filled with fine-grained silt and sand that originated as Quaternary loess deposits. These channels have been incised since at least the early 1900s; the incised areas are evident in the 1937 aerial photographs and mature trees can presently be observed within the incised channel areas in parts of Pataha Creek. It was not possible to determine the rate of ongoing incision or evolution of the channel cross-section within the incised areas with available data. However, continued erosion of the incised channel walls and bottom is occurring in Pataha Creek based on observations of erosion at bridge abutments along the creek.

Beechie et al. (2008) measured channel incision at several locations in Pataha Creek and provided the resulting measurements. Incision depths in Pataha Creek decreased in an upstream direction from 19 feet near the confluence with the Tucannon River to 6 to 7 feet near Pomeroy. Incision widths also decreased from 100 feet near the confluence to 34 feet near Pomeroy. Incision in Smith Hollow averaged 20 feet deep and 80 feet wide. Based on the field observations and a cross-section of lower Pataha Creek just upstream of the Highway 261 bridge taken from the LiDAR dataset (Figure C-2), it was estimated that 60% of the total width times depth of the incised area been eroded.

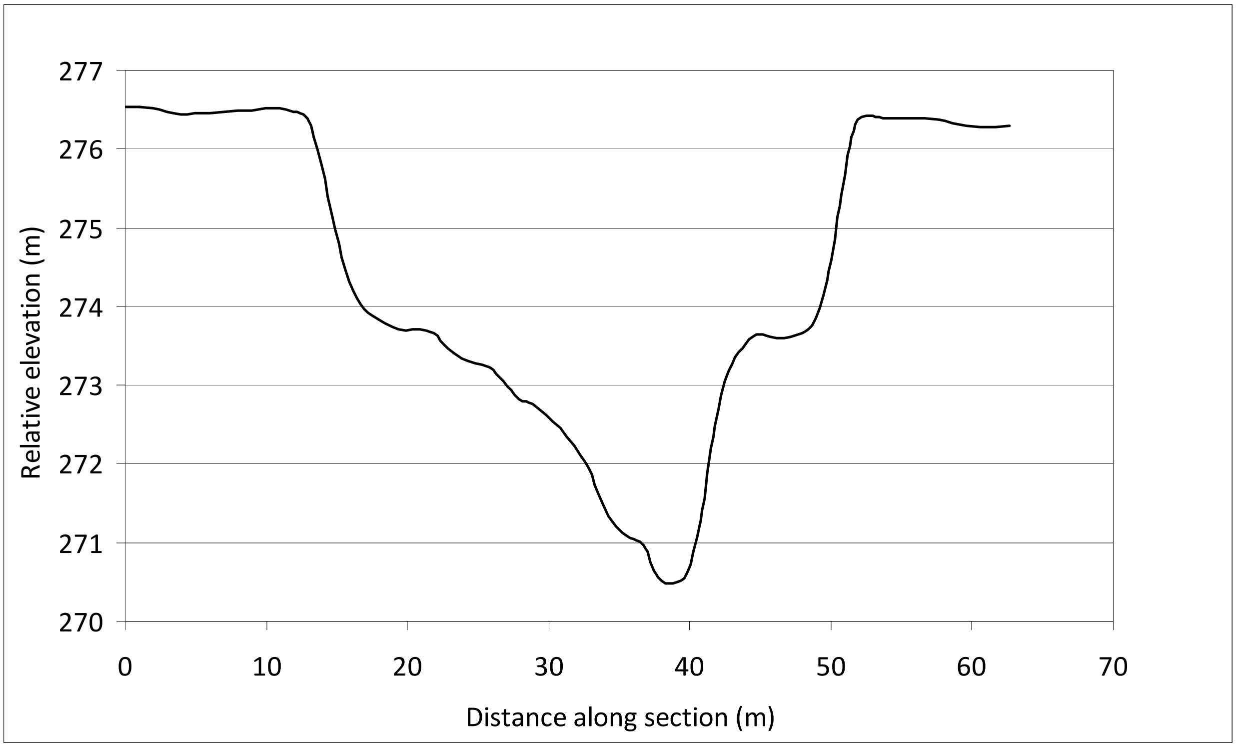


Figure C-2

Cross-Section of Pataha Creek Showing Channel Incision Profile

Note: Cross-section is located just upstream of the Highway 261 bridge crossing at a gravel sample site.

Observations and measurements of incision depth and measurements of the incised valley width from aerial photographs were used to estimate the total volume of sediment removed from the channels in the Pataha Creek and Smith Hollow subbasins (Table C-8). The rate of incision is not known; however, it is likely that incision is greatest during peak flow events. For sediment budgeting purposes, the total incised volume was divided by 100 years to provide an average annual input rate throughout the past century. It is possible that the channel incision started more than 100 years ago; therefore, the actual input rate from this source may be lower than estimated.

Table C-8

Parameters Used to Estimate Channel Incision Volumes

Subbasin	Length of Incised Channel (ft)	Average Incised Area (sq ft)	Total Incised Volume (cu yd)	Average Annual Erosion (t/yr over 100 yrs)
Bihmaier Gulch-Pataha Creek	55,611	126	259,519	2,855
Benjamin Gulch-Pataha Creek	41,055	176	267,620	2,944
Chard Gulch-Pataha Creek	68,793	722	1,839,585	20,235
Dry Hollow-Pataha Creek	28,857	880	940,538	10,346
Smith Hollow	8,026	960	285,355	3,139

C.2.8 Bedload Transport Modeling

Bedload transport modeling was conducted for the Tucannon River as part of this project (see Section 6.3 of the main report). The results of the bedload transport models were used to generate a bedload rating curve for two USGS gage locations in the Tucannon River: the Starbuck gage in the lower mainstem (USGS 13344500 Tucannon River near Starbuck, Washington) and the Marengo gage in the upper mainstem (USGS 13344000 Tucannon River near Pomeroy, Washington). The Starbuck rating curve was applied to the long-term mean daily flow records from the Starbuck gage to estimate total annual bedload transport capacity at that location. The mean daily flow at Starbuck was adjusted to 87% of the value and used to estimate annual transport at Marengo (Figure C-3).

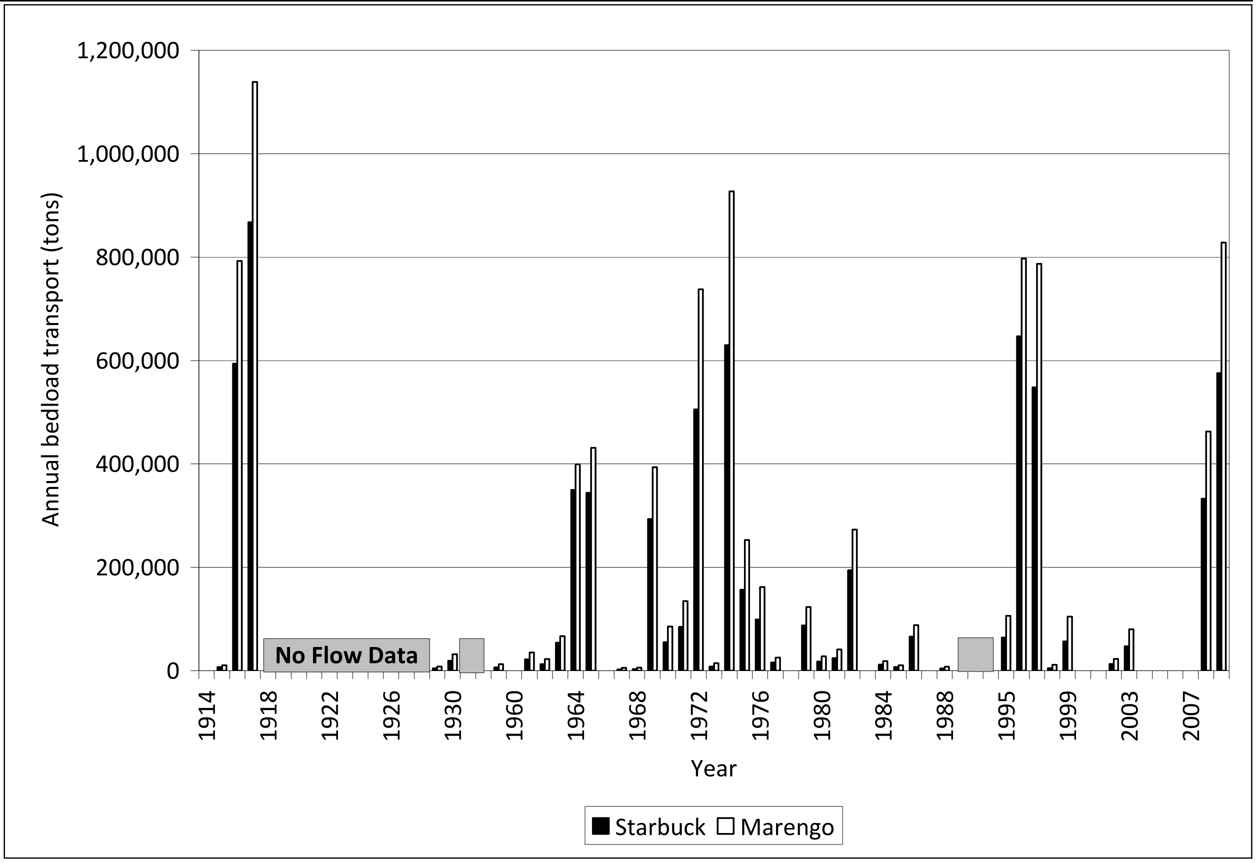


Figure C-3

Total Annual Computed Bedload Transport Capacity at the Starbuck and Marengo Gages

Bedload transport rates vary greatly between years because peak flows are needed to transport the cobble and gravel substrate in the Tucannon River. Little to no bedload movement is predicted to occur during years without peak flows that are high enough to initiate bedload transport (approximately 480 cubic feet per second (cfs) at the Starbuck gage). A transport capacity of more than 600,000 tons of bedload sediment is predicted during years with extreme floods (e.g., 1916 and 1996). Bedload transport capacity is different at the two gage locations due to differences in hydraulics, discharge, and typical substrate size.

As a check on the predicted bedload transport rates, the bedload transport rates computed by Hecht et al. (1982) for the 1980 water year based on measured bedload were compared with those computed using the bedload rating curve from our study. Hecht et al. (1982) reported 565 tons of bedload sediment at the Starbuck gage site and 1,079 tons downstream of the

Powers Road Bridge; we computed a transport capacity of 10,700 tons. These results indicate that bedload transport in the Tucannon River system is likely supply-limited, a common situation in gravel-bedded rivers.

Another comparison with bedload transport rates was made by comparing the estimated bedload input between aerial photo years with computed bedload transport for the same period. Estimated bedload transport capacity was higher than estimated input (Table C-9), also suggesting that the river is supply limited.

Table C-9
Comparison of Bedload Input and Transport Estimates

Period	Starbuck Gage		Marengo Gage	
	Estimated Average Annual Bedload Input (tons/year)	Estimated Average Annual Bedload Transport (tons)	Estimated Average Annual Bedload Input (tons/year)	Estimated Average Annual Bedload Transport (tons)
1954-1974	117,496	148,180	79,953	204,534
1974-1996	53,609	82,113	39,036	113,751
1996-2010	23,701	121,462	13,956	176,642

C.2.9 Analysis of ISCO Samples and Suspended Sediment Transport

In situ chemical oxidation (ISCO) sampling results from 2007 and 2008, which included daily measurements of total suspended sediment (TSS), were provided by the Columbia Conservation District (CCD) for several stations in the Tucannon River watershed. The data from the Fletcher and Territorial sites were chosen for analysis because they had relatively complete records. The Fletcher site is just downstream of the USGS Starbuck gage location, so those flow records were used to convert TSS to tons of suspended sediment/day. The Territorial site is just upstream from the Pataha Creek junction. Flows at this site were not gaged; a correction factor of 87% of the Starbuck gage flows were applied to the Fletcher site. It is likely that this slightly underestimates the discharge at the Fletcher site and thus results in slightly lower suspended sediment load than if actual discharge records were available at the site.

Figure C-4 shows the TSS (milligram per liter [mg/L]) measured at the Territorial and Fletcher sites, as well as the discharge at the Starbuck gage and rainfall at the Pomeroy weather station during the 2008 water year. Note that TSS at the Territorial site is generally higher than at the Fletcher site, which is upstream of Pataha Creek; this is consistent with the Hecht et al. (1982) study that found that the majority of fine-grained sediment that would be carried as suspended load came from Pataha Creek. Also note that while TSS increases during high flow events, it does not increase during rainfall events. This suggests that small to moderate rainfall events do not deliver eroded sediment directly to the mainstem river, but rather that the suspended sediment movement in the mainstem is related to high flows, particularly during spring snowmelt runoff.

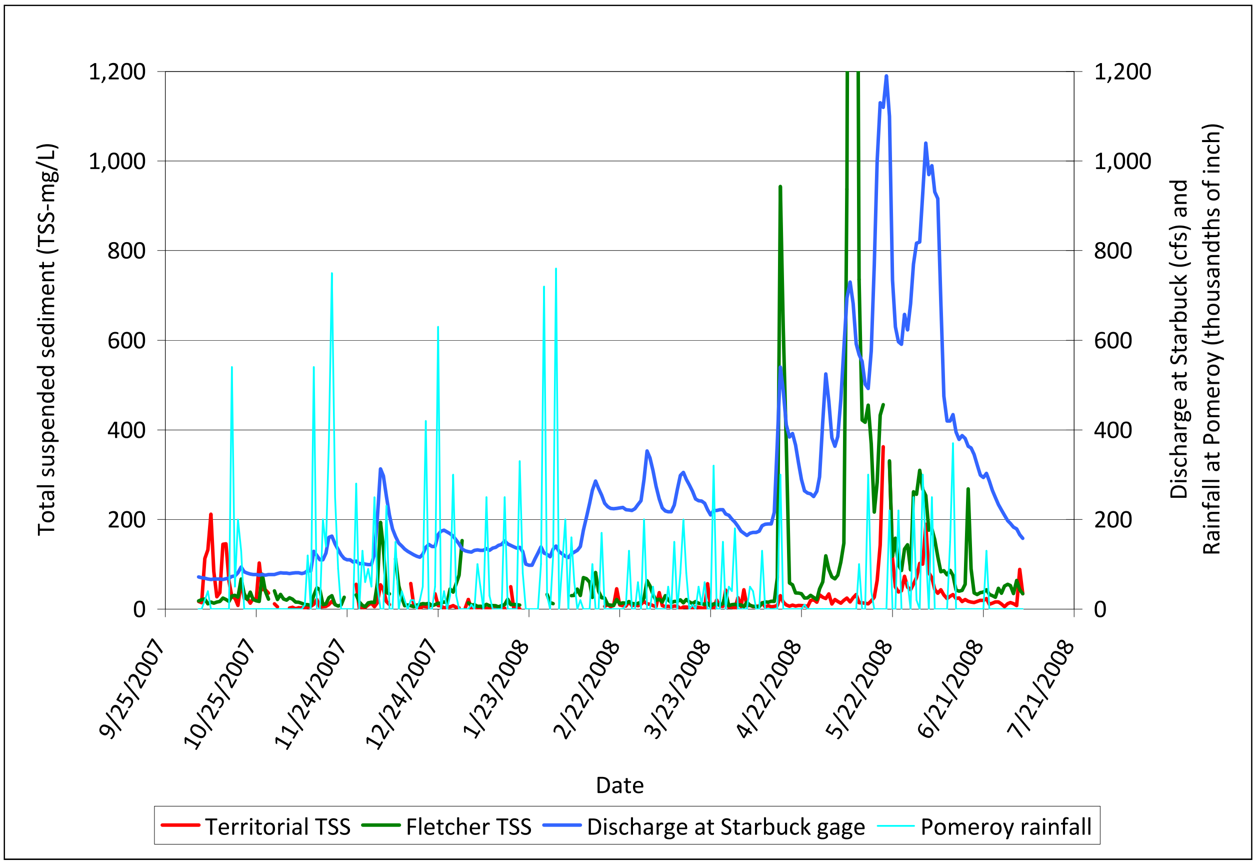


Figure C-4

Total Suspended Sediment, Discharge, and Rainfall, 2008 Water Year

Figure C-5 shows the correlation between TSS measured at the Fletcher site and discharge at the Starbuck gage for the 2007 and 2008 water years. There is a relatively good correlation between discharge and TSS.

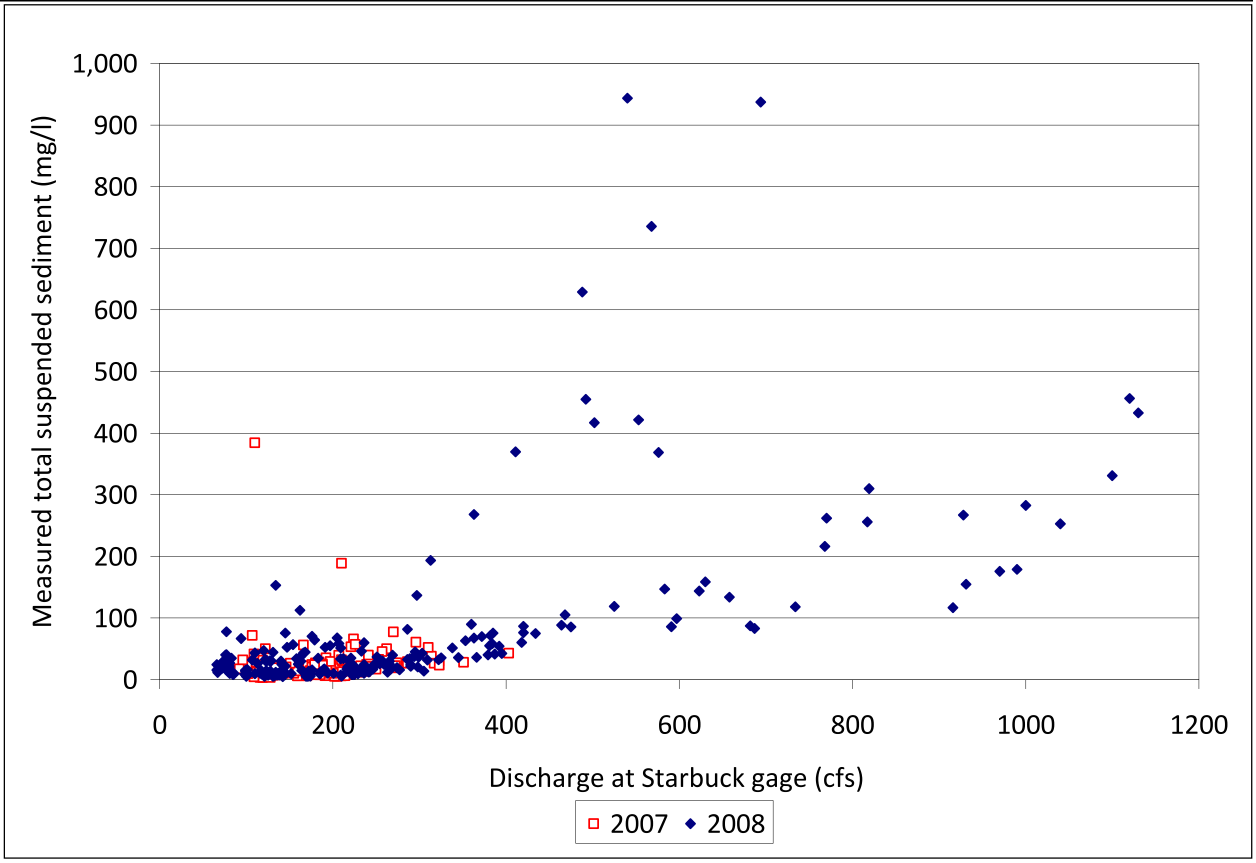


Figure C-5
Total Suspended Sediment at Fletcher vs. Discharge at Starbuck Gage

However, there is not a very good correlation between TSS and rainfall (Figure C-6). Previous researchers have suggested that overland flow does not normally occur in the deep, permeable loess soils that underlie much of the Pataha and Lower Tucannon watershed. Instead, they found that only extremely intense rainfall events or rainfall on frozen ground produced substantial overland flow and surface erosion (Williams et al. 2009). The rainfall/TSS record was reviewed to see if any data were available to support the hypothesis that rainfall on frozen ground results in a measureable increase in erosion/TSS. One storm was found (January 3, 2007) that met the criteria of relatively intense rainfall (0.65 inches/day) following freezing temperatures. Discharge during this period only increased from 137 to 210 cfs, but TSS increased from 20.4 to 1,015 mg/L, supporting the hypothesis the intense rainfall on frozen ground results in erosion and delivery of suspended sediment to streams.

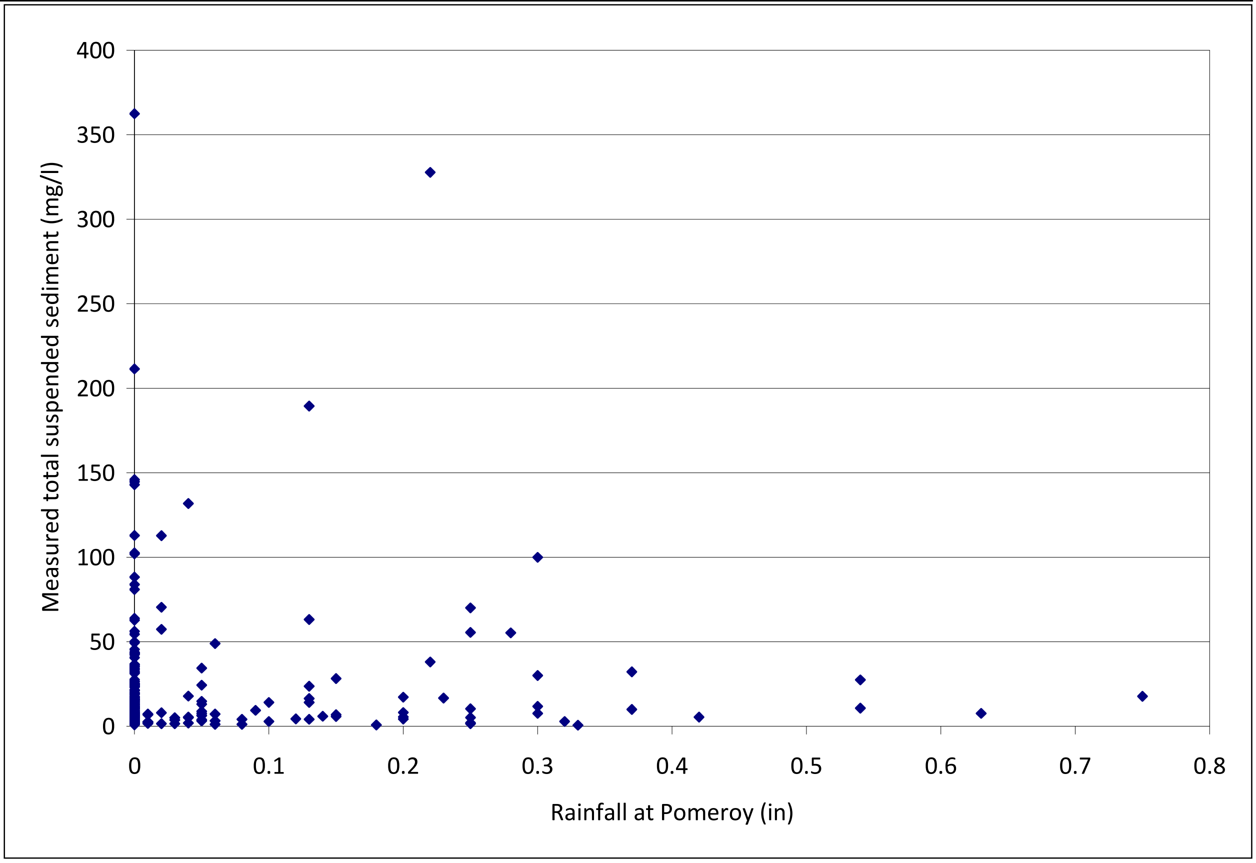


Figure C-6

Total Suspended Sediment at Fletcher vs. Rainfall at Pomeroy, 2008 Water Year

The daily TSS records at each of the sample sites were applied to the daily flow records from the Starbuck gage to obtain an estimate of total suspended load for the 2007 and 2008 water years. The total suspended load was adjusted for missing data by the proportion of missed flow to total flow for the water year. In addition to the 2007 and 2008 data, suspended sediment loads reported in Hecht et al. (1982) were compiled for comparison with the estimated sediment budget inputs. The portion of the total sediment input that travels as suspended load likely includes fines (silt and clay) and fine sand. Because the grain size that is carried as suspended load varies with discharge (e.g., more sand is carried during the higher velocity peak flows), all of the fines plus half of the sand-sized sediment input rates were used for comparison with the suspended load values.

Table C-10 shows a comparison of estimated sediment input and suspended sediment transport at the Starbuck and Marengo gages. Suspended sediment transport varies greatly between years; at the Fletcher/Starbuck site it ranges from 9,238 to 3,145,693 tons depending on whether or not there were large floods during a particular year. Estimated sediment input is based on average watershed conditions and is approximately 50,000 tons/year at the Starbuck gage. The estimated input values are in the range of transport values, but are lower than the average transport rate for the period measured, which included the largest flood on record (1965 water year).

Table C-10
Comparison of Suspended Sediment Input and Transport Estimates

Water Year	Fletcher Site/Starbuck Gage		Territorial Site/Marengo Gage	
	Estimated Average Annual Fines/50% Sand Input (tons/year)	Estimated Average Annual Suspended Transport (tons)	Estimated Average Annual Fines/50% Sand Input (tons/year)	Estimated Average Annual Suspended Transport (tons)
1963[a]	54,966[c]	399,275	9,395[c]	Not reported
1964		148,093		
1965		3,145,693		
1966		155,769		
1967		17,289		
1968		9,238		
1969		526,644		
1970		219,324		
Average 1963-1970		*577,666 w/1965 210,805 w/o 1965*		
1980	52,269[d]	138,271	8,675[d]	
2007[b]	47,814[e]	13,423	8,086[e]	4,235
2008[b]		26,007-52,965[f]		8,094

Notes:
[a] 1963-1980 data reported in Hecht et al. (1982)
[b] 2007-2008 ISCO data compiled for this report
[c] 1954-1974 period
[d] 1974-1996 period
[e] 1996-2010 period
[f] Range in 2008 suspended sediment transport at Fletcher is with and without 5 days of anomalously high TSS data included

C.3 SUMMARY

The Tucannon River watershed sediment budget considered sediment inputs as well as suspended and bedload transport rates. Sediment inputs were determined by estimating erosion rates and delivery to stream channels and were partitioned by source and grain size category. Table C-11 and Figure C-7 show current (2005 to 2010) average annual sediment input rates by source. Note that these values should be regarded as estimates of the relative magnitude of sediment inputs rather than precise quantities due to the uncertainties inherent in calculating input rates.

The majority of recent sediment input to the Tucannon has come from channel-related sources, either by erosion/gullying in bedrock swales and mainstem channel migration during peak flows, or by channel incision in Pataha Creek and Smith Hollow. We estimated that 17% of recent sediment delivered to streams is from land use activities, including roads, agriculture, timber harvest, and wildfire. More soil is eroded from these land use activities, but not all of it reaches the streams. This is supported by recent ISCO sampling in the watershed that shows that suspended sediment levels are correlated with streamflow, but there is little correlation between high suspended sediment levels and rainfall events.

Table C-11
Average Annual Input from Current (2005 to 2010) Sediment Sources

Subbasin	Area (acres)	Colluvial Erosion in Bedrock Swales	Mainstem Channel Migration	Channel Incision	Road Erosion	Land Use	School Fire	Total	Average tons/acre
Headwaters Tucannon River	24,490	600	U	-	82	49	-	25,220	1.03
Panjab Creek	16,253	497	-	-	347	32	-	17,129	1.05
Little Tucannon River-Tucannon River (see note below)	22,073	1,558	U	-	277	322	970	25,201	1.14
Cummings Creek	12,717	740	-	-	113	139	618	14,328	1.13

Subbasin	Area (acres)	Colluvial Erosion in Bedrock Swales	Mainstem Channel Migration	Channel Incision	Road Erosion	Land Use	School Fire	Total	Average tons/acre
Tumalum Creek	10,268	419	-	-	58	170	246	11,161	1.09
Hartsock Grade-Tucannon River	12,700	398	2,673	-	42	795	80	16,688	1.31
Town of Marengo-Tucannon River	23,023	285	9,424	-	36	413	-	33,181	1.44
Willow Creek	19,118	337	-	-	77	853	-	20,385	1.07
Headwaters Pataha Creek	18,306	825	-	-	430	112	334	20,007	1.09
Bihmaier Gulch-Pataha Creek	23,790	443	-	2,855	42	960	-	28,090	1.18
Benjamin Gulch-Pataha Creek	17,937	229	-	2,944	51	592	-	21,755	1.21
Linville Gulch	19,207	438	-	-	80	1,560	-	21,285	1.11
Chard Gulch-Pataha Creek	20,616	305	-	20,235	48	609	-	41,814	2.03
Dry Hollow-Pataha Creek	18,419	328	-	10,346	40	389	-	29,522	1.60
Smith Hollow-Tucannon River	16,697	313	2,687	3,139	35	776	-	23,647	1.42
Town of Starbuck-Tucannon River	15,476	362	1,314	-	24	443	-	17,618	1.14
Kellogg Creek	22,088	504	-	-	63	1,402	-	24,057	1.09
Tucannon River	8,429	175	2,425	-	15	86	-	11,130	1.32
Watershed Total	**321,609**	**8,754**	**18,523**	**39,519**	**1,863**	**9,703**	**2,248**	**402,217**	**1.25**

Notes:

U= unknown; mainstem channel migration was observed in the Little Tucannon-Tucannon River subbasin, as well as a minor amount in the Headwaters subbasin, but the magnitude of sediment input in these areas could not be quantified due to the lack of complete aerial photograph coverage. The estimate of average tons per acre for these subbasins may be affected.

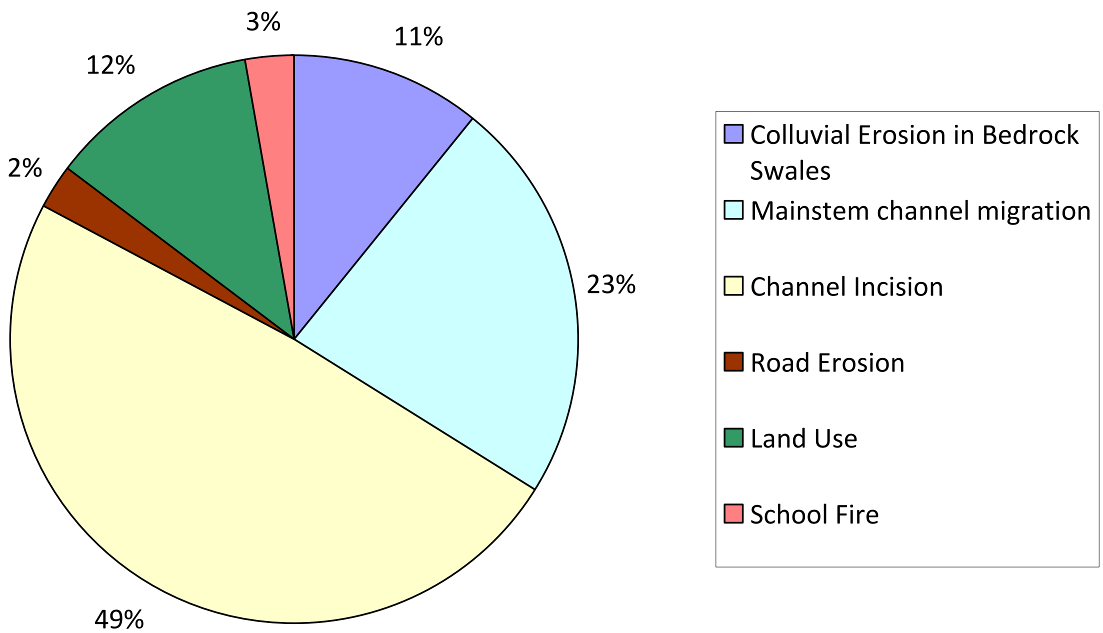


Figure C-7
Current Sediment Inputs by Source

The sediment input budget was also calculated for three different time periods based on available aerial photographs. Sediment inputs for the 1954 to 1974, 1974 to 1996, and 1996 to 2010 periods were estimated based on channel migration and land use changes. Table C-12 shows the sediment inputs by subbasin for each of these three periods. The primary differences between periods are higher inputs of bedload material (cobble/gravel) from channel migration during the large 1964 and 1996 flood events, and a decrease in erosion and sediment delivery from croplands through time as farming conservation efforts improved.

Table C-12

Tucannon River Watershed Sediment Input Budget (in Tons)

Subbasin	TOTAL 1954 to 1974			TOTAL 1974 to 1996			TOTAL 1996 to 2010		
	Cobble/ Gravel	Sand	Fines	Cobble/ Gravel	Sand	Fines	Cobble/ Gravel	Sand	Fines
Headwaters Tucannon River	143	170	496	143	170	496	141	162	488
Panjab Creek	131	274	530	131	274	530	130	270	526
Little Tucannon River-Tucannon River*	400	595	1,435	400	595	1,435	388	1,027	1,868
Cummings Creek	189	273	674	189	273	674	182	551	952
Tumalum Creek	121	217	444	121	217	444	112	298	525
Hartsock Grade-Tucannon River	18,910	2,679	1,007	12,628	2,039	971	2,563	785	680
Town of Marengo-Tucannon River	58,347	1,149	743	24,969	713	596	9,356	407	425
Willow Creek	175	997	889	175	997	889	99	655	547
Upper mainstem total	**78,416**	**6,354**	**6,218**	**38,756**	**5,279**	**6,036**	**12,971**	**4,154**	**6,009**
Headwaters Pataha Creek	221	434	866	221	434	866	214	568	1,001
Bihmaier Gulch-Pataha Creek	246	2,940	1,924	246	2,940	1,924	170	2,595	1,579
Benjamin Gulch-Pataha Creek	145	2,636	1,522	145	2,636	1,522	99	2,427	1,314
Linville Gulch	358	1,507	1,597	358	1,507	1,597	224	904	994
Chard Gulch-Pataha Creek	150	14,766	6,735	150	14,766	6,735	108	14,576	6,545
Dry Hollow-Pataha Creek	110	7,698	3,601	110	7,698	3,601	83	7,575	3,478
Pataha total	**1,231**	**29,982**	**16,245**	**1,231**	**29,982**	**16,245**	**897**	**28,646**	**14,909**
Smith Hollow-Tucannon River	9,567	4,439	2,012	4,205	3,639	1,879	2,398	3,063	1,520
Town of Starbuck-Tucannon River	7,907	1,592	725	3,288	967	646	1,232	515	431
Kellogg Creek	320	1,476	1,481	320	1,476	1,481	194	910	915
Tucannon River	15,834	1,713	381	5,624	704	248	2,213	335	170
Lower mainstem total	**33,628**	**9,220**	**4,600**	**13,438**	**6,787**	**4,254**	**6,037**	**4,823**	**3,036**
Total Tucannon Watershed	**113,275**	**45,555**	**27,063**	**53,424**	**42,047**	**26,535**	**19,905**	**37,624**	**23,955**

Note: *Mainstem channel migration was observed in the Little Tucannon-Tucannon River subbasin as well as a minor amount in the Headwaters subbasin, but the magnitude of sediment input in these areas could not be quantified due to the lack of complete aerial photograph coverage.

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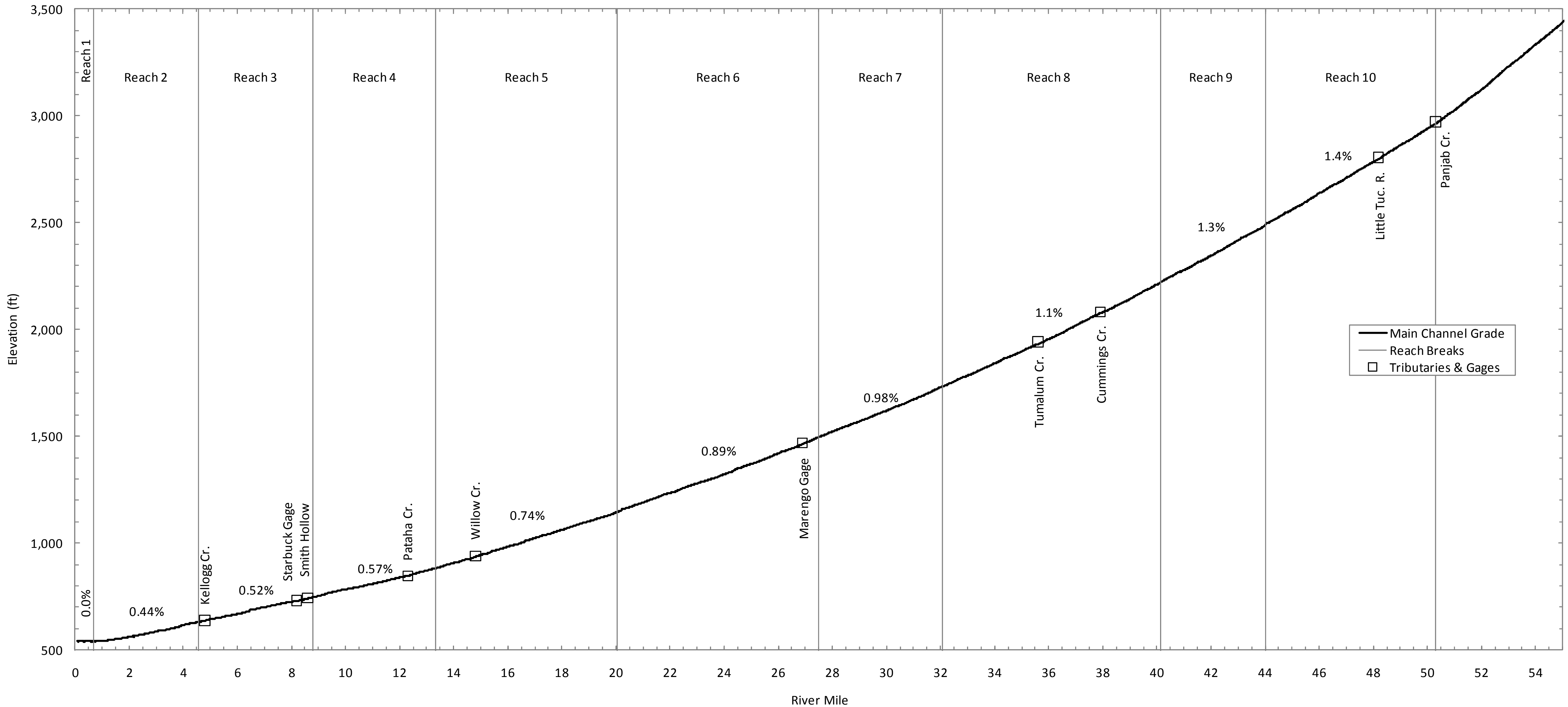
APPENDIX D
REACH CHARACTERISTICS AND FIGURES

D.1 REACH CHARACTERISTICS AND FIGURES

Reach delineation was based on our site reconnaissance, basin-scale geomorphic analyses, hydraulic model output, sediment mobility results, existing and past river management actions, and hydrography. The following sections describe the analyses performed to estimate characteristics of each reach, including the relative amounts of confinement, valley area, low floodplain, area impacted by human infrastructure, and riparian conditions. Figures D-1a through D-10b display aerial photographs, topographic surfaces, and spatial characteristics and features present within each reach. Spatial analyses were performed in ArcGIS Desktop ArcView 9.3 using the spatial and three-dimensional (3D) analyst extensions. The spatial data sets shown in Table D-1 were used to determine reach characteristics.

D.1.1 Gradient

The average gradient for each reach was calculated by determining the gradient between bare-earth LiDAR elevations at 100-foot intervals along the 2010 mainstem channel alignment. The gradient of the 100-foot intervals were averaged for each reach. The results are presented in Chart D-1 and Table D-2a. The profile of the Tucannon River displays a smooth, concave profile with a steeper gradient near the headwaters that becomes flatter moving closer to the confluence with the Snake River.



Notes:

1) Main channel grade elevation based on aerial LiDAR from 2010
2) River stationing developed by Anchor QEA (2010) using aerial photography for channel centerline delineation
3) For reach information see Section 7 in the main report
4) Slope shown for each basin is the average channel slope calculated at 100 ft intervals

Chart D-1

Tucannon River Longitudinal Profile and Reach Extents

D.1.2 Relative Elevation Map

The 2010 bare-earth LiDAR tiles collected by Watershed Sciences (2010) were re-projected and converted to a horizontal datum of Washington State Plane, South Zone (feet) and a vertical datum of North American Vertical Datum (NAVD) 88, feet. The re-projected LiDAR surface was processed using 3D and spatial analyst tools to create a surface relative to the elevation along the 2010 mainstem channel alignment. The elevation values in this surface are converted from actual values to values based on a perpendicular cross-section across the river channel, extending into the floodplain such that the elevations along that line are relative to the elevation of the main channel. The relative elevation map was used for several of the reach characteristic calculations and is shown in the attached figures.

The relative elevation surface is a tool to view relatively high areas and relatively low areas of the floodplain such as side channels, remnant (historic) channel positions, and overbank flow paths. The relative elevation surface also allows us to identify potential disconnected habitats and other opportunities for restoration.

D.1.3 Valley and Low Floodplain Area

From the relative elevation surface, a GIS polygon was created that represented the extent of the surface that was less or equal to 40 feet relative elevation to the main channel. This area was assumed to encompass the Tucannon River valley bottom. Another polygon was created that represented the area of the valley surface that was less or equal to 5 feet in relative elevation to the main channel. This area generally included the lowest areas of the active channel and vegetated floodplain; this was assumed to be the “low” floodplain. The low floodplain is the area that is most frequently connected to the river during flood events. In the Tucannon basin, the low floodplain is typically inundated from the 5- to 10-year flood event. In a majority of the valley, the low floodplain is covered with riparian vegetation. From the calculated low floodplain area, we also determined the amount of low floodplain in each reach per river mile. The area of the valley, low floodplain, acres of low floodplain per river mile, and the percent low floodplain within each reach are shown in Table D-2a.

D.1.4 Percent Confinement

Confining features including levees, road grades, apparent dredge spoils, and other human features were digitized in ArcGIS. Bare-earth LiDAR topography, geologic mapping, and field investigation were used to identify naturally confining features such as alluvial fans and bedrock. Using this information, along with observation of historic channel positions and 2010 aerial imagery, the floodplain was delineated into confined, moderately confined, and unconfined zones that are represented by georeferenced polygon shapefiles in ArcGIS. Confined areas are typically locations of the channel with a narrow floodplain restricted by human features or bedrock, while unconfined areas are typically areas with wide floodplain corridors and an unrestricted channel that is able to migrate freely across the floodplain. Depositional areas, typically associated with unconfined and moderately confined areas, were also identified and mapped from observation of aerial photos and observations in the field.

To determine percent confinement within each reach, a GIS polyline representing the 2010 main channel alignment was segmented by the relative confinement polygons. The lengths of each segment were calculated and compared the total length of the mainstem channel to estimate the percent of the channel length that is confined, moderately confined, and unconfined in each reach. The results of these calculations are presented in Table D-2a and summarized in Chart D-2.

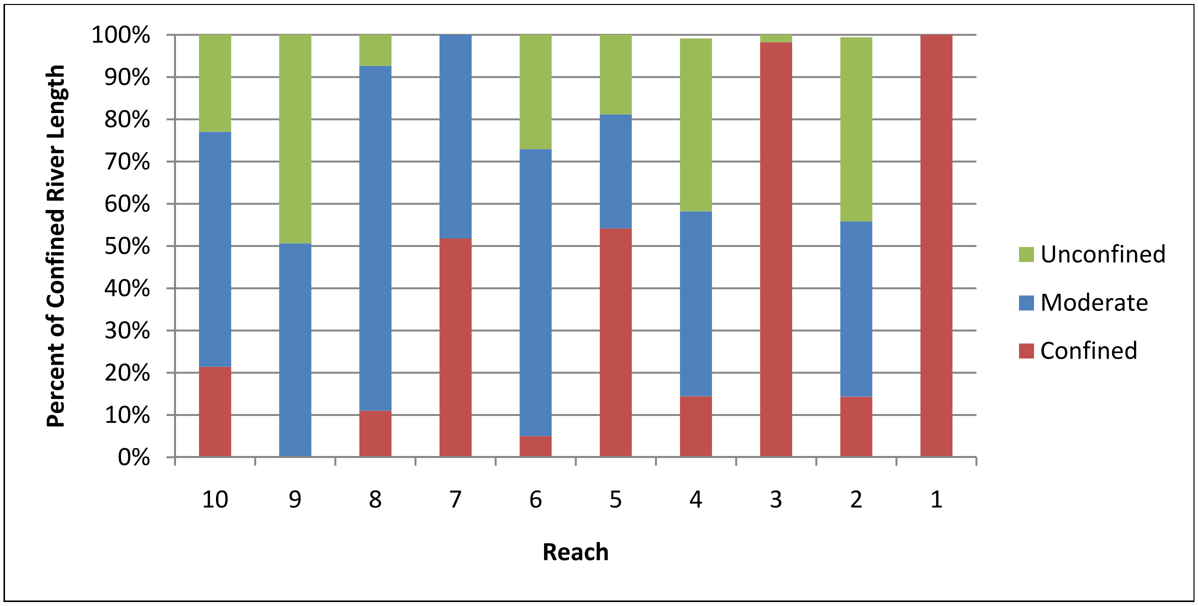


Chart D-2
Percent of Relative Confinement Areas

D.1.5 Percent of Disconnected Low Floodplain

The GIS polyline representing the 2010 main channel alignment was visually segmented where levees or other human features physically separated the main channel from relatively low features of the floodplain. For example, a length of the channel where a levee cuts off the main channel from a remnant meander bend is classified as "disconnected." The lengths of each segment were calculated and compared the total length of the mainstem channel to estimate the percent of the channel length that is disconnected from the low floodplain by human features (Table D-2b). **The disconnected segments do not include areas where the valley has been graded out and the river channelized against the edge of the valley, or areas where valley bottom is primarily occupied by a man-made lake. The disconnected segments also do not include smaller levees, berms, or side-cast dredge materials that appear to impede channel migration but do allow floodwaters to overtop the banks.** Although these areas have been greatly impacted by anthropogenic activities, they typically do not include opportunities for restoration.

The percent of disconnected channel length was then multiplied by the low floodplain area per river mile. The result of this calculation is a relative number in acres per mile that represents the amount of disconnected low floodplain that may potentially be re-connected. Chart D-3 compares the percent of disconnected low floodplain (red bar) within each reach to the acres per mile of disconnected low floodplain (green line).

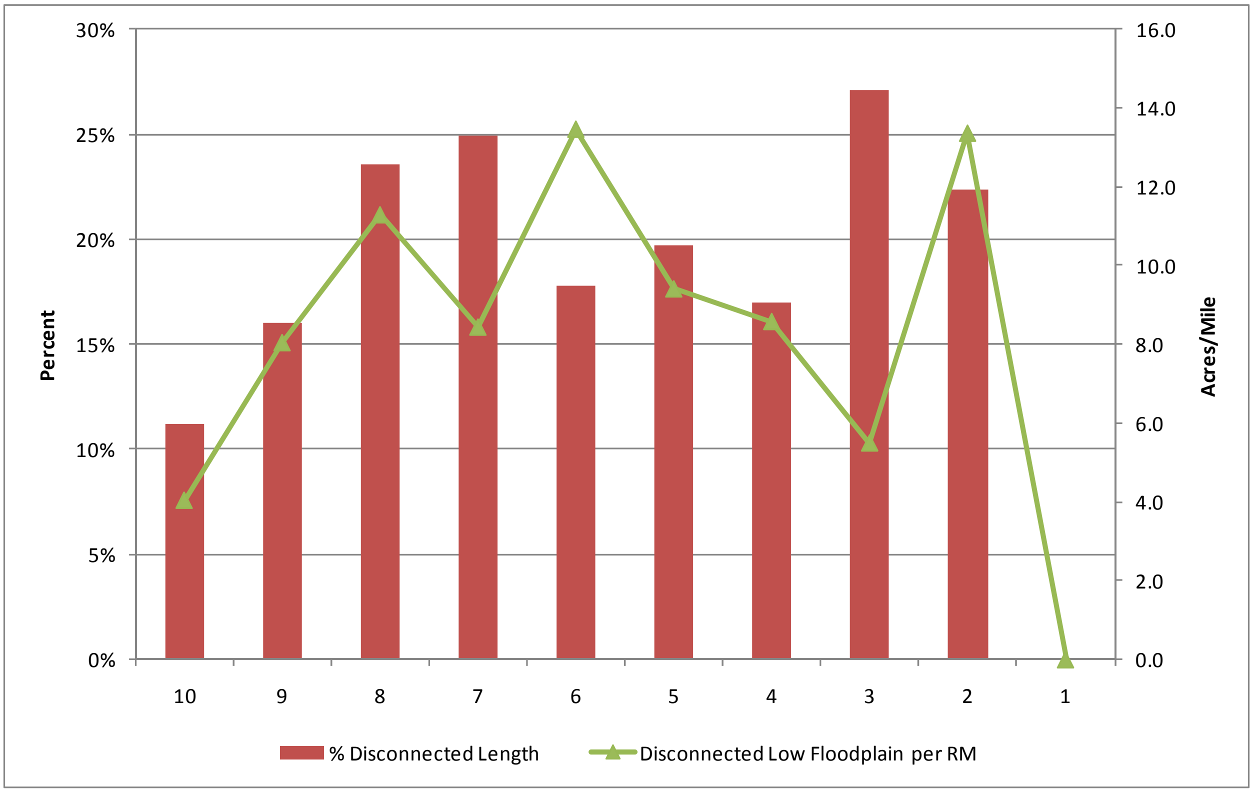


Chart D-3

Percent of the Disconnected Channel Length versus Percent Low Floodplain

D.1.6 Riparian Characteristics

Forest canopy density and height were estimated within the low floodplain areas (areas within 5 feet in elevation relative to the river) for each reach. These areas are typically vegetated and have more frequent connectivity with the channel than the valley area (within 40 feet relative elevation), and were therefore assumed to be representative of the riparian zone. The methodology presented by Crawford (2010) was followed to perform this spatial analysis. LAS (LiDAR point cloud files) points containing the highest hit elevation (i.e., canopy surface) were compared to the total number of LiDAR hits within a specific grid cell size to determine density. The highest hit points were then compared to the bare-earth

LiDAR surface to determine canopy heights. These results are provided in Table D-3a and D-3b, and Chart D-4 summarizes the relative canopy heights. The areas where highest hit points were not provided were assumed to have low-lying vegetation or no vegetation (less than 5 feet) such as road surfaces, grain crops, and grazing pastures. The percent of low floodplain covered with vegetation at least 5 feet in height (black line) is also shown on Chart D-4 for reference.

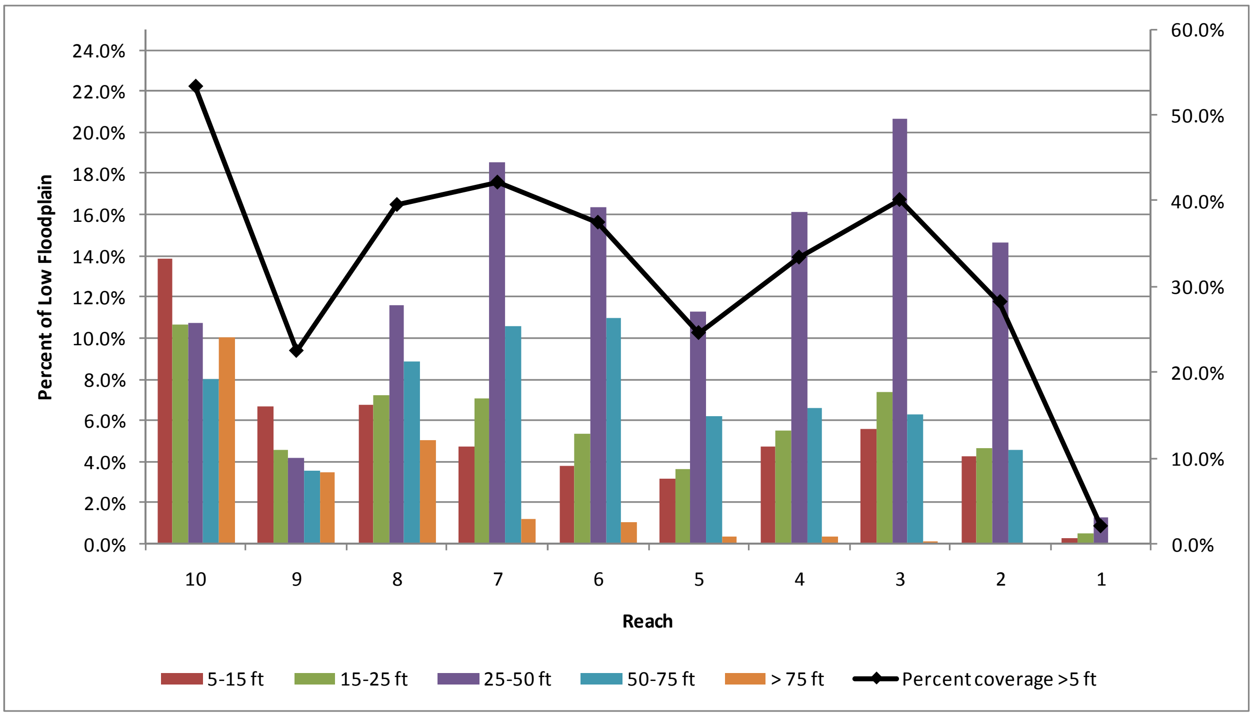


Chart D-4

Percent of Low Floodplain Covered by Canopy Height Categories by Reach

D.2 REFERENCES

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APPENDIX D
TABLES

Table D-1

Spatial Data Sources Used to Determine Reach Characteristics

Data	Type	Source
2010 LiDAR bare-earth coverage	Raster GRID	Columbia Conservation District (Watershed Sciences 2010)
2010 LiDAR highest hit	LAS (point) files	
2010 orthophotography	Raster (TIFF)	
Drainage basin areas	Polygon	Streamstats (USGS 2010)

Table D-2a

Summary of Reach Characteristics

Reach	River Mile		Length (mi)	Average Gradient (%)[a]	Approx. Drainage Area at Downstream End (mi^2)[b]	Major Tributaries	Valley Area (acres)[c]	Low Floodplain Area (acres)[d]	Percent Low Floodplain	Low Floodplain per River Mile (acres/mi)
	From	To								
10	50.2	44.0	6.2	1.40	87	Little Tucannon River, Panjab Creek	478	224	47%	36.1
9	44.0	40.0	4.0	1.30	95	None	417	201	48%	50.2
8	40.0	32.1	7.9	1.10	144	Tumalum Creek, Cummings Creek	987	379	38%	48.0
7	32.1	27.5	4.6	0.98	159	None	580	156	27%	33.9
6	27.5	20.0	7.5	0.89	178	None	1173	567	48%	75.6
5	20.0	13.2	6.8	0.74	220	Willow Creek	943	325	34%	47.7
4	13.2	8.9	4.3	0.57	410	Pataha Creek	608	217	36%	50.5
3	8.9	4.5	4.4	0.52	490	Kellogg Creek, Smith Hollow	693	89	13%	20.3
2	4.5	0.7	3.8	0.44	503	None	561	227	41%	59.8
1	0.7	0.0	0.7	0.00	503	None	81.4	59[h]	72%	83.9[g]

Table D-2b

Summary of Reach Characteristics

Reach	River Mile		Length (mi)	Degree of Confinement, Length (mi)[e]			Degree of Confinement (%)			Disconnected Low Floodplain by River Length (%)[f]		Disconnected Low Floodplain per Rive Mile (acres/mi)[h]
	From	To		Confined	Moderate	Unconfined	Confined	Moderate	Unconfined	Disconnected	Open	
10	50.2	44.0	6.2	1.5	4.7	0.0	24%	76%	0%	11.2%	88.8%	4.0
9	44.0	40.0	4.0	0	2.0	2.0	0%	51%	50%	16.0%	84.0%	8.0
8	40.0	32.1	7.9	0.9	6.4	0.6	11%	82%	8%	23.5%	76.5%	11.3
7	32.1	27.5	4.6	2.4	2.2	0.0	52%	48%	0%	24.9%	75.1%	8.4
6	27.5	20.0	7.5	0.4	5.1	2.1	5%	68%	28%	17.8%	82.2%	13.5
5	20.0	13.2	6.8	3.7	1.8	1.3	54%	27%	19%	19.7%	80.3%	9.4
4	13.2	8.9	4.3	0.6	1.9	1.8	14%	44%	41%	17.0%	83.0%	8.6
3	8.9	4.5	4.4	4.3	0.0	0.1	98%	0%	3%	27.1%	72.9%	5.5
2	4.5	0.7	3.8	0.5	1.6	1.7	14%	42%	44%	22.3%	77.7%	13.4
1	0.7	0.0	0.7	0.7	0.0	0.0	100%	0%	0%	0.0%	100.0%[g]	0.0

Notes:
a. Average gradient calculated from 2010 LiDAR topography.
b. Drainage area calculated from USGS Streamstats (2011).
c. The area of the reach that is less or equal to 40 feet in elevation relative to the channel, based on relative elevation maps created from 2010 LiDAR.
d. The area of the reach that is less or equal to 5 feet in elevation relative to the channel, based on relative elevation maps created from 2010 LiDAR.
e. The length the river alignment in the reach that falls within each confinement category.
f. Value is approximate and was estimated visually. “Open” includes areas where the floodplain has been graded out and the river channelized against one area of the valley.
g. Reach 1 is a highly modified reach; this metric is not necessarily applicable to assessing conditions in this reach.
h. The product of low floodplain per river mile and percent disconnected length.

Table D-3a
Riparian Height Calculations by Reach

Reach	River Mile		Length (mi)	Low Floodplain Area (acres)[a]	Height Class (acres)						Height Class (% of Valley)					
	To	From			0-5 ft[c]	5-15 ft	15-25 ft	25-50 ft	50-75 ft	> 75 ft	0-5 ft[c]	5-15 ft	15-25 ft	25-50 ft	50-75 ft	> 75 ft
10	55.0	44.0	11.0	704.3	104.6	31.0	23.8	24.0	17.9	22.4	46.7%	13.9%	10.6%	10.7%	8.0%	10.0%
9	44.0	40.0	4.0	416.6	155.6	13.4	9.2	8.4	7.1	7.0	77.5%	6.7%	4.6%	4.2%	3.5%	3.5%
8	40.0	32.1	7.9	987.1	229.2	25.6	27.2	44.0	33.6	19.2	60.5%	6.8%	7.2%	11.6%	8.9%	5.1%
7	32.1	27.5	4.6	580.2	90.2	7.4	11.0	28.9	16.5	1.9	57.9%	4.7%	7.1%	18.5%	10.6%	1.2%
6	27.5	20.0	7.5	1172.8	354.5	21.5	30.2	92.6	62.0	5.9	62.6%	3.8%	5.3%	16.3%	10.9%	1.0%
5	20.0	13.2	6.8	943.3	244.9	10.3	11.7	36.7	20.1	1.1	75.4%	3.2%	3.6%	11.3%	6.2%	0.3%
4	13.2	8.9	4.3	607.9	144.8	10.3	12.0	35.1	14.4	0.8	66.6%	4.7%	5.5%	16.1%	6.6%	0.4%
3	8.9	4.5	4.4	692.7	53.5	5.0	6.6	18.5	5.6	0.1	59.9%	5.6%	7.4%	20.7%	6.3%	0.1%
2	4.5	0.7	3.8	561.3	163.2	9.7	10.6	33.3	10.4	0.1	71.8%	4.3%	4.7%	14.6%	4.6%	0.0%
1	0.7	0.0	0.7	81.4	57.5	0.2	0.3	0.8	0.0	0.0	97.9%	0.3%	0.5%	1.3%	0.0%	0.0%

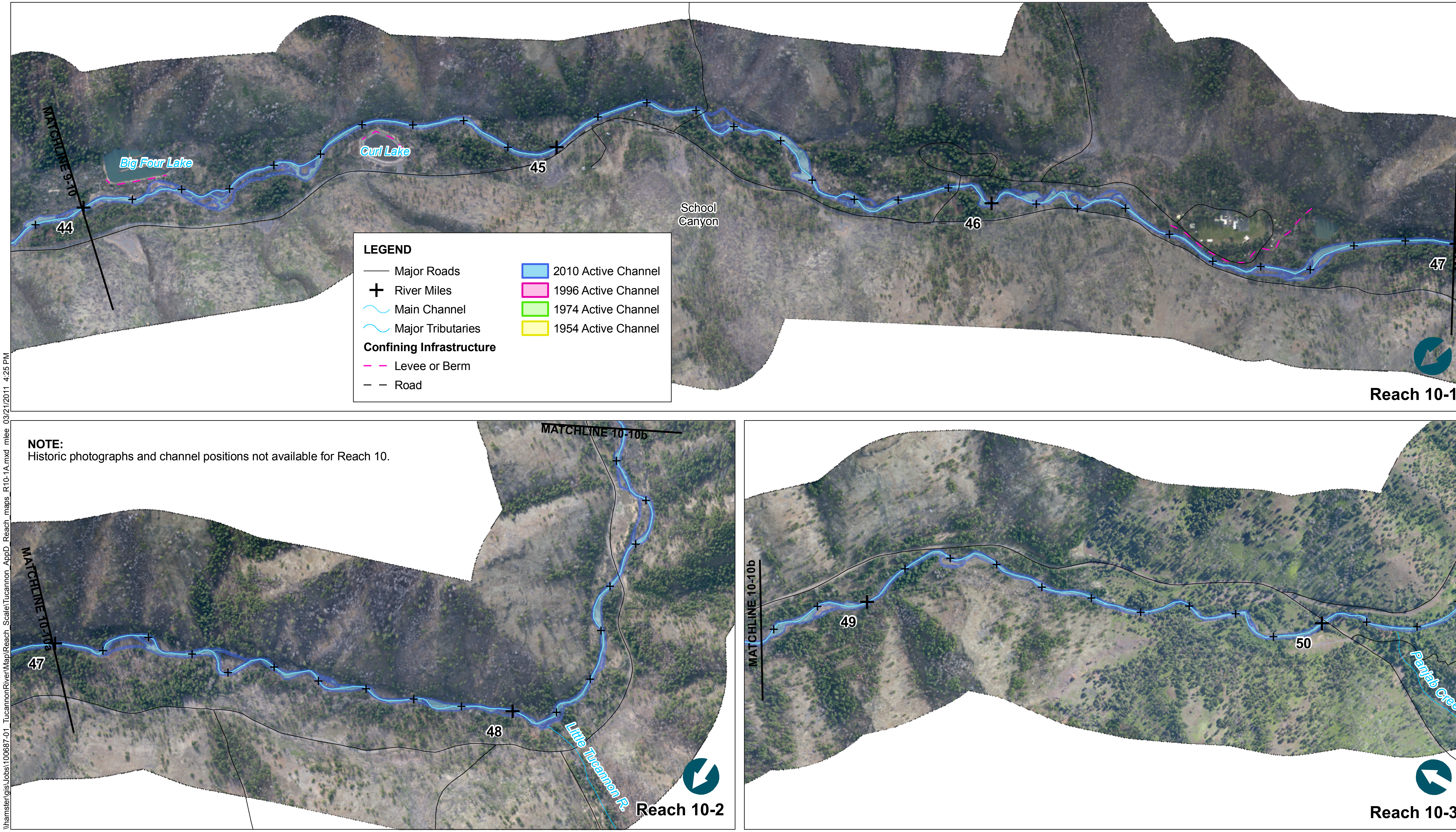
Table D-3b
Riparian Density Calculations by Reach

Reach	River Mile		Length (mi)	Low Floodplain Area (acres)[a]	Relative Density of Vegetation by Area (acres)[b]					Relative Density of Vegetation (% of Valley)[b]					Percent Coverage Greater Than 5 feet Height
	To	From			0.0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	0.8-1.0	0.0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	0.8-1.0	
10	55.0	44.0	11.0	704.3	79.4	6.5	0.6	10.8	22.0	35.5%	2.9%	0.3%	4.8%	9.8%	53.3%
9	44.0	40.0	4.0	416.6	40.6	4.3	0.3	0.0	0.0	20.2%	2.1%	0.2%	0.0%	0.0%	22.5%
8	40.0	32.1	7.9	987.1	123.3	25.4	0.8	0.2	0.1	32.5%	6.7%	0.2%	0.0%	0.0%	39.5%
7	32.1	27.5	4.6	580.2	57.6	7.9	0.2	0.0	0.0	37.0%	5.0%	0.1%	0.0%	0.0%	42.1%
6	27.5	20.0	7.5	1172.8	202.5	9.4	0.3	0.0	0.0	35.7%	1.7%	0.0%	0.0%	0.0%	37.4%
5	20.0	13.2	6.8	943.3	76.9	2.8	0.2	0.0	0.1	23.7%	0.9%	0.0%	0.0%	0.0%	24.6%
4	13.2	8.9	4.3	607.9	70.1	2.2	0.2	0.0	0.1	32.3%	1.0%	0.1%	0.0%	0.0%	33.4%
3	8.9	4.5	4.4	692.7	34.7	1.0	0.0	0.0	0.0	38.9%	1.2%	0.0%	0.0%	0.0%	40.1%
2	4.5	0.7	3.8	561.3	62.3	1.6	0.2	0.1	0.0	27.4%	0.7%	0.1%	0.0%	0.0%	28.2%
1	0.7	0.0	0.7	81.4	1.2	0.1	0.0	0.0	0.0	2.0%	0.1%	0.0%	0.0%	0.0%	2.1%

Notes:

a. The area of the reach that is less than or equal to 40 feet in elevation relative to the channel, based on relative elevation maps created from 2010 LiDAR.
b. Areas of vegetation less than 5 feet tall were excluded from the density data set; does not account for areas with highest hit values equal or close to bare earth.
c. Cells without a highest hit return were assumed to be close to zero and have been added to the 0 to 5-foot category.

APPENDIX D
FIGURES



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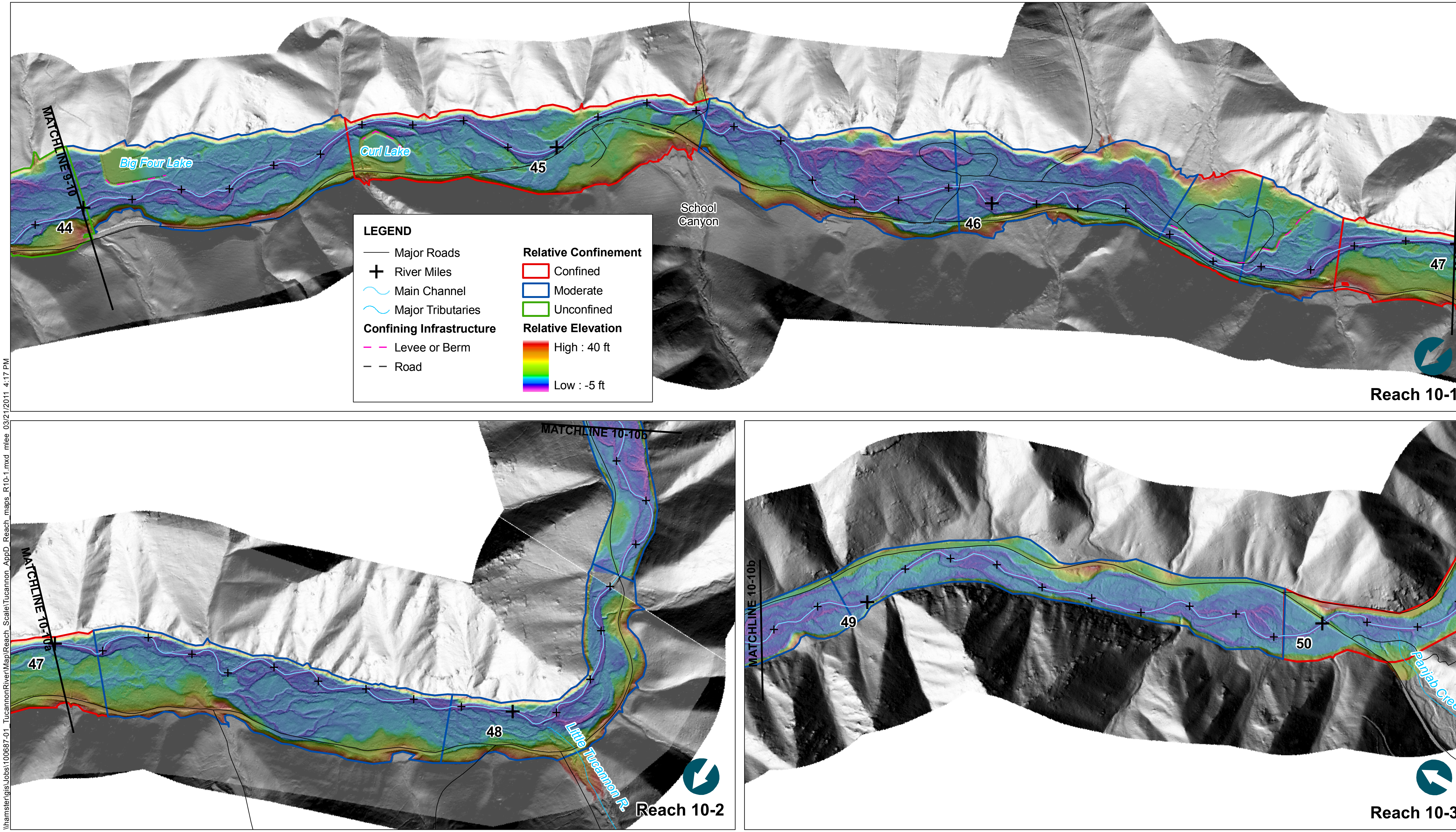
NOTES:
2010 orthophotos shown. Georeferenced historic channel patterns are approximate; traced from historic photos obtained from NRCS, USGS, USFS and CCD. Roads from WA DNR. Tributary alignments from DOE. Locations of features are approximate. This figure is to be used for conceptual purposes only.

Feet
0 950 1,900

Figure D-10a
Reach 10 Current Aerial Photo and Historic Active Channel Positions
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District



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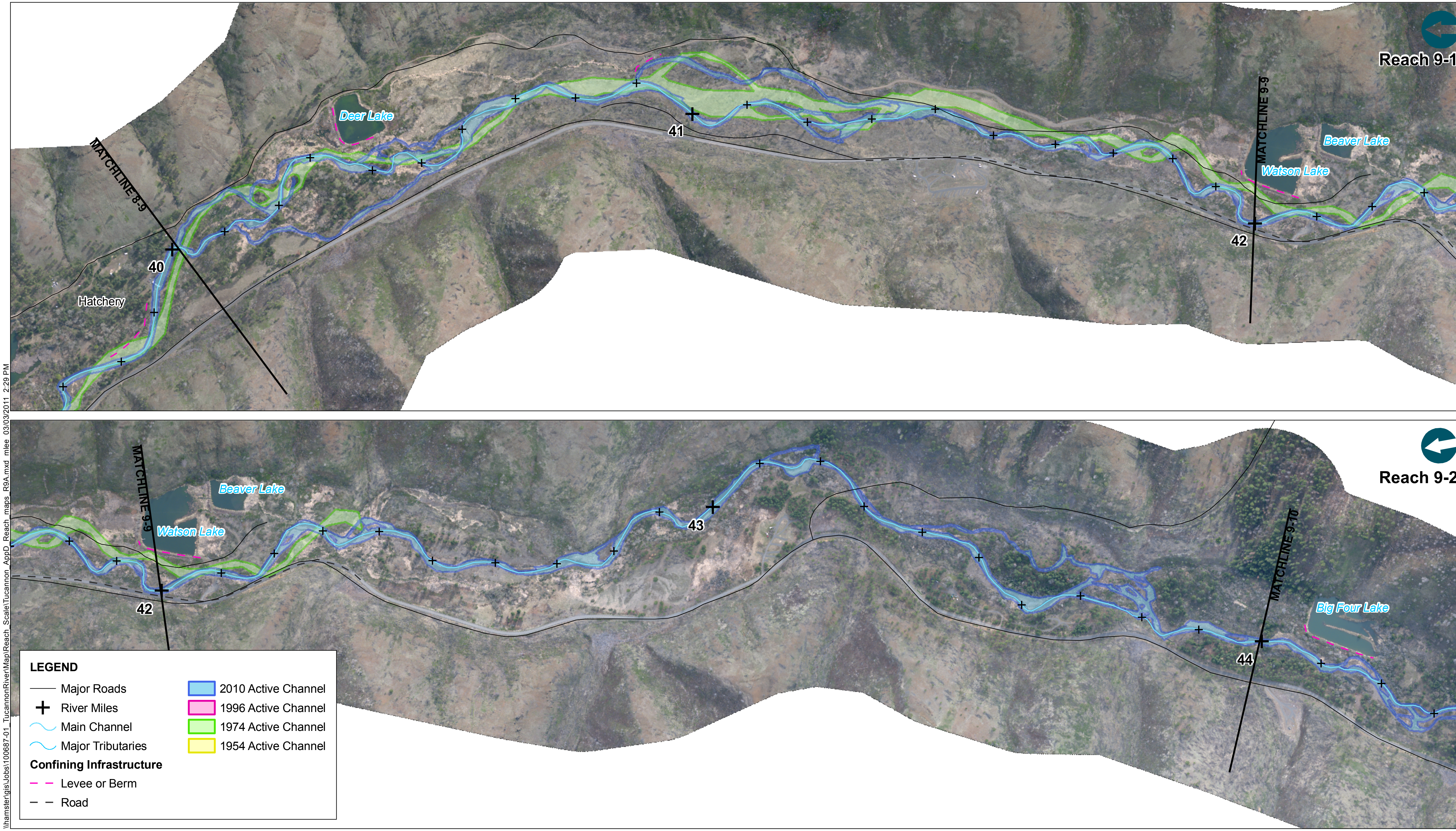
NOTES:
Relative elevation map created from 2010 LiDAR. Roads from WA DNR. Tributary alignments from DOE. Locations of features are approximate. This figure is to be used for conceptual purposes only.

Feet
0 950 1,900

Figure D-10b
Reach 10 Relative Elevation and Topographic Features
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District



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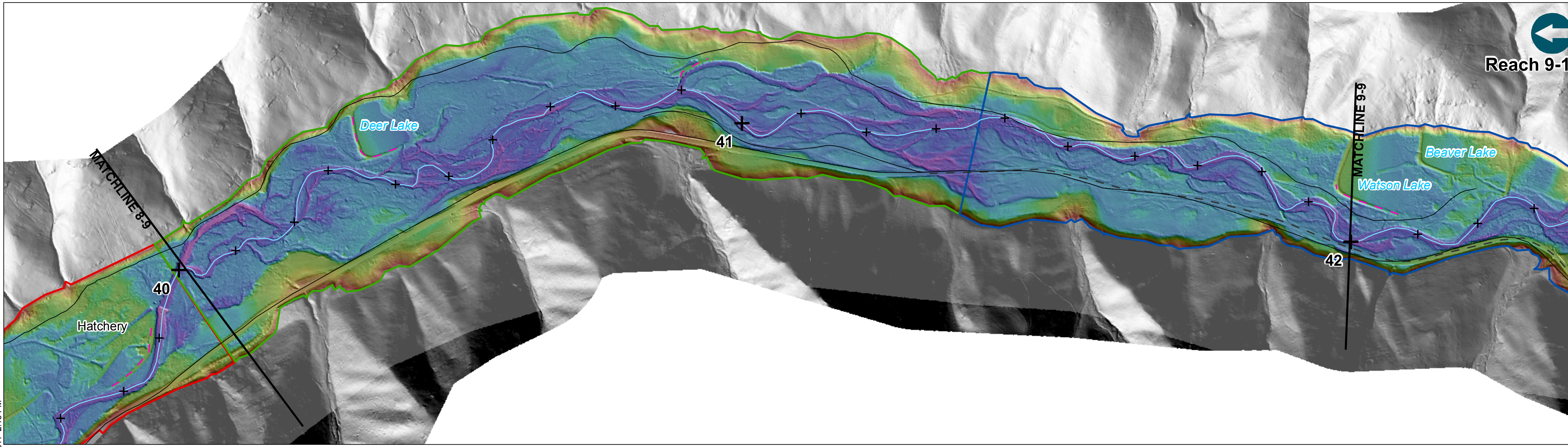
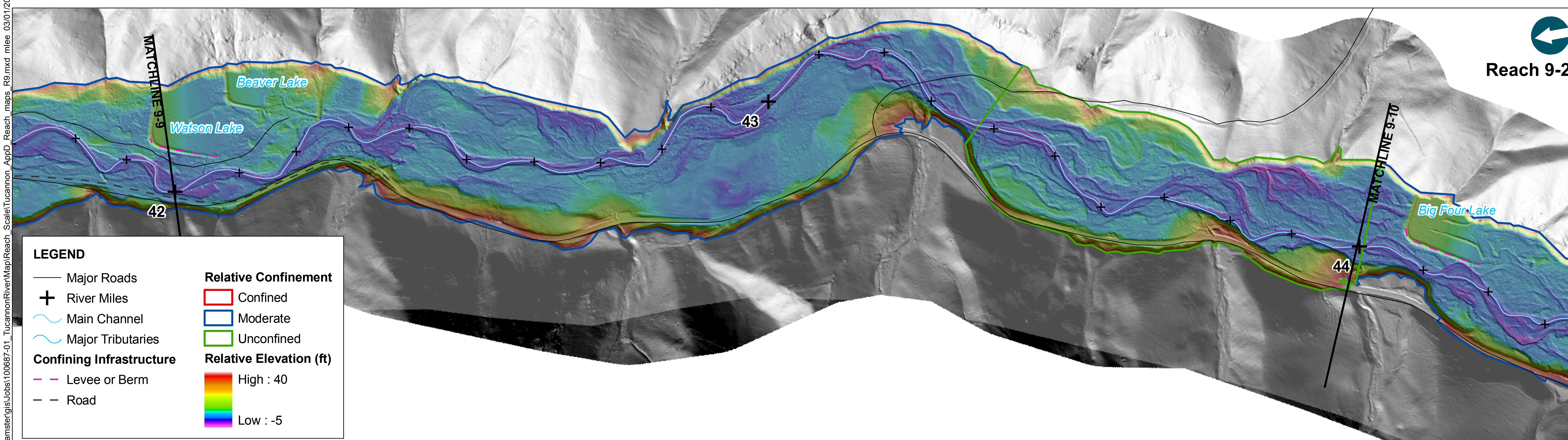
NOTES:
2010 orthophotos shown. Georeferenced historic channel patterns are approximate; traced from historic photos obtained from NRCS, USGS, USFS and CCD. Roads from WA DNR. Tributary alignments from DOE. Locations of features are approximate. This figure is to be used for conceptual purposes only.

Figure D-9a
Reach 9 Current Aerial Photo and Historic Active Channel Positions
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District





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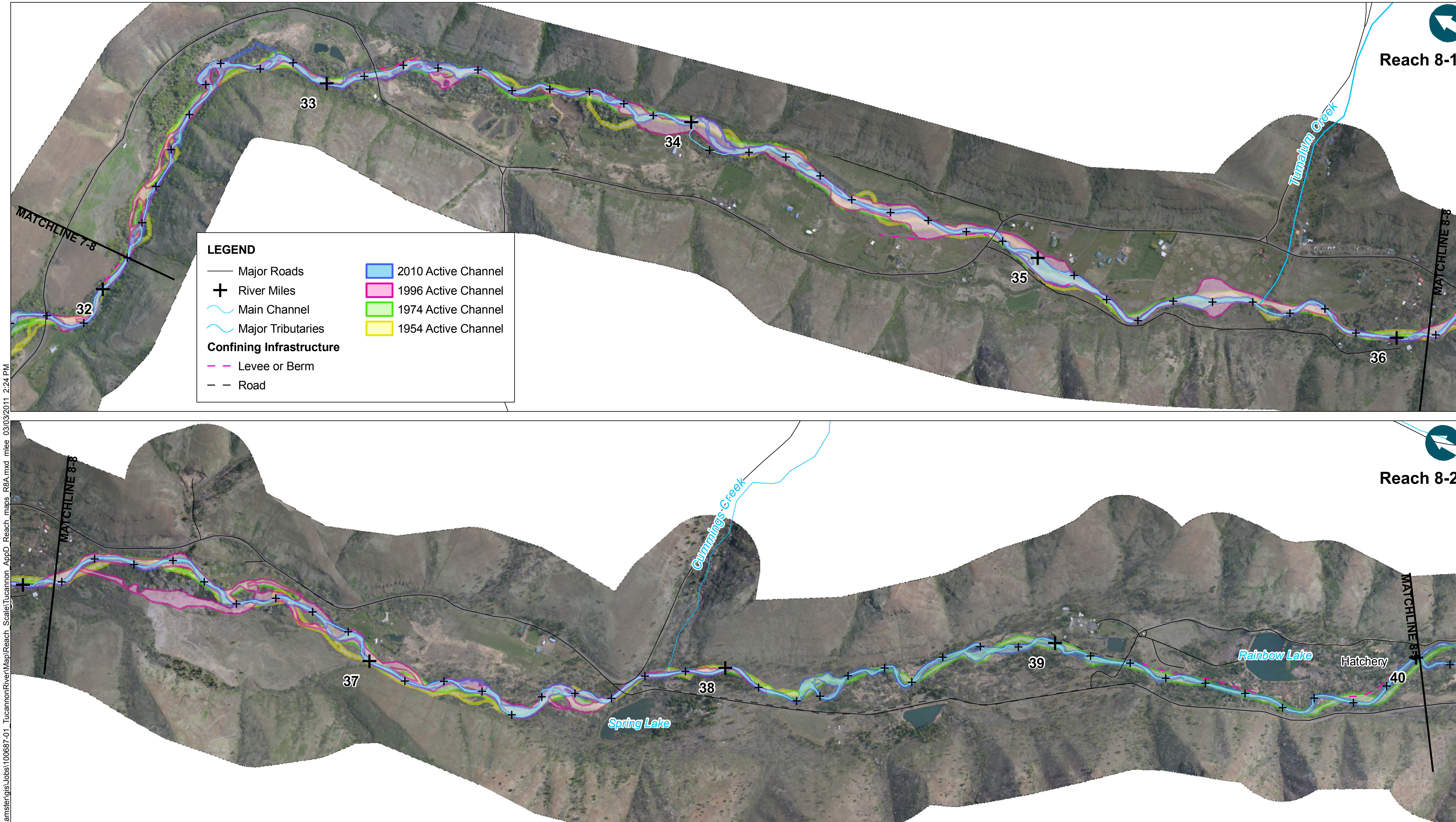
NOTES:
Relative elevation map created from 2010 LiDAR. Roads from WA DNR. Tributary alignments from DOE. Locations of features are approximate. This figure is to be used for conceptual purposes only.

Feet
0 750 1,500

Figure D-9b
Reach 9 Relative Elevation and Topographic Features
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District



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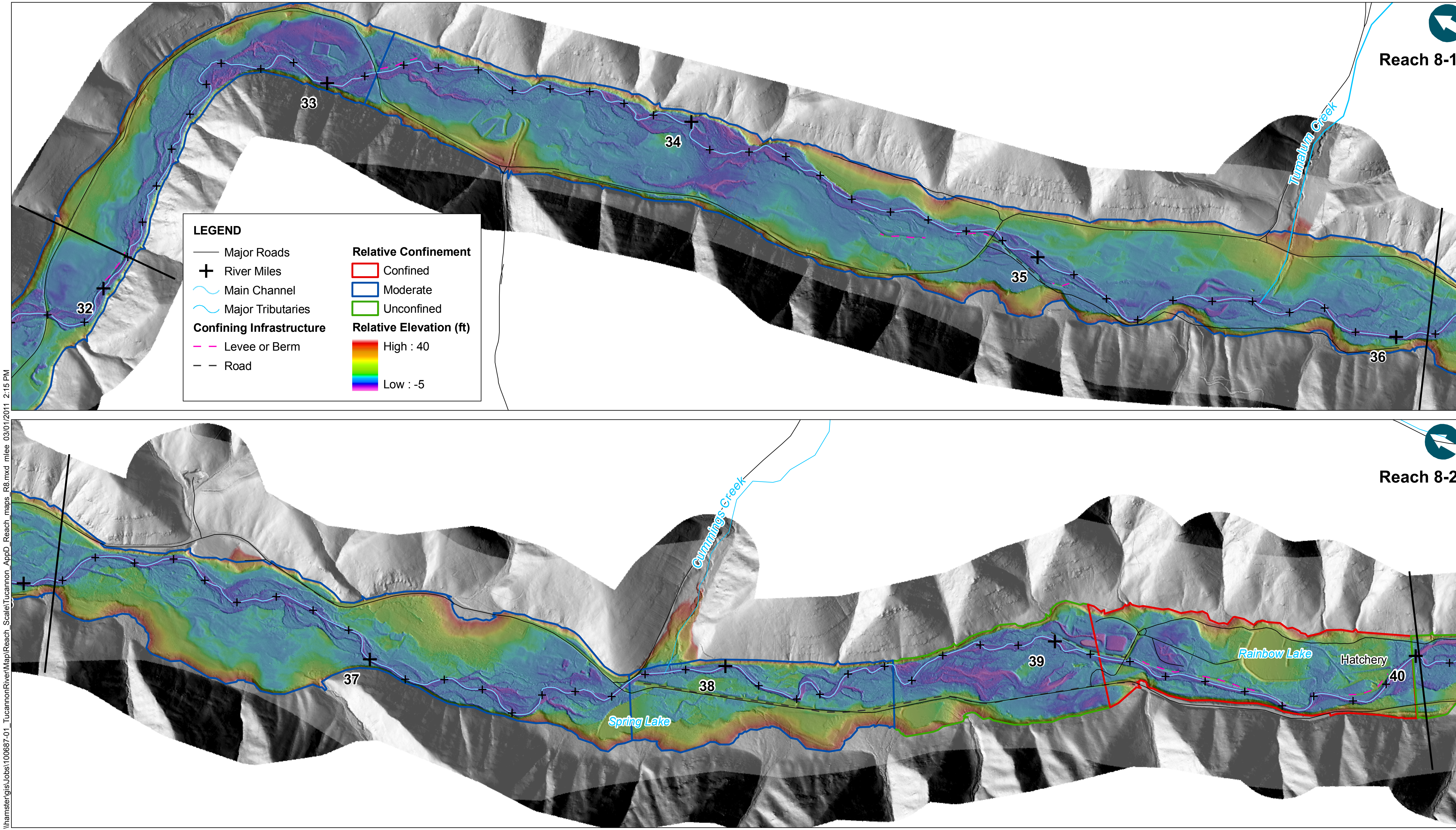
NOTES:
2010 orthophotos shown. Georeferenced historic channel patterns are approximate; traced from historic photos obtained from NRCS, USGS, USFS and CCD. Roads from WA DNR. Tributary alignments from DOE. Locations of features are approximate. This figure is to be used for conceptual purposes only.

Feet
0 1,200 2,400

Figure D-8a
Reach 8 Current Aerial Photo and Historic Active Channel Positions
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District



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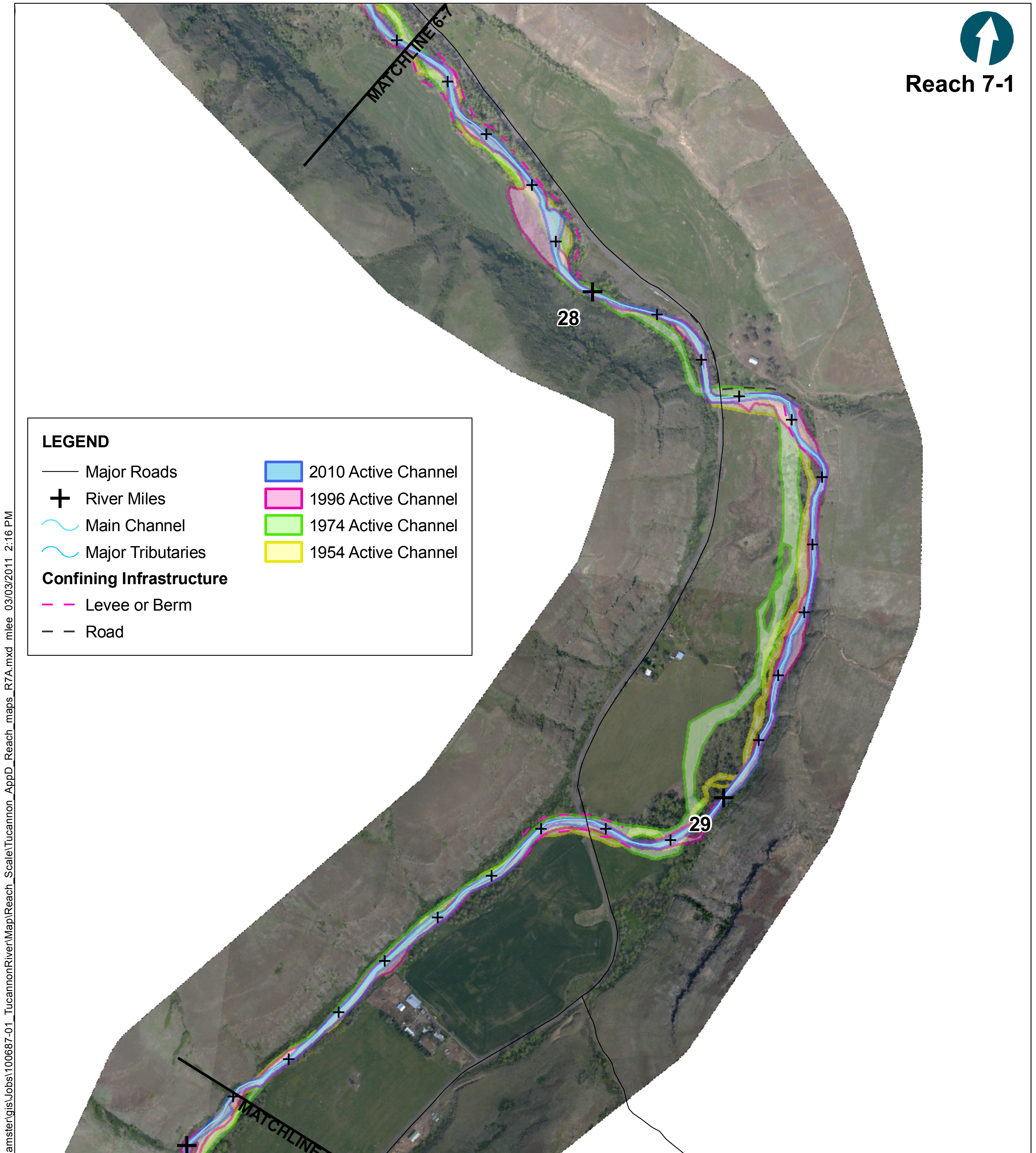
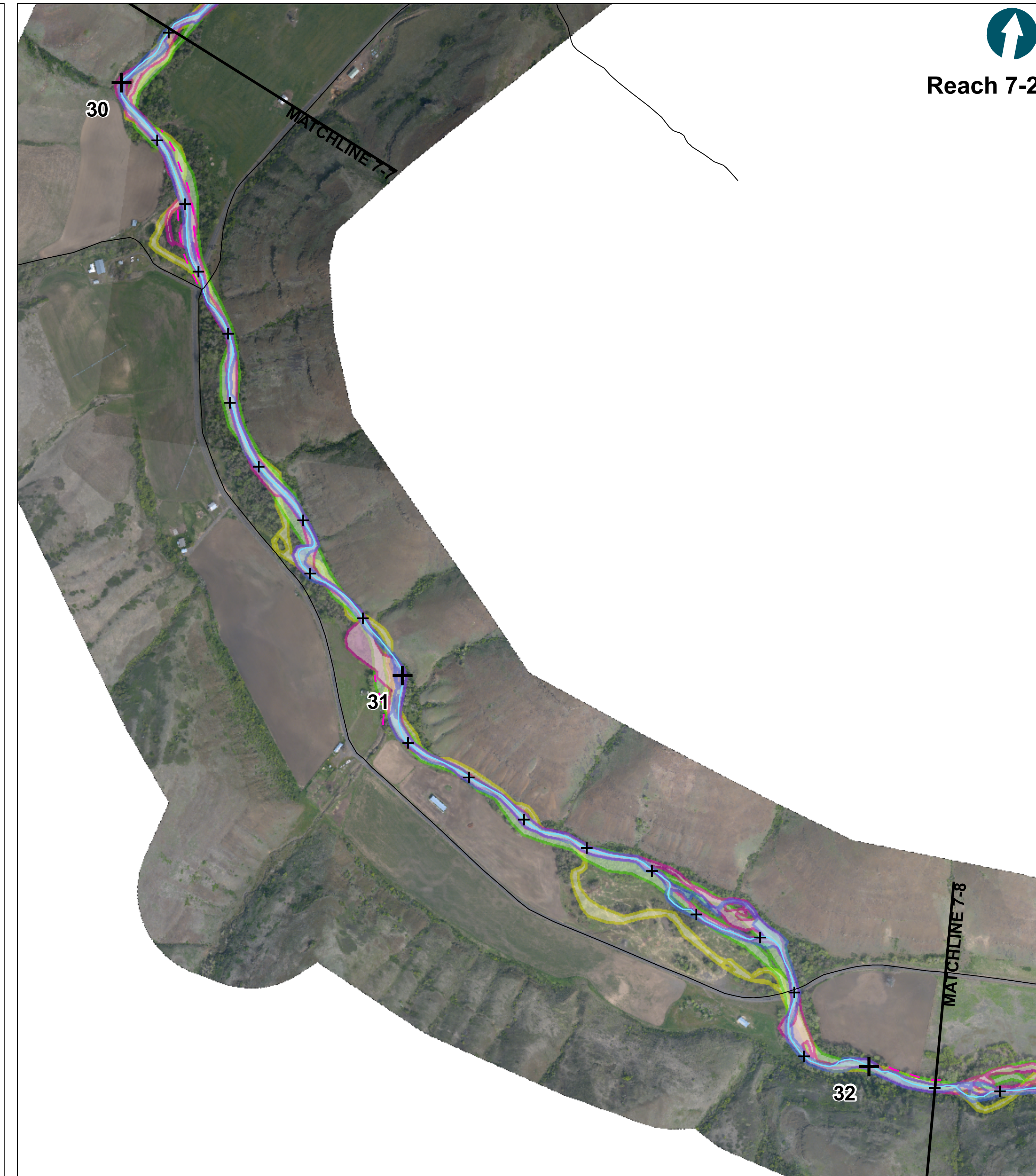
NOTES:
Relative elevation map created from 2010 LiDAR. Roads from WA DNR. Tributary alignments from DOE. Locations of features are approximate. This figure is to be used for conceptual purposes only.

Feet
0 1,200 2,400

Figure D-8b
Reach 8 Relative Elevation and Topographic Features
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District





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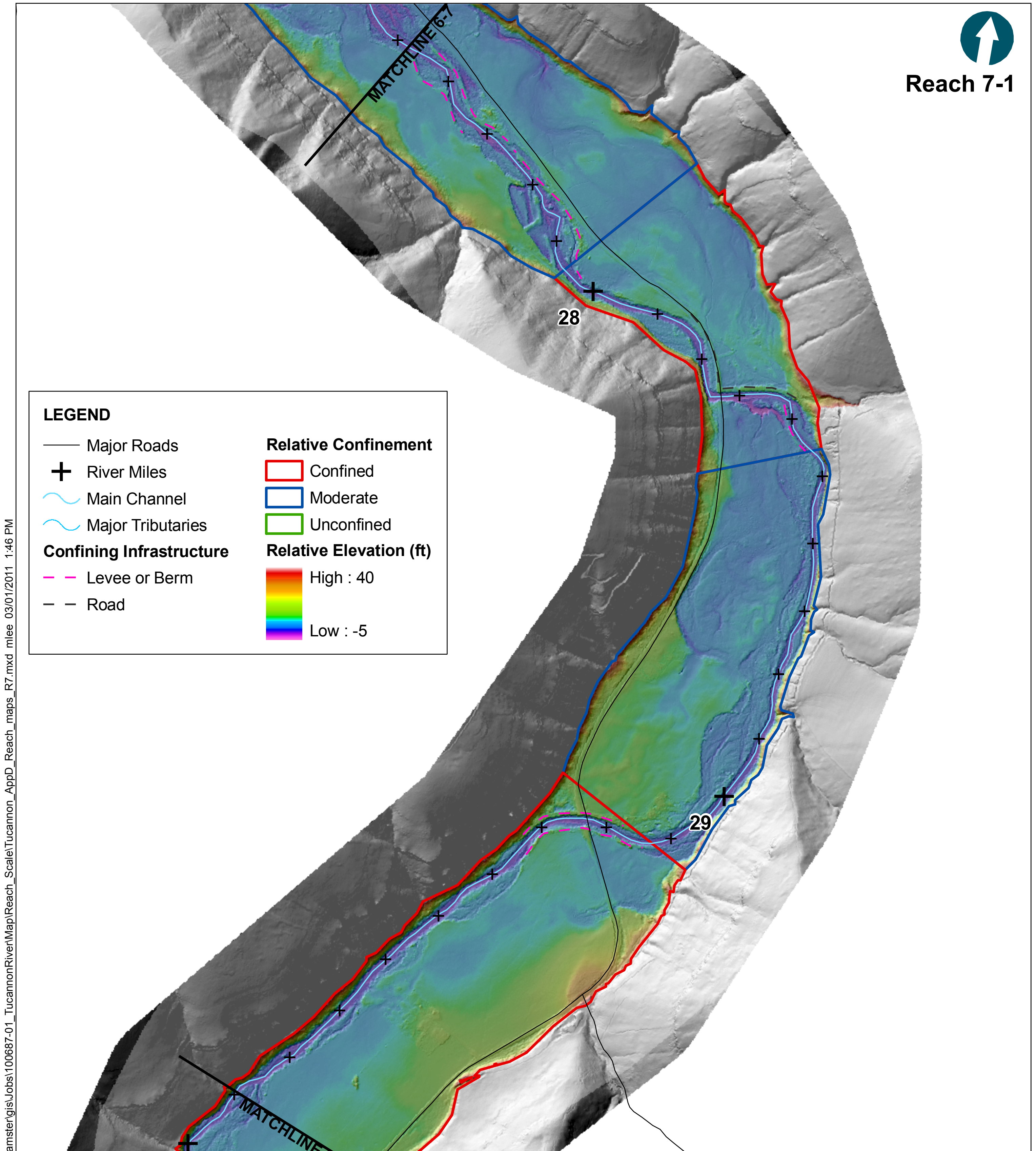
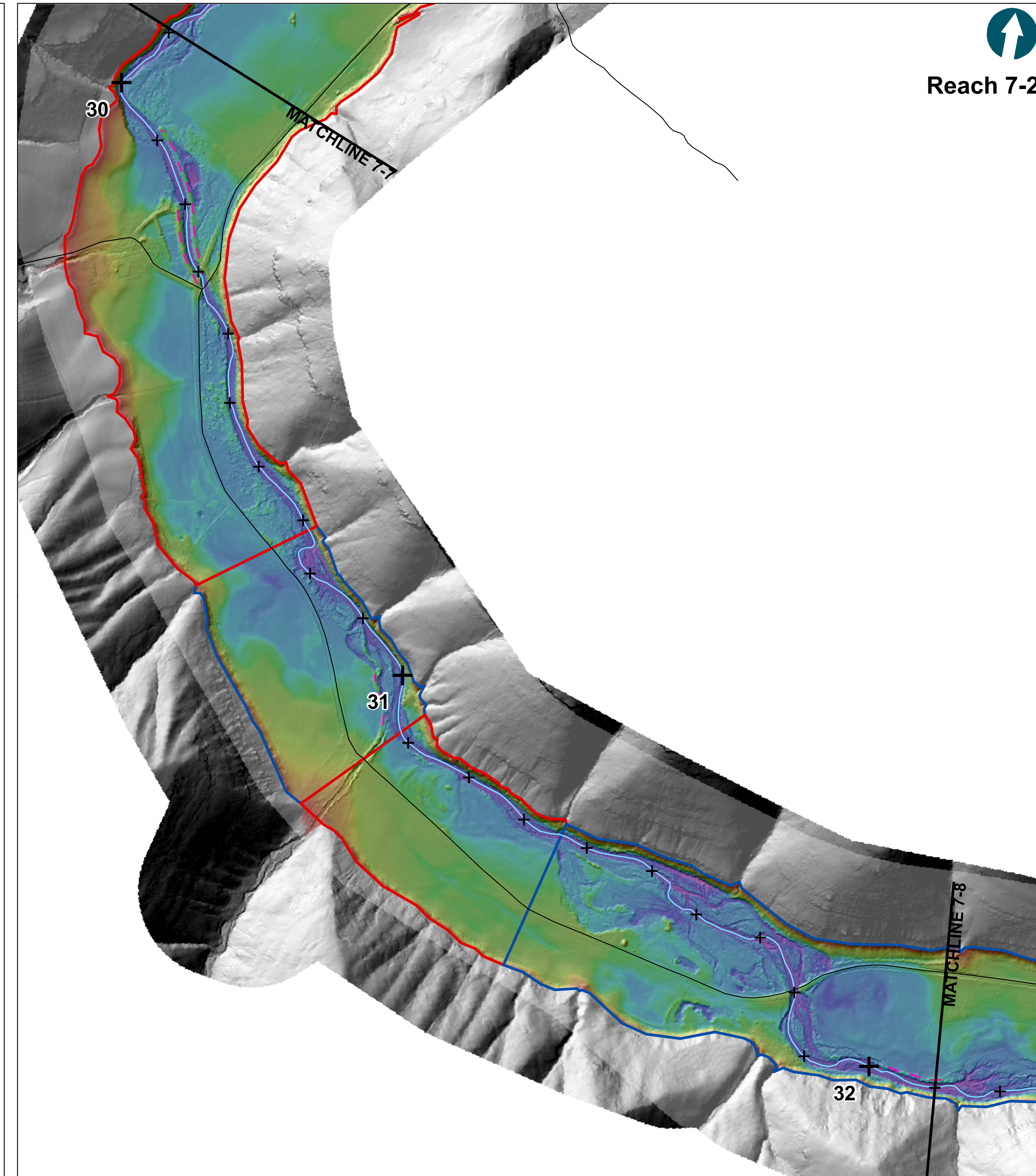
NOTES:
2010 orthophotos shown. Georeferenced historic channel patterns are approximate; traced from historic photos obtained from NRCS, USGS, USFS and CCD. Roads from WA DNR. Tributary alignments from DOE. Locations of features are approximate. This figure is to be used for conceptual purposes only.

Feet
0 1,000 2,000

Figure D-7a
Reach 7 Current Aerial Photo and Historic Active Channel Positions
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District





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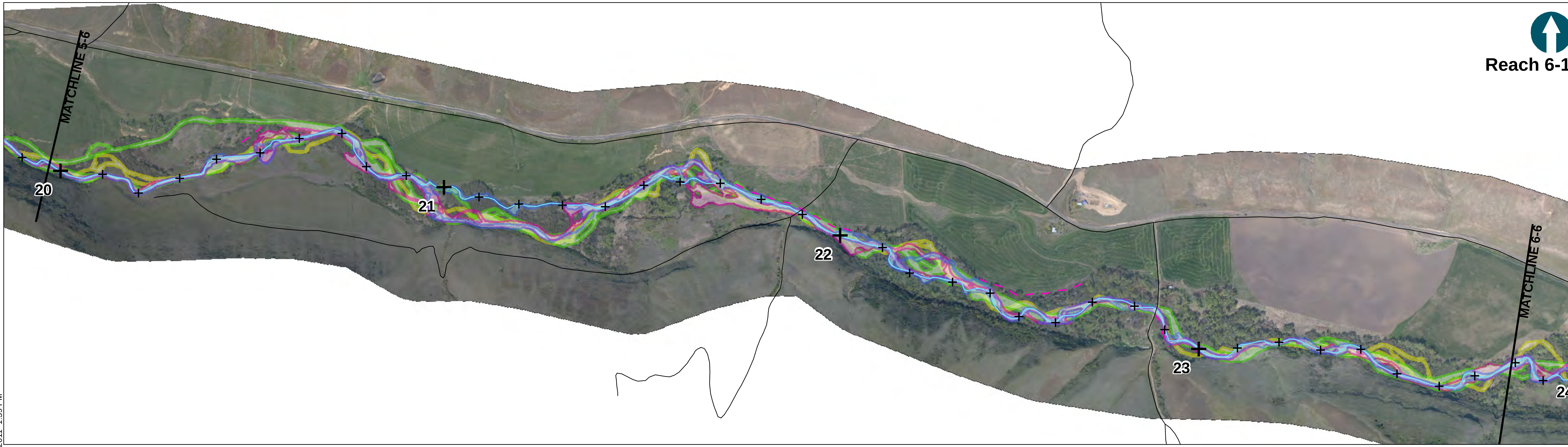
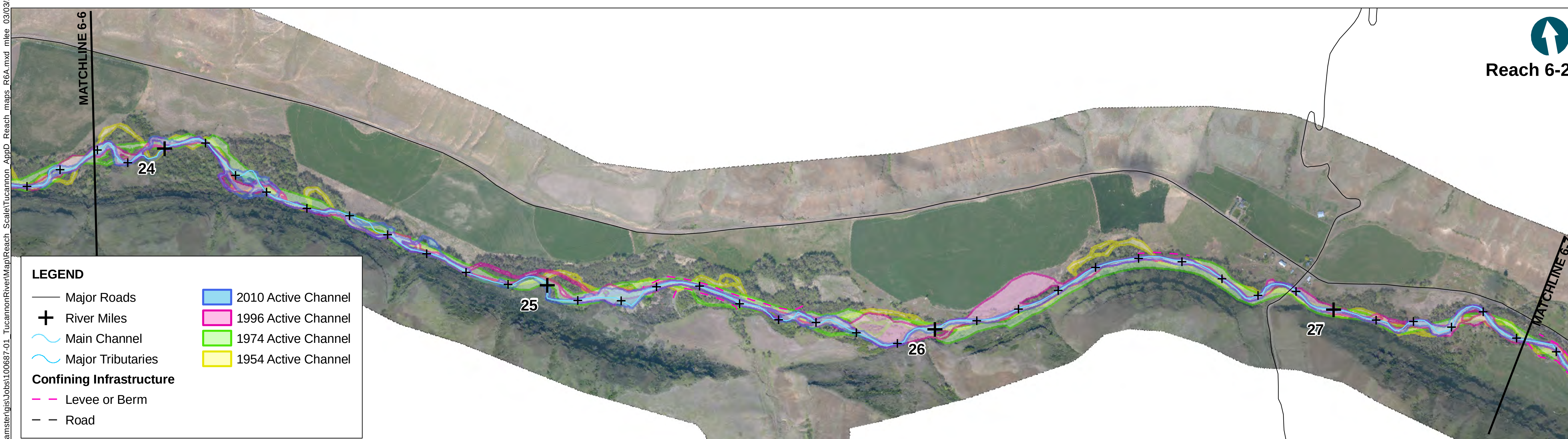
NOTES:
Relative elevation map created from 2010 LiDAR. Roads from WA DNR. Tributary alignments from DOE. Locations of features are approximate. This figure is to be used for conceptual purposes only.

Feet
0 1,000 2,000

Figure D-7b
Reach 7 Relative Elevation and Topographic Features
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District





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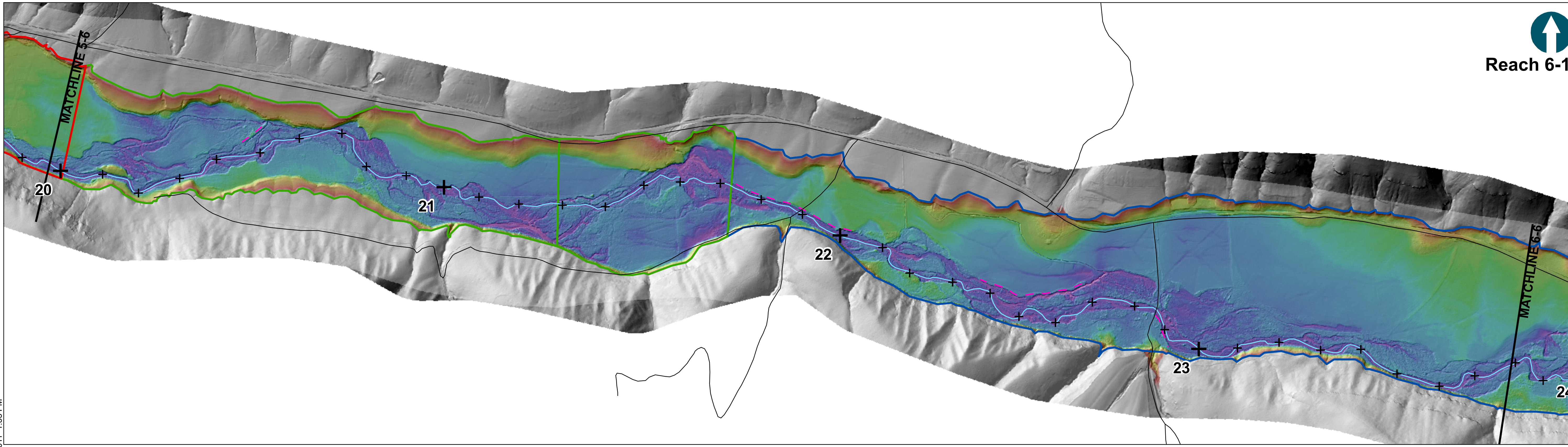
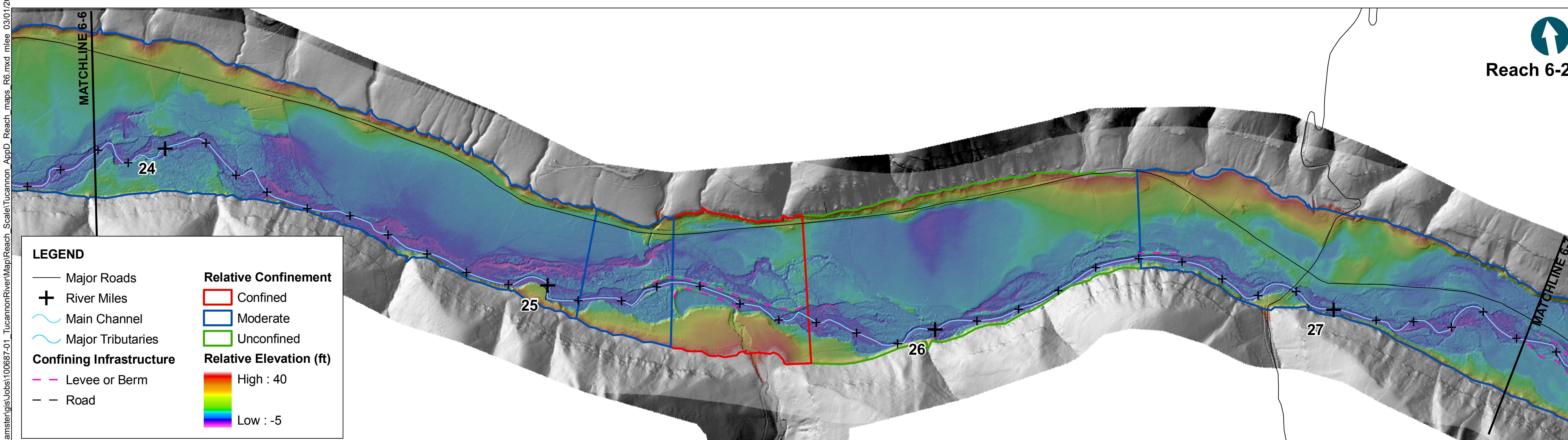
NOTES:
2010 orthophotos shown. Georeferenced historic channel patterns are approximate; traced from historic photos obtained from NRCS, USGS, USFS and CCD. Roads from WA DNR. Tributary alignments from DOE. Locations of features are approximate. This figure is to be used for conceptual purposes only.

Feet
0 1,200 2,400

Figure D-6a
Reach 6 Current Aerial Photo and Historic Active Channel Positions
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District





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NOTES:
Relative elevation map created from 2010 LiDAR. Roads from WA DNR. Tributary alignments from DOE. Locations of features are approximate. This figure is to be used for conceptual purposes only.

Feet
0 1,200 2,400

Figure D-6b
Reach 6 Relative Elevation and Topographic Features
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District

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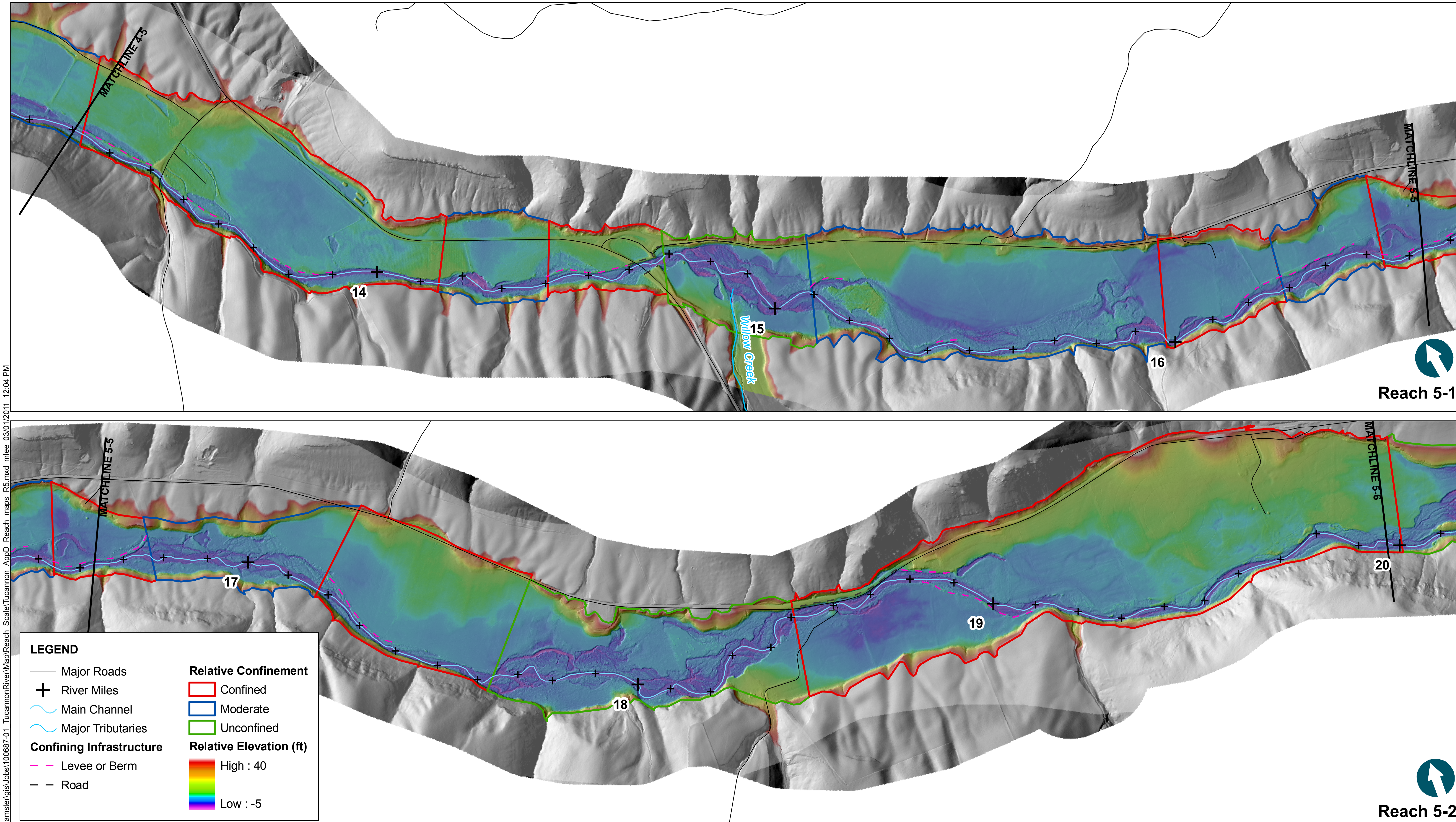
NOTES:
2010 orthophotos shown. Georeferenced historic channel patterns are approximate; traced from historic photos obtained from NRCS, USGS, USFS and CCD. Roads from WA DNR. Tributary alignments from DOE. Locations of features are approximate. This figure is to be used for conceptual purposes only.

Feet
0 1,100 2,200

Figure D-5a
Reach 5 Current Aerial Photo and Historic Active Channel Positions
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District



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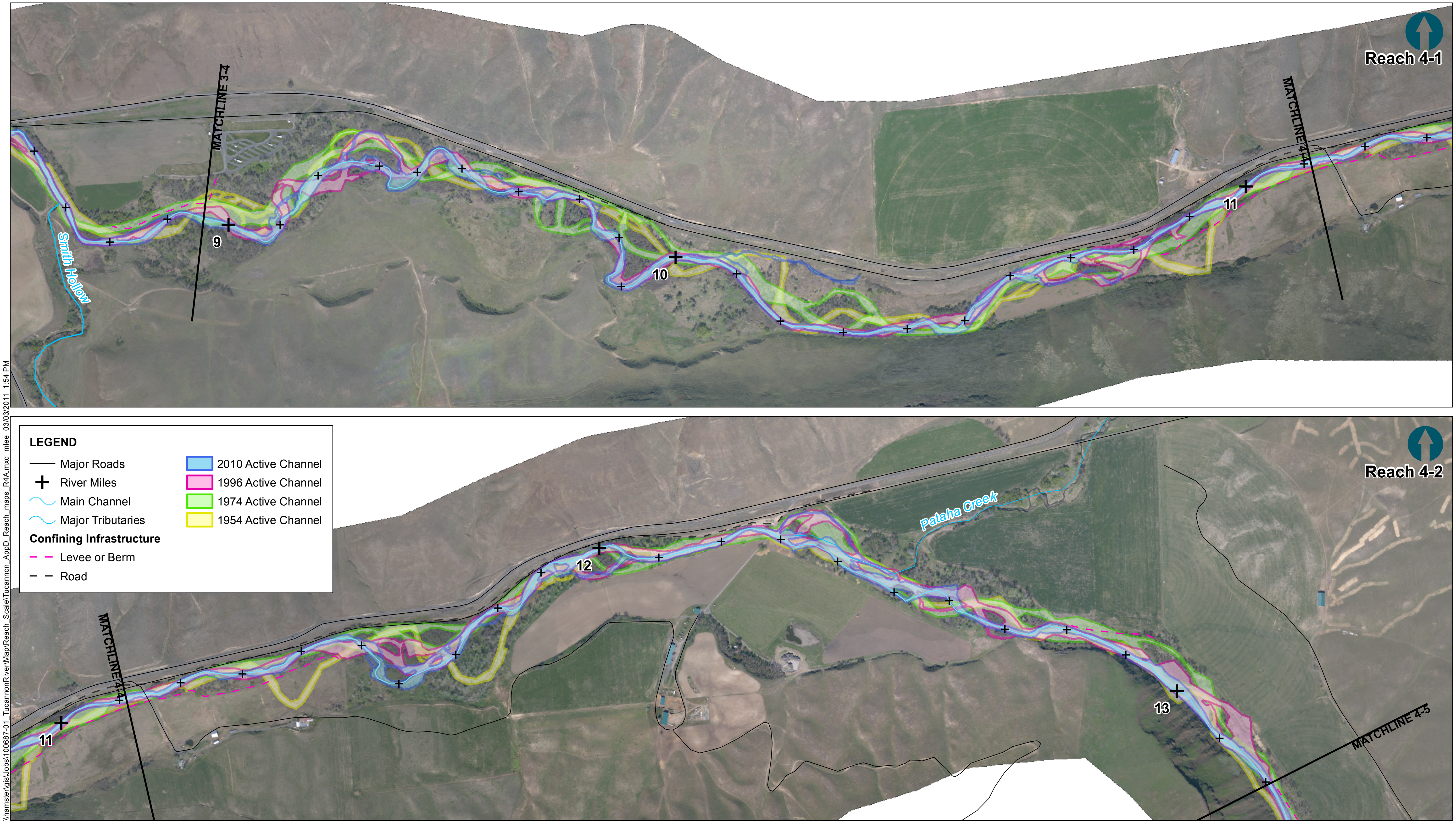
NOTES:
Relative elevation map created from 2010 LiDAR. Roads from WA DNR. Tributary alignments from DOE. Locations of features are approximate. This figure is to be used for conceptual purposes only.

Feet
0 1,100 2,200

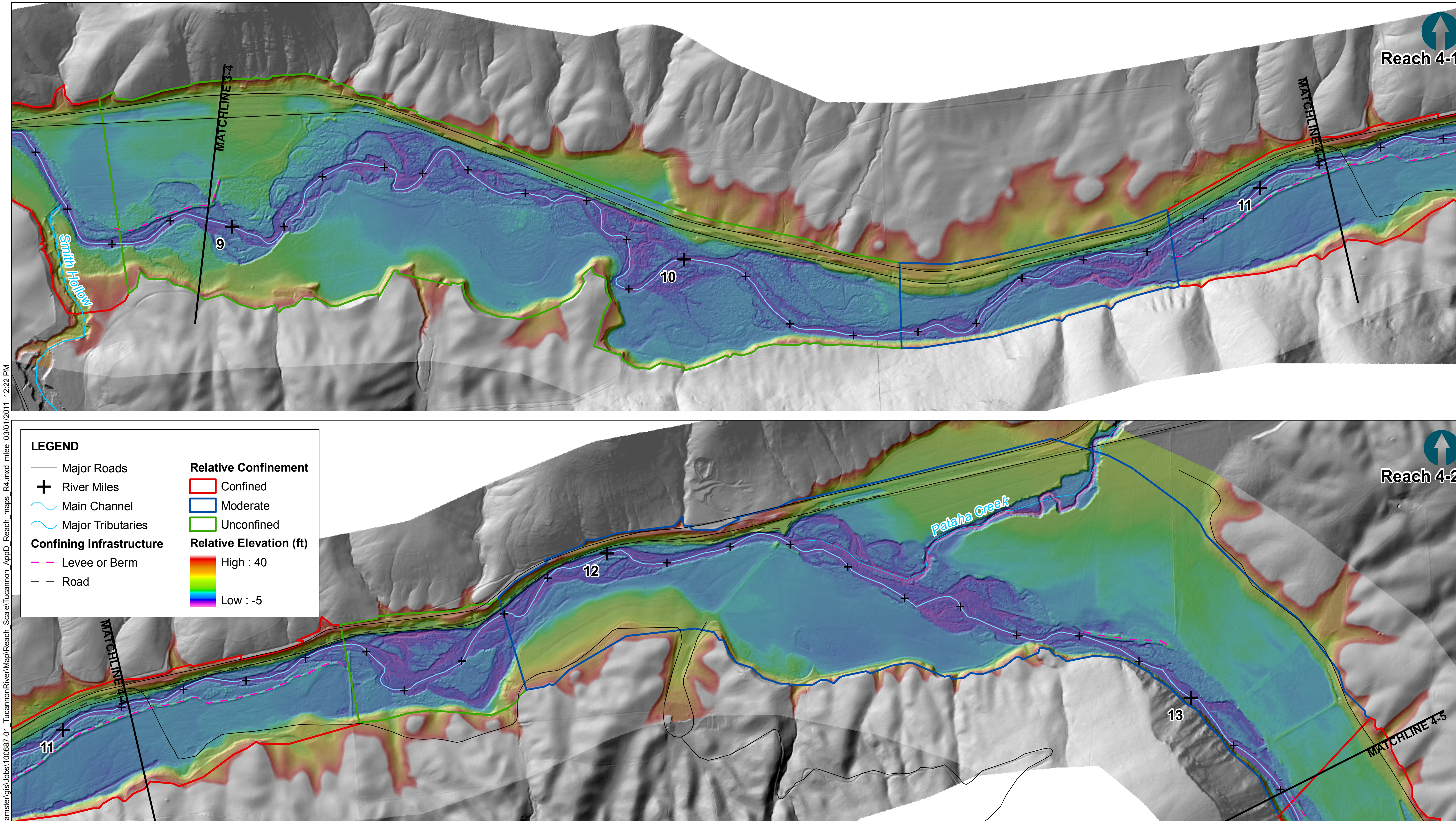
Figure D-5b
Reach 5 Relative Elevation and Topographic Features
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District



NOTES:
2010 orthophotos shown. Georeferenced historic channel patterns are approximate; traced from historic photos obtained from NRCS, USGS, USFS and CCD. Roads from WA DNR. Tributary alignments from DOE. Locations of features are approximate. This figure is to be used for conceptual purposes only.

Feet
0 750 1,500

Figure D-4a
Reach 4 Current Aerial Photo and Historic Active Channel Positions
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District



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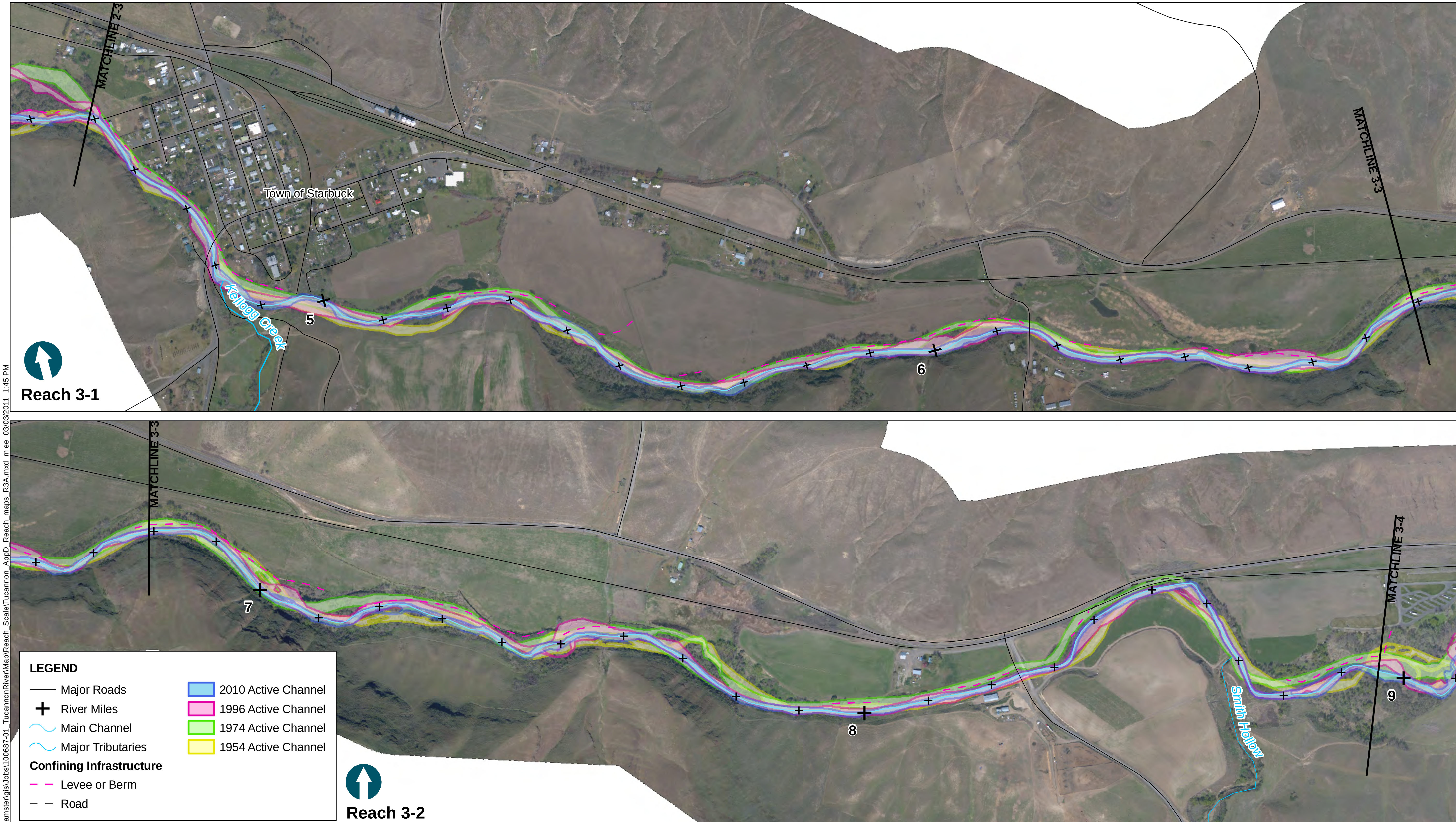
NOTES:
Relative elevation map created from 2010 LiDAR. Roads from WA DNR. Tributary alignments from DOE. Locations of features are approximate. This figure is to be used for conceptual purposes only.

Feet
0 750 1,500

Figure D-4b
Reach 4 Relative Elevation and Topographic Features
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District



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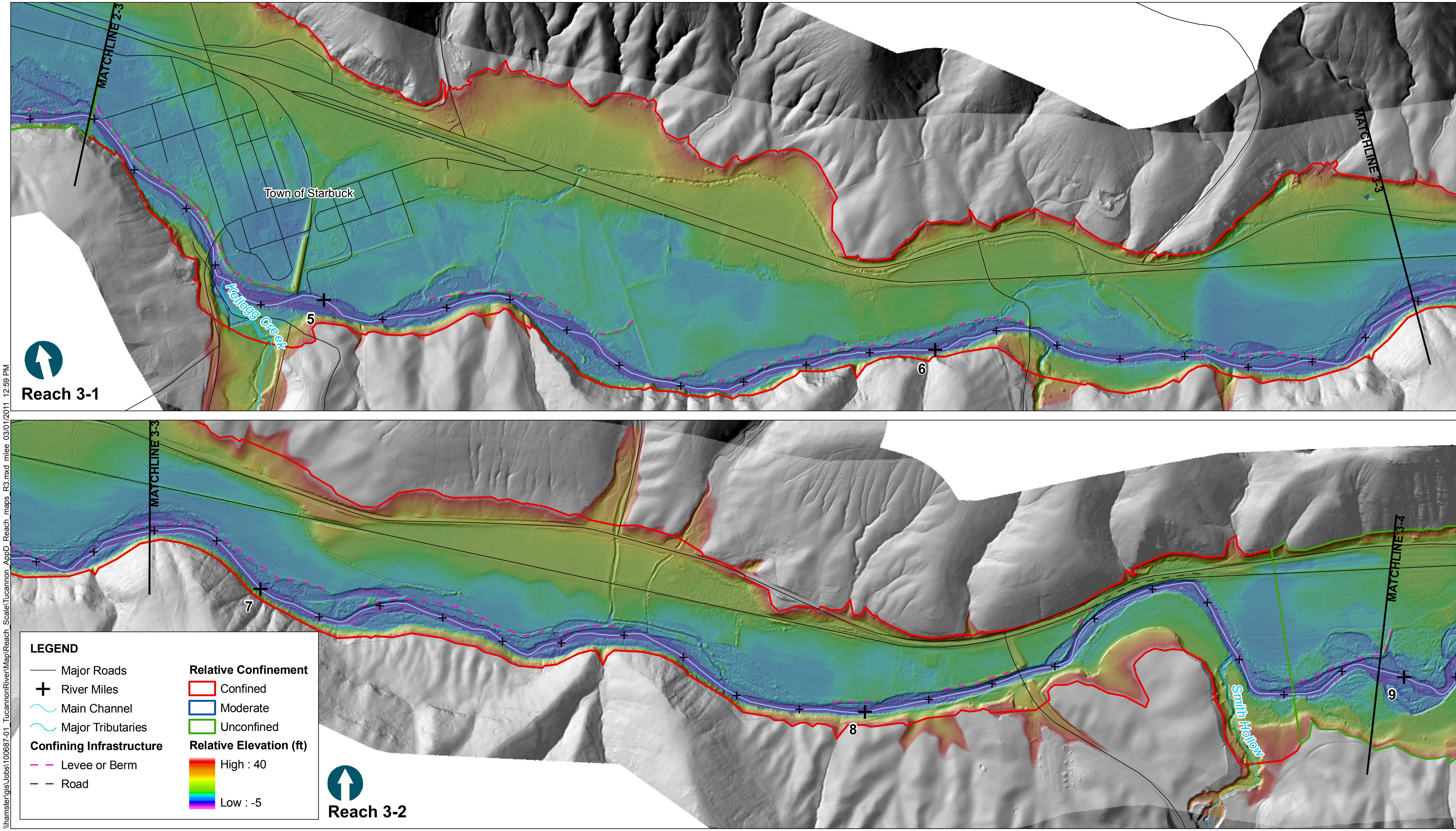
NOTES:
2010 orthophotos shown. Georeferenced historic channel patterns are approximate; traced from historic photos obtained from NRCS, USGS, USFS and CCD. Roads from WA DNR. Tributary alignments from DOE. Locations of features are approximate. This figure is to be used for conceptual purposes only.

Feet
0 750 1,500

Figure D-3a
Reach 3 Current Aerial Photo and Historic Active Channel Positions
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District



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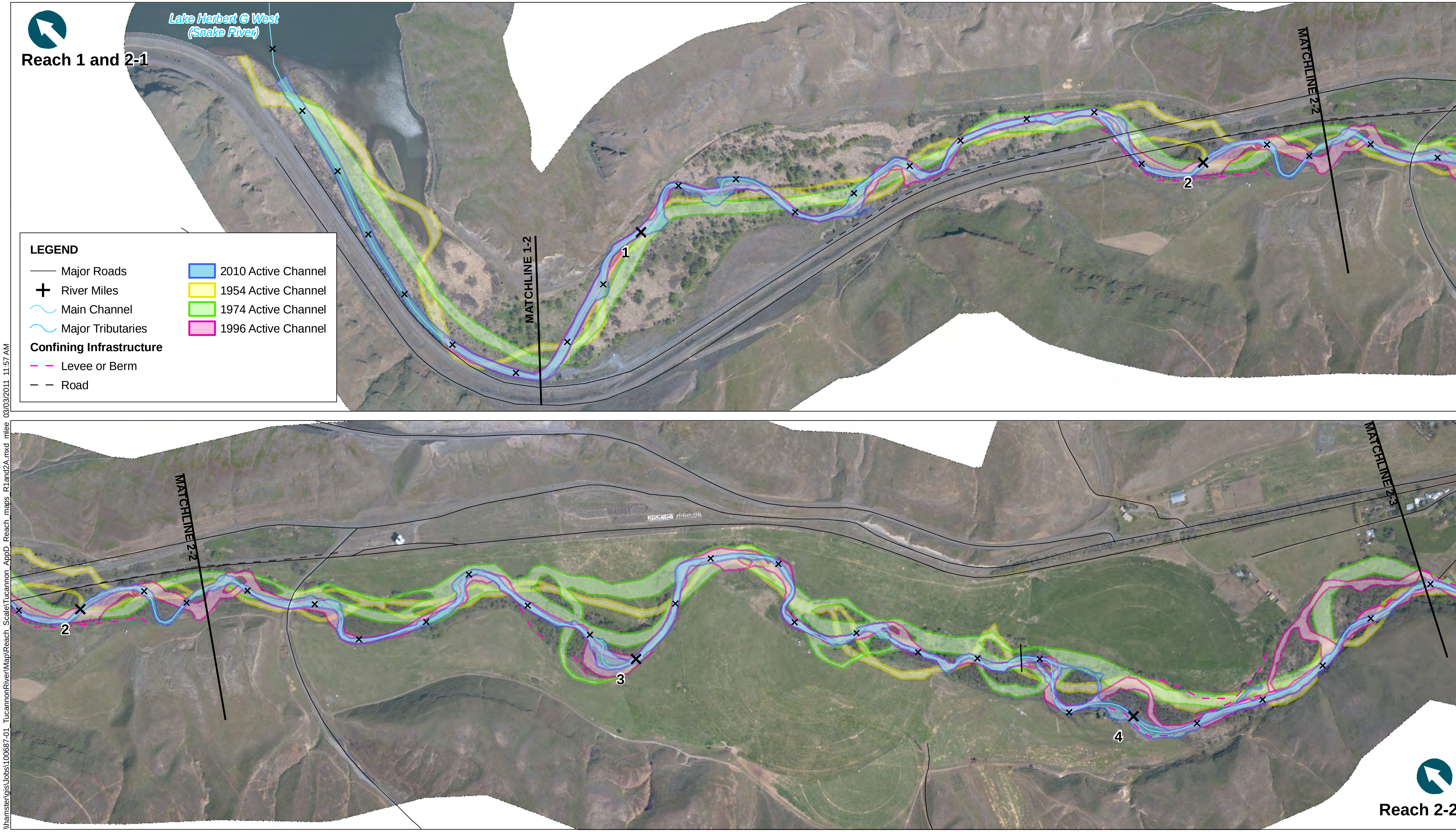
NOTES:
Relative elevation map created from 2010 LiDAR. Roads from WA DNR. Tributary alignments from DOE. Locations of features are approximate. This figure is to be used for conceptual purposes only.

Feet
0 750 1,500

Figure D-3b
Reach 3 Relative Elevation and Topographic Features
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District



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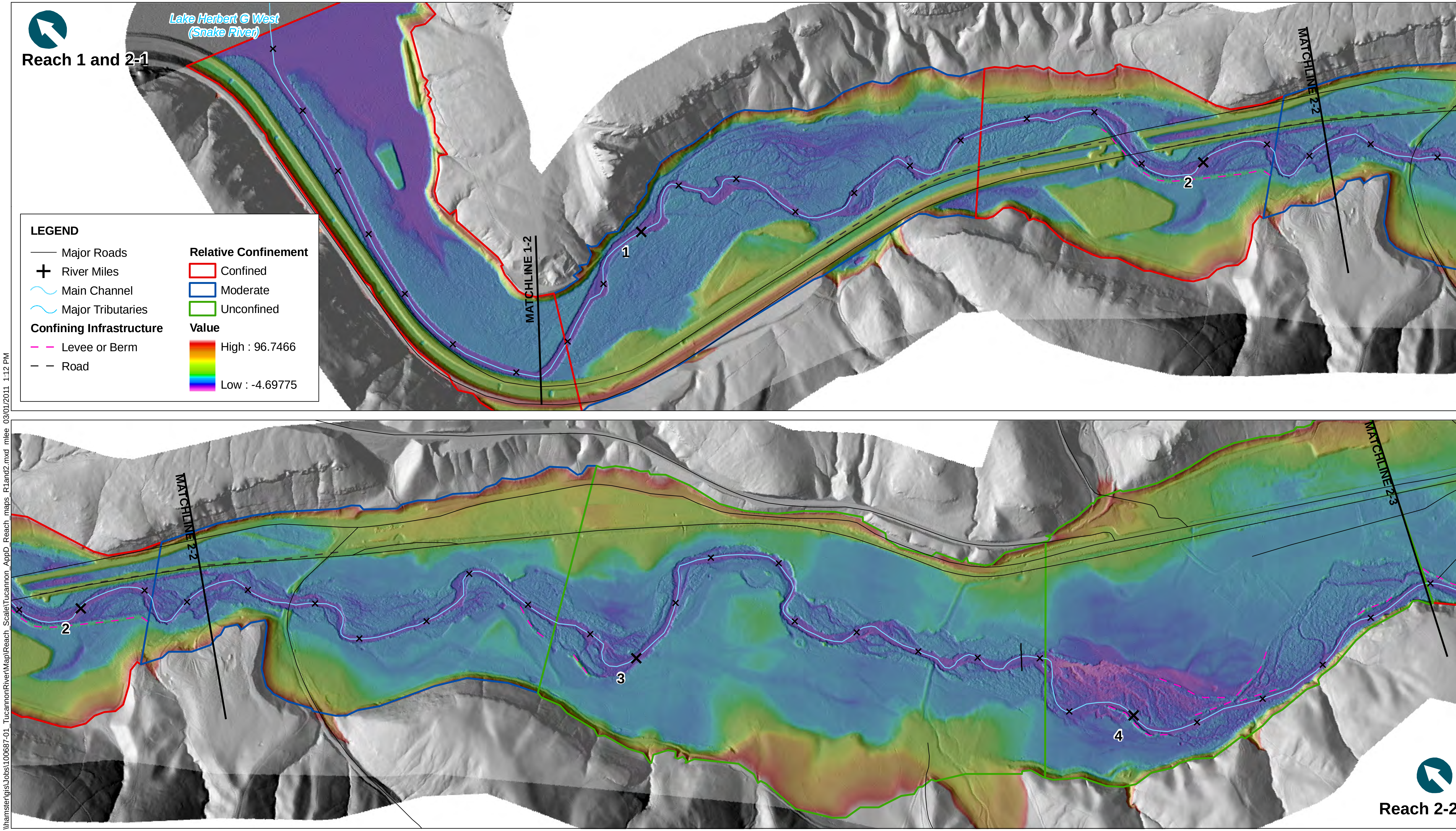
NOTES:
2010 orthophotos shown. Georeferenced historic channel patterns are approximate; traced from historic photos obtained from NRCS, USGS, USFS and CCD. Roads from WA DNR. Tributary alignments from DOE. Locations of features are approximate. This figure is to be used for conceptual purposes only.

Feet
0 750 1,500

Figure D-1a and D-2a
Reach 1 and 2 Current Aerial Photo and Historic Active Channel Positions
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District



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NOTES:
Relative elevation map created from 2010 LiDAR. Roads from WA DNR. Tributary alignments from DOE. Locations of features are approximate. This figure is to be used for conceptual purposes only.

Feet
0 750 1,500

Figure D-1b and D-2b
Reach 1 and 2 Relative Elevation and Topographic Features
Tucannon River Geomorphic Assessment and Habitat Restoration Study
Columbia Conservation District