VANCE CREEK WATERSHED ASSESSMENT AND ACTION PLAN

Prepared for

Mason Conservation District

August 2022

Mason Conservation District

VANCE CREEK WATERSHED ASSESSMENT AND ACTION PLAN

Prepared by ESA in collaboration with
Mason Conversation District and Wolf Water Resources

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Acronyms and Abbreviations

2D	Two-Dimensional
cfs	Cubic Feet per Second
Corps	U.S. Army Corps of Engineers
ELJ	Engineered Log Jam
ESA	Environmental Science Associates
GI	General Investigation
LiDAR	Light Detection and Ranging
MCD	Mason Conservation District
NWIFC	Northwest Indian Fisheries Commission
Plan	Watershed Assessment and Action Plan
Reclamation	U.S. Bureau of Reclamation
RFEG	Regional Fisheries Enhancement Group
RM	River Mile
SIT	Skokomish Indian Tribe
SSHIAP	Salmon and Steelhead Habitat Inventory and Assessment Program
SWAT	Skokomish Watershed Action Team
SWIFD	Statewide Washington Integrated Fish Distribution
USGS	United States Geological Survey
W2W	Wolf Water Resources
WDFW	Washington Department of Fish and Wildlife

EXECUTIVE SUMMARY

The Mason Conservation District (MCD) contracted with Environmental Science Associates (ESA) to complete this Watershed Assessment and Action Plan for Vance Creek. The purpose of the work is to document physical, hydrologic, and biologic conditions within lower Vance Creek and develop priorities to improve conditions for the long-term sustainability of both salmon and human populations within the watershed. As the largest tributary to the South Fork Skokomish River, interest in Vance Creek stems from its potential significance for the overall recovery of salmon populations in the Skokomish River watershed. This assessment focuses on geomorphic, hydrologic, hydraulic, and habitat conditions within the lower 4 miles of Vance Creek, extending from the confluence with the South Fork Skokomish River, upstream to the mouth of the canyon section at River Mile (RM) 4.2.

The Vance Creek watershed has been subject to historic land disturbance dating back to the first documented European settlement of the area in 1877, including significant logging activities throughout the riparian corridor and upper watershed. Vance Creek has documented periods of dry channel conditions within the mid to upper sections of the study reach (extending at various times from RM 2.3–RM 3.9) as far back as 1938, when the earliest aerial photos of the area are available. The dry channel conditions during certain periods of the year affect the ability of salmon and steelhead population to thrive in Vance Creek. The relationship of historical land use practices to sediment transport, deposition patterns, and dry channel conditions is considered in this study.

The primary elements of the Vance Creek Watershed Assessment and Action Plan include the following:

- <u>Sediment Data Collection</u> - This study draws upon suspended and bedload data collected by the United States Geological Survey (USGS) in partnership with MCD at station 12061250 from 2018–2020 and surface measurements (pebble counts) collected by the project team in 2020.
- <u>Hydrologic Data Collection and Analysis</u> - This study utilizes flow data recorded by the USGS at station 12061250 in place from October 1, 2018 to September 31, 2020. MCD staff also made flow measurements along the project reach to assess gains and losses within the historically de-watered reach. MCD also developed rating curves and deployed stage sensors for continuous measurement at two locations in the study area.
- <u>Geomorphic Analysis</u> - A geomorphic study was completed to document historical channel conditions along Vance Creek, document trends in channel evolution, and aid in the development of geomorphically appropriate restoration strategies.
- <u>Sediment Budgeting</u> - A detailed sediment study was completed to document the trends in sediment transport, deposition, and channel change over recent history. Analysis also considered the effects of historical logging practices on sediment trends.
- <u>Geophysical Data Collection</u> - Seismic refraction was conducted throughout the upper study area in August 2020 to estimate the thickness of alluvial deposits, depth to the groundwater table, and depth to bedrock.
- <u>Groundwater Assessment</u> - Using geophysical data, surface hydrology, and temperature measurements, groundwater depths were evaluated at the reach scale, and zones of shallow and cool hyporheic flow were identified for restoration objectives.

- Fisheries Life History Analysis - An historical review and analysis of the Vance Creek/South Fork Skokomish River fisheries populations, spawning locations, and the effects of channel conditions on potential habitat opportunities were completed as part of the assessment and restoration strategy.
- Hydraulic/Flood Analysis - A 2-Dimensional (2D) hydraulic model was developed for the purposes of determining flood conditions and risks in the lower valley as well as the hydraulic performance of conceptual restoration actions.
- Restoration Action Identification - A suite of potential restoration actions are presented aimed at stabilizing mobile sediment sources in the upper watershed, increasing access to perennial pool features in the middle reach, and adding habitat complexity in the lower reach.

The intent of this Watershed Assessment and Action Plan is to identify feasible strategies for habitat restoration in Vance Creek that can be implemented with broad stakeholder agreement. Stakeholders include valley residents, Mason County, fisheries co-managers (state and tribal) and MCD.

1 INTRODUCTION AND BACKGROUND

1.1 Purpose and Objectives

Environmental Science Associates (ESA) has prepared this this Watershed Assessment and Action Plan (Plan) for the Mason Conservation District (MCD) to expand upon a multi-decade effort to characterize the physical, hydrologic, and biological relationships that exist within Vance Creek to determine feasible strategies to guide community planning, climate resiliency, and salmon recovery efforts. Broadening our understanding of watershed-scale processes through targeted data collection and analysis, this assessment summarizes conditions in Vance Creek that are detrimental to recovery of endangered salmon and steelhead. This assessment accounts for conditions associated with the entire watershed, but the Plan focuses on detailed assessment and recommendations within the lower 4miles of Vance Creek (herein referred to as the "study area"). This lower reach, located from where Vance Creek emerges from the upper canyon downstream to its confluence with the South Fork Skokomish River (Figures 1 and 2), represents the initial priority for watershed restoration activities.

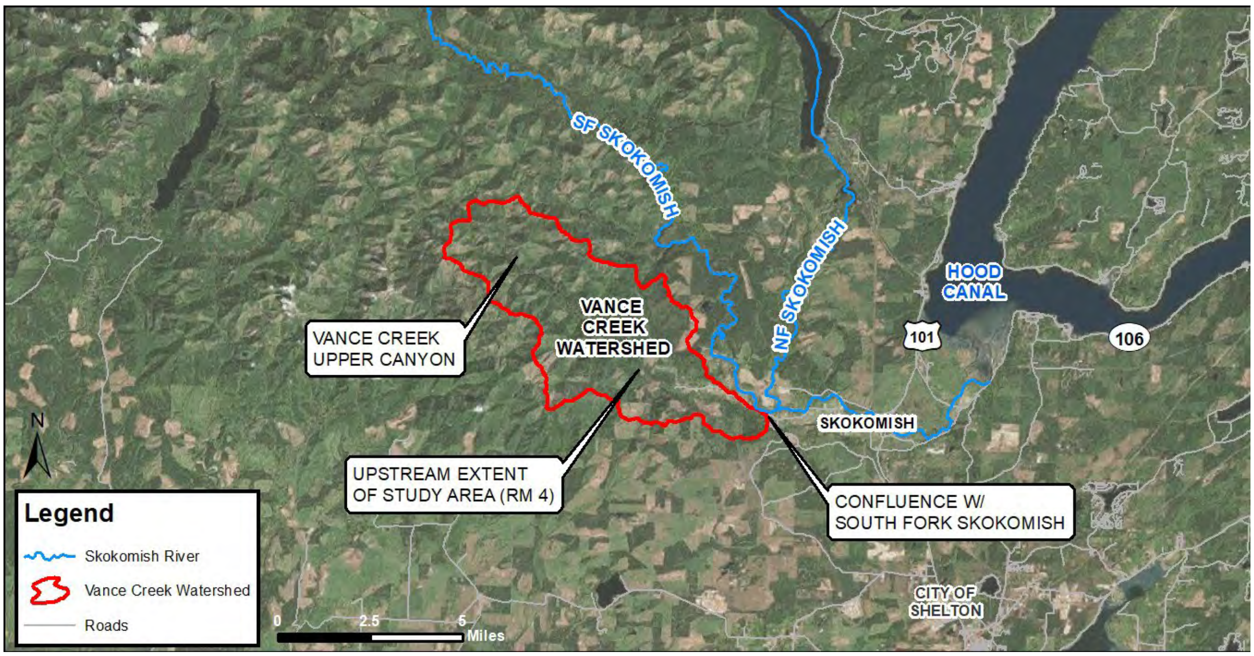

Figure 1. Watershed Boundary Map

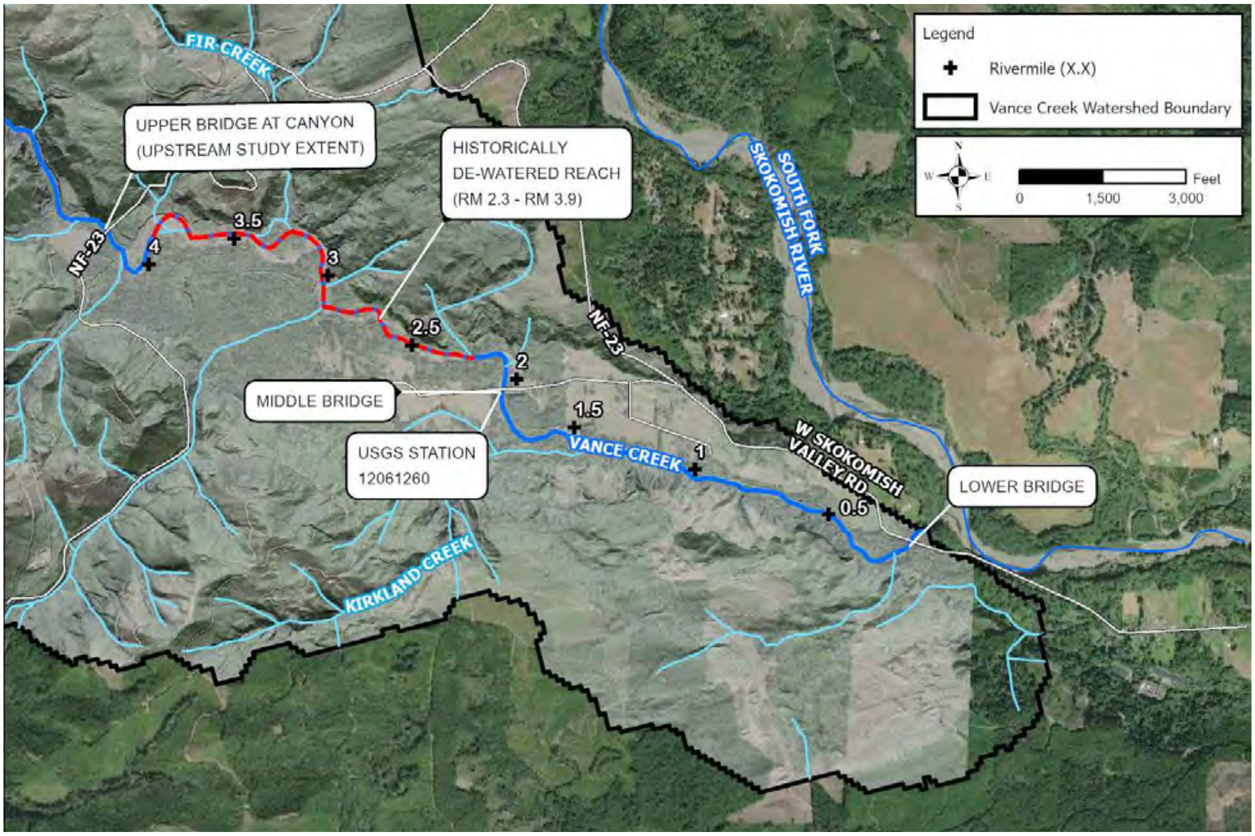

Figure 2. Study Area

This Watershed Assessment and Action Plan serves a dual purpose: first, as a compilation report documenting the significant findings and watershed characteristics of new and prior studies; and, second, to identify feasible restoration actions that offer multiple benefits that are both process-based and site-specific to address biological needs, restore normative geomorphic process and function, and succeed within the context of the current anthropogenic setting (i.e., flood reduction and infrastructure protection). The concepts for restoration approaches are presented in Appendix A.

New data acquisition was targeted specifically at identifying existing and potential future threats to the human populations in the valley resulting from flooding or erosion and the feasibility of restoration actions toward addressing the habitat outcomes caused by physical degradation in the Vance Creek watershed. In support of this objective, two companion studies were completed that are foundational to the findings of this Plan. This Plan presents an overview of these studies to support the identification of reach-scale limiting factors and the feasibility of potential restoration actions. These assessments include:

- **Geomorphic and Sediment Budget Assessment (Appendix B)** – This assessment characterizes the rate and patterns of bedload movement within the study area. This includes the sources of sediment production and flux within the study area, informing the scale of physical process-drivers and their relative impact on biological diversity and key habitat features (W2R 2021a).

- **Stream Dewatering Assessment (Appendix C)** – A dewatering assessment was completed to understand the feasibility of restoration actions that target opportunities to restore surface flow conditions during flow-limited periods of the year (W2R 2021b).

A primary outcome of this Plan is a restoration strategy that will establish priorities for future work and suggest a sequencing strategy so that the most critical work can be pursued first. Conceptual design figures (Appendix A) are included to identify actions that could be completed on a reach-by-reach basis, focused on preventing future flood risks to communities in the lower valley while also offering the greatest opportunities to assist in salmon population recovery. These conceptual designs have been evaluated using hydraulic modeling and geomorphic analysis, and the plans can be used to support future grant funding opportunities and to advance discussions with project partners about the types and locations of actions recommended in the Plan.

1.2 Prior Investigations in the Vance Creek Watershed

This Plan builds upon prior investigations in the Vance Creek and South Fork Skokomish River watersheds. These prior studies include documentation of geology, geomorphology, sediment regime, hydrology, hydraulics, land use, and other aspects of the current and historical condition of the Vance Creek watershed. These prior studies include:

- The 1999 Hydraulic and Geomorphic Analysis and Recommendations for Vance Creek, completed by Skillings-Connolly, Inc. and Simons and Associates (Skillings-Connolly and Simons and Associates 1999).
- The 2011 U.S. Bureau of Reclamation (Reclamation) Vance Creek Geomorphology and Hydraulic Modeling Report (Reclamation 2011).
- Skokomish Indian Tribe (SIT) and Washington Department of Fish and Wildlife (WDFW) 2010 Recovery Plan for Skokomish River Chinook Salmon and the 2017 Update (SIT and WDFW 2010, 2017).
- U.S. Fish and Wildlife Service's 2011 Biological Sampling in the Skokomish River Basin (Appendix A of the Skokomish River Basin Ecosystem Restoration General Investigation Integrated Feasibility Report).
- The U.S. Army Corps of Engineers (Corps) General Investigation (GI) for the Skokomish River watershed (Corps 2019).

Fish use and distribution data for Vance Creek were derived primarily from:

- Data from the Northwest Indian Fisheries Commission (NWIFC) Salmon and Steelhead Habitat Inventory and Assessment Program (SSHIAP).
- Data from the Statewide Washington Integrated Fish Distribution (SWIFD) database (WDFW and NWIFC 2021).
- WDFW SalmonScape Database (WDFW 2021a).
- WDFW Spawning Ground Survey Database: Vance Creek 2009–2019 (WDFW 2021b).

Topographic and bathymetric elevation data were derived primarily from:

- Topographic and bathymetric datasets available for use in the study area, including a channel survey completed by Reclamation in summer 2009 (as part of its 2011 study). Surveyed thalweg elevations were primarily used for this study.
- Light Detection and Ranging (LiDAR) data collected by the Puget Sound LiDAR consortium in 2002 (6-foot resolution grid, collected on March 3, 2002 at an estimated flow of 150 cubic feet per second [cfs]).
- Topo-bathymetric LiDAR data collected by Quantum Spatial Inc. for MCD in 2016 (3-foot resolution grid, collected on September 28, 2016 at an estimated flow of 4,000 cfs).

2 STUDY METHODS

Several key technical studies were completed during the development of this Plan, with the objective of identifying feasible opportunities to enhance community well-being and ecosystem recovery in the Vance Creek watershed. These opportunities were developed using two fundamental approaches: (1) limiting-factors analysis, and (2) process-based restoration (Booth et al. 2016). These approaches are similar in their overall goals, but are fundamentally different in their perspective in restoring key habitat features. Limiting-factors analysis seeks to identify the physical limitations to salmonid productivity that can be addressed by site-specific actions and focuses on building habitat, whereas a process-based restoration approach seeks to recover the underlying physical processes that promote biological diversity. Together, these two approaches offer a lens through which restoration actions may be prioritized at multiple spatial scales to provide both immediate ecological uplift and promote long-term resiliency.

The following sections describe the technical studies foundational to the outcome of this Plan.

2.1 Hydrology and Flow Monitoring

Given that Vance Creek is well documented to go dry in its upper reaches, a greater understanding of seasonal and peak hydrologic patterns was needed to support habitat, geomorphic, and feasibility considerations throughout the study area. MCD worked in concert with the United States Geological Survey (USGS) to fund the installation and maintenance of a flow gage on Vance Creek at the middle bridge (Figure 2). MCD also completed flow monitoring in the upper reaches of Vance Creek, including establishing cross sections for regular interval flow monitoring, developing rating curves, and installing data loggers to monitor river stage. Seepage (flow loss) monitoring was timed to determine streamflow losses in varying seasons and hydrologic conditions. MCD conducted three monitoring events between May 2019 and March 2020 to capture potential seasonal variation.

A summary of hydrologic data collected in support of the Vance Creek watershed assessment includes:

- Longitudinal flow measurements along 2 linear miles of Vance Creek were completed by MCD on May 30, 2019 and March 4, 2020. With several measurements made along the creek on each day, these measurements were used to determine the rates of gain and loss along Vance Creek. This data is summarized in the Stream Dewatering Assessment (Appendix B).

- Flow monitoring records from the summer of 2019, recorded by MCD at the NF-2341 Road and in Fir Creek. These gages used local datums and locally developed rating curves to measure flow rates. These data are summarized in the Stream Dewatering Assessment (Appendix B).

- The Vance Creek USGS gage (12061250) was installed at the middle bridge (Figure 2) and in place reporting continuous stage and discharge from September 28, 2018 to October 1, 2020. Continuous flow monitoring in Vance Creek allowed for the development of improved flow statistics compared to prior efforts, for which Vance Creek flows were estimated based solely on watershed area. Flow return periods (Table 1) have been updated to reflect the inclusion of the new USGS data.

Following October 2020, the gage was converted to stage only given the lack of ongoing funding to support refinement of the rating curve. The USGS gage is located within the lower end of the dewatered reach and therefore is well placed to inform rates of loss.

Table 1. Vance Creek Flow Events

Return Period or Flow	Discharge (cfs)
Representative Summer Low Flow	150
Representative Spring Low Flow	400
1-Year	2,575
2-Year	3,925
10-Year	5,975
100-Year	7,700

2.2 Geophysical Survey

Global Geophysics conducted a geophysical survey to approximate depths to groundwater and bedrock. The investigation utilized seismic refraction technology and was performed to identify the limits of surface water loss to groundwater beneath the streambed.

The survey was carried out along 10 transects upstream of the middle Skokomish Valley Road bridge (Figure 2) on August 17 and 18, 2020. The dates coincided with summer low flows and thus were thought to best represent the deepest groundwater elevations to be observed throughout the year. The transects selected for sampling focused on areas where dewatering had been observed.

Bedrock was observed approximately 25 to 40 feet below the streambed in most locations; the groundwater table was consistently be 10 to 20 feet thick where bedrock was encountered. In areas where dewatering has been observed in the upper study area, the water table was 15 to 20 feet below the streambed.

Appendix D presents the findings of the geophysical survey.

2.3 Hydraulic Modeling and Analysis

A two-dimensional (2D) HEC-RAS hydraulic model was developed for the 4-mile project reach using a topo-bathymetric terrain collected by Quantum Spatial in 2016. The model supports multiple objectives:

- Evaluate flood extents and inundation patterns throughout Vance Creek for floods of varying return periods.
- Support the Geomorphology and Sediment Budget Assessment through characterizing the longitudinal variation of sediment competence and the associated critical particle diameter.

- Quantitatively inform the feasibility and scale of actions required to influence hydraulics and achieve the geomorphic and biological objectives defined in this Plan.

Modeling was performed for a range of peak flow values ranging from the 1-year to the 100-year recurrence interval flood events (the 100% and 1% annual probability flood, respectively), as well as representative summer and spring low-flow conditions (Table 1). For each of these flows, the model produces results for water depth, velocity, inundation extent, and shear stress). Modeling was also performed to simulate the hydraulic performance of recommended restoration actions and is discussed later in the document.

2.4 Geomorphic and Sediment Budgeting Assessment

A Geomorphic and Sediment Budget Assessment was completed to characterize channel planform evolution, the rate and patterns of bedload movement, and the sources of sediment production and flux within the study area. A key objective of this task was to distinguish between natural processes and anthropogenic factors influencing sediment transport and channel evolution in Vance Creek. In doing so, there is an opportunity to inform potential restoration strategies and recovery timescales.

The technical approach of the geomorphic assessment consisted of four primary components:

- Bedload flux was estimated using a bedload-derived rating curve developed with USGS measurements (2018–2020) at the gage located at River Mile (RM) 2 (USGS 12061250). The rating curve and flow record in Vance Creek together allow for a historical estimate of bedload flux over the last two decades, where topo-bathymetric data are available.

- Longitudinal thalweg elevations and relative change between 2009 and 2016 were estimated from survey measurements collected by Reclamation and 2016 LiDAR-based measurements.

- Average change in streambed elevation over the past 14 years was estimated through differencing LiDAR terrain models from between 2002 and 2016.

- Longitudinal patterns in sediment size and transport conditions were assessed through field measurement of grain sizes and basic modeling of sediment competence. Pebble counts (Wolman 1954) were collected at 18 gravel bars along the creek.

Appendix B presents the detailed approach and findings of the Geomorphic and Sediment Budget Assessment.

3 SALMONID HABITAT, DISTRIBUTION, AND MANAGEMENT

3.1 Distribution of Salmonid Species

Vance Creek is the largest tributary to the South Fork Skokomish, and anadromous salmonid spawning is documented along nearly 8 miles of the creek's mainstem. Vance Creek provides important spawning habitat for several species, and the lower reaches of the creek may also be used for rearing juveniles and upstream migrating adult salmonids from other parts of the Skokomish River watershed.

Vance Creek currently supports the following species and runs of anadromous salmonids: fall Chinook salmon, fall chum salmon, coho salmon, pink salmon, winter steelhead, and coastal cutthroat trout, according to the SWIFD (WDFW and NWIFC 2021) and SalmonScape (WDFW 2021a) databases. An additional run, summer steelhead, is presumed to be present as well (WDFW and NWIFC 2021; WDFW 2021a). The biological data contained on the SalmonScape site was collected by state, federal, tribal, and local biologists as well as Regional Fisheries Enhancement Groups (RFEGs) and watershed partners in the course of monitoring salmon and watershed health across Washington State. The SalmonScape data are a compilation of knowledge from field biologists and are updated periodically as knowledge improves. The distribution information is considered the best available, but is generally acknowledged to likely underestimate fish distribution based on where survey efforts have occurred previously. In Vance Creek specifically, the distribution information may also be affected by reduced access to the creek in the mid- to late-summer due to the South Fork Skokomish River commonly running dry.

The salmonid distribution information supports the strategy and prioritization of actions toward increasing the accessibility of existing habitat and improving conditions within the study area. The distribution of each species according to SWIFD and SalmonScape is summarized in Figure 3.

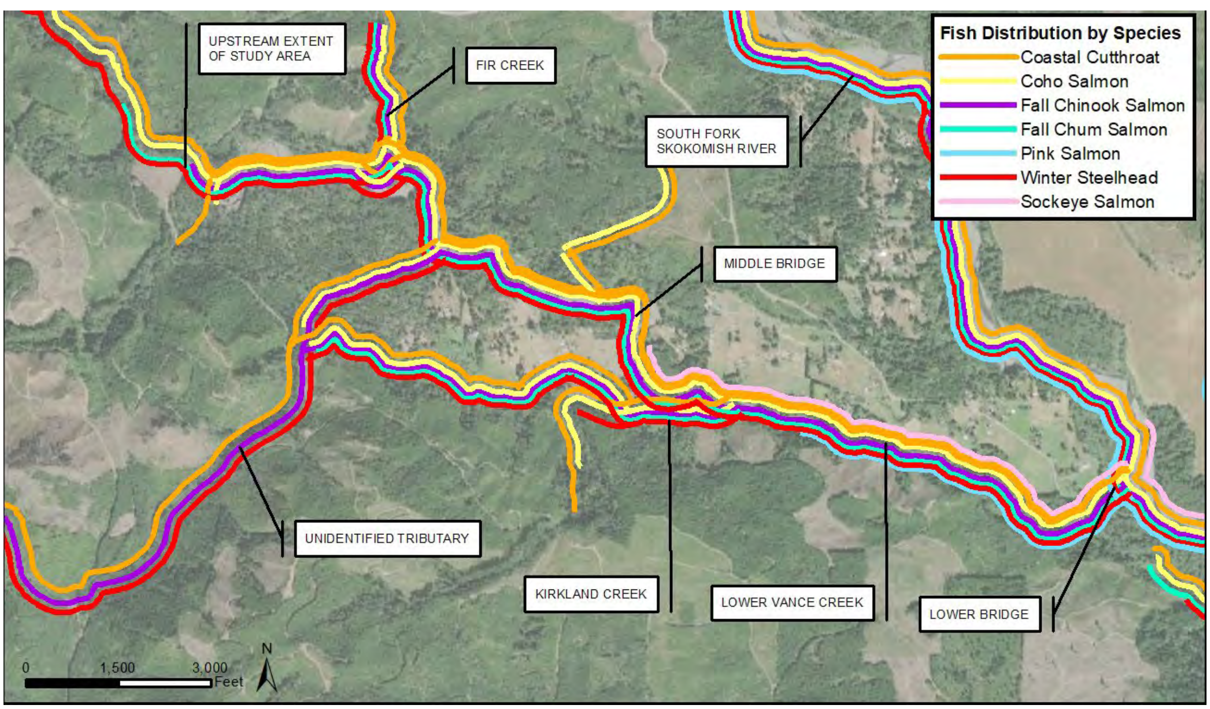

Figure 3. Fish Distribution by Species in Vance Creek Watershed

3.2 Salmonid Abundance

The best long-term dataset for salmon abundance in Vance Creek is WDFW's spawning ground surveys. Spawning ground survey data from 2009–2019 were analyzed to provide the following overview for the timing of salmonid species and their life-stages in Vance Creek. Of note, the numbers seen may be lower than would otherwise occur because summer low flows in the South Fork Skokomish River may prevent upstream migrating salmon from accessing Vance Creek. The South Fork Skokomish River commonly goes dry in mid- to late-summer, which restricts the migration of adult salmonids trying to move upstream at that time. The lack of access to Vance Creek during this timeframe is most likely to affect the returning adult numbers of Chinook salmon, steelhead, and pink salmon as these species tend to return earlier than other species.

A summary of the annual number of live salmonids of each species is provided in Table 2. WDFW also recorded dead salmonids, but these were not evaluated to avoid likely double counting during repeated surveys (i.e., live in one survey, dead in the next survey). There is still the possibility of double-counting of live fish seen in successive surveys. Among all species and years, the number of live salmonids observed in a year exceeded the number dead except in 2016 and 2017, when more dead chum salmon were documented. This indicates that this summary of live chum salmon underrepresents the number of chum salmon who occupied Vance Creek in those years.

Additional details on the live salmonid observations by species is described below. The hatchery influence on the numbers documented is unknown, but exceptionally high numbers in a year may be related to hatchery fish releases.

Table 2. Live Salmon in Vance Creek Documented during WDFW Spawning Ground Surveys

Run Year	Chinook Salmon	Chum Salmon	Coho Salmon	Pink Salmon	Sockeye Salmon	Steelhead
2009	0	323	414	0	--	--
2010	18	426	51	--	--	3
2011	0	4,976	376	1	--	5
2012	0	1,300	930	--	--	1
2013	6	5,902	440	9	--	10
2014	2	1,367	188	--	--	1
2015	23	1,871	335	497	--	4
2016	2	2,527	488	--	1	0
2017	0	399	196	0	--	0
2018	0	1,452	208	--	--	0
2019	106	407	2,793	47	--	0

3.2.1 Chinook Salmon

A total of 157 live Chinook salmon adults were identified in 53 survey entries between 2009 and 2019. Live Chinook salmon were seen in five out of the 11 survey years (dead Chinook salmon were observed in one additional year). Chinook were only observed in September and October, although only two surveys were conducted in other months (both in August). As noted above, the documented timing of Chinook salmon in Vance Creek is likely delayed due to the dry reach in the South Fork Skokomish River preventing the fish from migrating upstream to the creek mouth.

Of the 157 live Chinook salmon documented, 104 of the observations were from a 2-week period in 2019 in which four surveys were conducted the reach RM 0.0–1.7[1]. It is likely that the same fish was counted more than once in the different survey times. The maximum number of Chinook observed in any one survey during this time was 33. A total of 24 redds were documented during this 2-week period. This pulse of fish in a short timeframe is likely related to Chinook salmon waiting downstream until flows are adequate in the South Fork Skokomish River to allow the fish to access Vance Creek. If flows allowed, it is assumed that Chinook salmon would return to Vance Creek earlier.

3.2.2 Chum Salmon

Large numbers of chum salmon return to Vance Creek each year. Between 2009 and 2019, 20,950 live chum salmon were documented. The peak is concentrated in November and December, with some as early as September and others as late as January. Between 2009 and 2019, 60 percent of the live adult chum salmon observed were in the reach RM 0.0–1.7, with the remaining 40 percent in the reach RM 1.7–2.9.

3.2.3 Coho Salmon

Coho salmon were the second-most numerous salmonids observed in Vance Creek during WDFW spawning ground surveys. More than 6,400 coho salmon were observed between 2009 and 2019. In 2019 surveys, 2,793 live coho salmon were observed. This is more than three times the number seen in any year between 2009 and 2018, despite similar levels of sampling effort that had been conducted in previous years. The high numbers in 2019 were documented in surveys in mid-November through mid-December. It is likely that the same fish was counted in multiple surveys, which results in an overestimation of the actual number of coho salmon returning to the creek. Approximately 74 percent of the adult coho salmon were observed in the reach RM 0.0–1.7, while the remaining 26 percent were observed in the reach RM 1.7–2.9. Few spawning survey data have been collected upstream of RM 2.9.

3.2.4 Pink Salmon

Pink salmon were infrequently documented in most odd-numbered years, except in 2015 when 497 adults were recorded in three surveys conducted over a 2-week period. These surveys likely included some observations of the same fish in multiple surveys, which results in an overestimation of the actual

[1] WDFW's database identifies the survey reach downstream of the middle bridge on Skokomish Valley Road as RM 0.0 to 1.7. WDFW's river miles are presented throughout this section, but differ from river miles used elsewhere in the Plan. For example, the Plan lists the middle bridge as being at RM 1.9.

number of pink salmon returning to the creek. All documented pink salmon were observed in the reach RM 0.0–1.7.

3.2.5 Steelhead

A total of 24 adult steelhead were documented in surveys between 2010 and 2019. WDFW listed all documented steelhead as winter run, or they left the run field blank. As noted earlier, summer steelhead, are presumed to be present as well (WDFW and NWIFC 2021; WDFW 2021a). The timing of the live fish observed makes it possible that some were summer run. No adult steelhead have been documented in Vance Creek since 2015. Those steelhead documented in Vance Creek were observed in March, April, or May. Of the 24 adult steelhead observed, 17 were in the reach RM 3.5–7.0.

3.3 Salmonid Timing

Fish periodicity (Figure 4) was compiled to better understand the timing and presence of life-stages for the most common salmonids within the Vance Creek watershed. Understanding life-stage timing and associated historic changes in timing is a primary component toward the identification of physical conditions that limit habitat and access. This consideration is most significant in two ways. First, the low and dry flows in South Fork Skokomish River in the mid- to late-summer can restrict the movements of salmonids trying to migrate into or out of Vance Creek. Second, once in Vance Creek, the dry channel conditions that occur in Vance Creek (approximately from RM 2.3–RM 3.9) in the late summer and early fall restrict fish access and habitats. These conditions affect salmonid species differently because of the overlap of the life-stages affected. For fall Chinook salmon, the dry channel period coincides with when adults are returning to the river and trying to migrate to upstream spawning areas. As a result, fall Chinook salmon adults are largely blocked from spawning in habitats upstream of the dry reach. Summer steelhead may be similarly affected.

The other species affected are coho salmon, winter steelhead, and coastal cutthroat trout. For these species, the dry channel periods occur when fish are rearing. Fish unable to move out of the reach will be stranded in isolated habitats. The only juvenile fish to survive are those that find deep pools that remain wetted. The dry reach has a limited number of large pools that are connected to cool groundwater; otherwise, even the pools are vulnerable to drying out or overheating, unless surface flows return again.

The current timing of Chinook salmon runs in Vance Creek and the entire Skokomish River watershed is significantly different than historic run timing (SIT and WDFW 2010). Historically, two run-timing stocks used Vance Creek: spring Chinook salmon and fall Chinook salmon. Spring Chinook entered the river from April through July. This stock is now extinct. The river entry for fall Chinook was historically timed with elevated streamflow when fall freshets first begin. This was between September and November, with a sharp peak in late October.

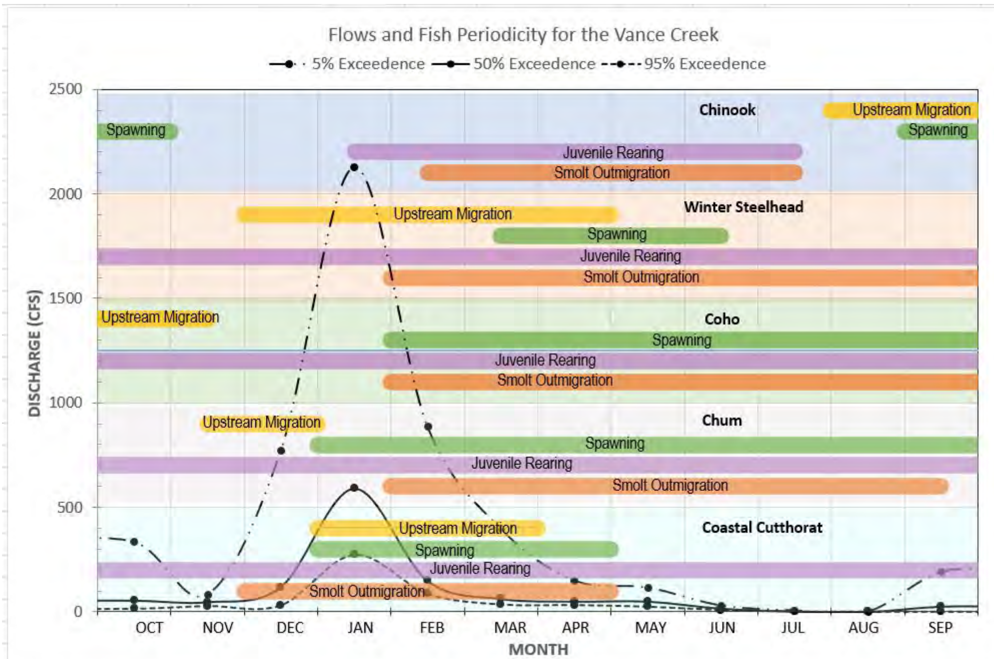

Figure 4. Flows and Fish Periodicity for the Vance Creek Study Area

Today, the fall Chinook run – including those spawning naturally – is dominated by hatchery-origin fish (SIT and WDFW 2010). Peak numbers of fall Chinook in the Skokomish River watershed now enter the river between late August and mid-September, the time of year when river flows are lowest. This return to the river when flows are low affects the ability for Chinook salmon to access upper watershed habitats. As a result, the current distribution of naturally spawning Chinook salmon in the Skokomish River watershed is less than one-third of the historic distribution. Vance Creek is a key target area of WDFW to shift the spawn timing of fall Chinook to later in the season (Downen, pers. comm.).

4 REACH CHARACTERIZATION

The Vance Creek study area was delineated into four geomorphic reaches (Figure 5) to better characterize the dominant, reach-specific relationships between physical processes, biological limiting factors, and restoration opportunities. These reach breaks represent distinct transitions in channel morphology, sediment budget, and hydrologic connectivity and consider both the historical and current extent of the floodplain, off-channel habitats, and channel migration history. The Plan identifies potential restoration actions that are intended to treat and potentially address impaired processes and target specific limiting factors identified within each reach. These breaks are similar to the three sub-divisions established in the *2011 Vance Creek Geomorphology and Modeling* report (Reclamation 2011), but are further expanded using four sub-divisions to characterize present-day morphology and identify recovery actions.

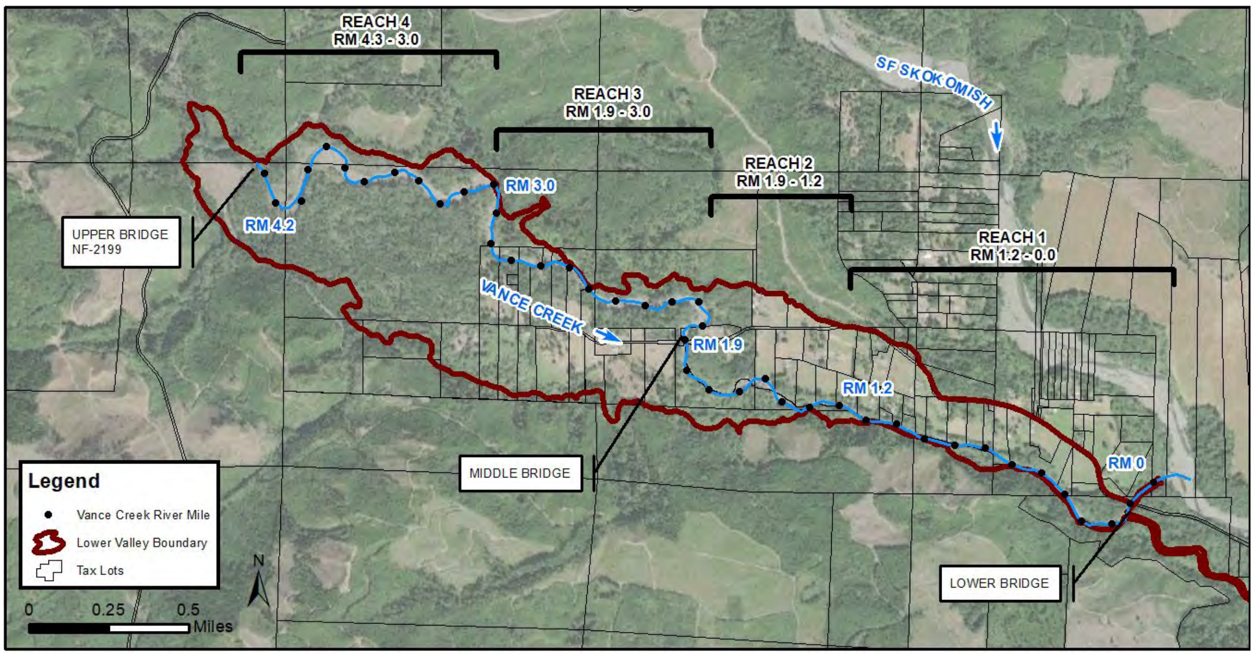

Figure 5. Vance Creek Reach Map

4.1 Reach 1

Reach 1 extends from RM 0.0 to RM 1.2 and represents the lowest reach in the watershed before the confluence of Vance Creek with the South Fork Skokomish River. This reach is characterized predominantly by a single-thread channel with small gravel bars that typically alternate with minimal sinuosity during low summer flows. Analysis of historic photographs and LiDAR indicates that this reach once had multiple flow pathways across the floodplain, one of which is currently the main channel of Vance Creek. Additional tributaries and spring flows have historically provided important flow contributions and off-channel habitat within this reach during periods of low or high flows on Vance Creek (Reclamation 2011).

Over the past century, both the quality and diversity of habitat have been significantly impaired by development in the floodplain and stream corridor, including residential development, hobby farms, and transportation-related infrastructure. Levee building, land clearing, and channel straightening practices associated with floodplain development have been observed as early as the 1938 aerial photographs. Over time, the channel has become constrained against the valley wall (Figure 6), and channel simplification is observed to advance until physical complexity was severely diminished by the latter half of the 20th century.

Figure 6. Lower Vance Creek against Bedrock along Right Bank

Figure 7. Upstream of Lower Bridge (Looking downstream)

Sediment budgeting supports the notion of ongoing sediment management challenges within the lower watershed. With a significant upstream sediment supply and low transport capacity, the rate of sediment deposition within this reach is estimated to be up to 4 feet per decade. A dominant factor toward the rate of deposition is the construction of the Skokomish Valley Road lower bridge (Figure 7). Prior to the 1950s, the historical Vance Creek channel was approximately 1-mile long in this reach and connected with the Skokomish River near the modern-day Swift Creek bridge. Following a significant avulsion event, the Vance Creek mouth has been re-routed into a historic arm of the Skokomish River, limiting sediment transport capacity by reducing the reach slope and associated channel length, which also reduces the capacity for sediment storage.

4.2 Reach 2

Reach extends from RM 1.2 upstream to RM 1.9, marked by the downstream end of the Skokomish Valley Road middle bridge. This reach is characterized by a predominantly single-thread channel with low relief gravel deposits and point bars. Floodplain development and valley constraints are set back farther away from the stream corridor, providing room for greater channel movement and development of better-quality instream habitat compared to areas farther downstream. Flow extents remain relatively narrow at the 1- and 2-year flood events as simulated in the hydraulic model. Areas of ongoing bank erosion are evident through Reach 2 (Figure 8).

Figure 8. Downstream of Middle Bridge (looking downstream at channel erosion/incision against left bank)

Reach 2 has not been subject to channel de-watering like areas farther upstream and in fact appears to be the zone of groundwater recharge, where groundwater re-emerges, providing inputs of cold water that benefits fish habitat. As such, this reach is a high opportunity area to improve fish habitat with potential immediate to near-term benefits, especially in the context of a warming climate. Where Kirkland Creek enters Vance Creek at RM 1.6, multiple remnant floodplain terraces and side channels are an indication of where the channel was located prior to the earliest photos in 1938.

Sediment budgeting discussed in Appendix B indicates that this reach has existed closer to a sediment equilibrium over the past two decades, with the volume of bed aggradation balanced by streambed erosion. The current condition is likely in part due to this reach existing farther outside the influence of the South Fork Skokomish River and Skokomish Valley Road lower bridge. The combination of position within the watershed with less direct constraints within the riparian corridor has allowed for greater habitat value and stream process to persist, with less risk to nearby landowners. This, plus factors described above, make Reach 2 among the highest areas of likely success for restoration of habitat conditions in Vance Creek.

4.3 Reach 3

Reach 3 extends from RM 1.9 upstream to RM 3.0 and represents a significant shift in river pattern and habitat types that begins just upstream of the Skokomish Valley Road middle bridge. This reach is generally meandering and alternates between a single-thread channel and island-braided planforms. Several private property parcels are located along the east side of the channel; however, hydraulic modeling indicates that floodplain development lies outside of regularly flooded areas.

The Skokomish Valley Road middle bridge at RM 1.9 is the only significant channel modification in the reach that constrains unimpeded channel movement. Over the past century, the channel meander through the bridge opening has translated downstream (east), and the active channel has continued to scour into the east streambank just upstream of the bridge (Figure 9); over 250 feet of channel migration has occurred since the 1938 aerial photograph. If the channel continues to migrate and initiate a more sinuous pattern over the long term, the bridge will be at risk for being outflanked, which could prompt a need for hard bank protection measures (such as riprap) that may worsen rather than improve aquatic habitat. Exacerbating the severity of this situation is a potential avulsion pathway within the footprint of ongoing migration. If this pathway were to activate during a larger flow event, a more imminent threat to multiple landowners and the community may develop.

Figure 9. Upstream of Middle Bridge (looking upstream at eroding left bank)

Figure 10. Upstream of Middle Bridge (looking upstream)

During lower flows, discontinuous surface flows in Reach 3 impact access to higher quality spawning and rearing habitat when the timing of these conditions overlap. Groundwater is estimated to be approximately 3 to 5 feet below the streambed and bedrock up to 30 feet, providing an opportunity to target upwelling and maintain deep-water pools through the addition of wood jams.

While many vegetated banks exist along the margins of the channel, bank exposures are also common, with eroding glacial terraces and high sediment transport capacity that directly support ongoing depositional issues observed farther downstream. Evaluation of 1938 aerial imagery suggests that this reach has experienced the greatest degree of lateral channel migration over the past century, with several locations where the historic main channel now exists as a floodplain terrace. Observations of lateral migration and channel incision are consistent with the findings of the sediment budget assessment (Appendix B), with significant volumes of net erosion occurring from within this reach from both streambank and streambed sources. Vegetated islands within this reach are generally in earlier stages of development (Figure 10), but observed to be steadily growing for the latter half of the 20th century and maintaining the margins during the 1- to 2-year events, but diminishing in size during larger flood events. No correlation has currently been made between island growth and upstream watershed recovery; however, island growth does appear greatest where wood has deposited, which supports the potential to accelerate future growth and evolution.

4.4 Reach 4

This reach extends between RM 3.0 and RM 4.2 and represents the uppermost portion of the study area. At the mouth of the upper canyon, Vance Creek enters a broad alluvial valley creating a distinct change in channel behavior, dimensions, and flow and sedimentation processes. While the upstream canyon reach is distinctly confined with a streambed slope exceeding 2.5 percent, Vance Creek enters Reach 4 and immediately becomes unconfined with a slope of less than 1 percent. Land use surrounding the reach is exclusively commercial logging, with the exception of the NF-2341 bridge, which marks the farthest upstream extent of the study area.

Channel pattern in Reach 4 is generally meandering and alternates between single-thread and island-braided patterns, with several vegetated islands at the upstream extent that appear to have developed due to localized stream dynamics and the hydraulic influence of large woody debris (Figure 11). The island braided hydraulic pattern is most evident during conditions where upstream salmonid migration and rearing would be expected. As flows exceed the 1- to 2-year annual event, the inundation becomes increasingly uniform across the entire channel. During larger and less frequent events, smaller relic side channels are observed to become active, indicating a potential shift toward more complex conditions if these flow pathways were to become active at more frequent and fish-bearing flow conditions. During summer low-flow conditions, discontinuous surface flow impacts access to higher quality spawning and rearing habitat when the timing of these conditions overlap. The geophysical survey estimates that groundwater may be up to 30 feet below the streambed in this reach, making reconnection to a perennial water source in this reach highly unlikely.

Figure 11. In-stream Wood in Reach 4

Figure 12. Streambed Incision and Broad Gravel Terraces in Reach 4

Sediment budgeting (Appendix B) concluded that a significant portion of the sediment load transported and supplied to the lower reaches originates from within this reach in the form of both streambed incision and streambank erosion. Incision is estimated to be relatively rapid over the past several decades, at rates of between 0.5 and 1.5 feet per decade from the 1980s to present.

5 LINKING PHYSICAL PROCESSES TO HABITAT LIMITING FACTORS

It is generally accepted that low-flow fish stranding, limited access to habitats resulting from dry bed conditions, lack of complex channel structure, and disconnection of off-channel habitats are the primary factors that have limited the abundance and productivity of Chinook salmon and steelhead in the Vance Creek watershed (SIT and WDFW 2010). Dewatered sections of stream act as partial fish passage barriers where discontinuous flow limits the access to upstream habitat (Reclamation 2011). The overall approach to succeeding in process-based restoration actions is to provide the conditions and time necessary to allow for natural processes to occur and create/sustain natural habitats over the long term. Through the heightened understanding of the influence of sediment gained through the work described more fully in Appendix B, we can begin to characterize the relationship that the sediment regime has in shaping channel planform, structure, hydrology, and habitat conditions. Furthermore, potential actions can be identified and advanced to manage the sediment regime to the benefit of both fish and human communities in the Vance Creek watershed.

The geomorphic assessment identified sediment production within the upper study area (Reaches 3 and 4) as the dominant contribution to sediment movement throughout the period of study. This sediment flux results in a net export of material from Reaches 3 and 4, with deposition of much of that material in the lower reaches of Vance Creek, where streambed raising is a concern for long-term flood risk and for maintenance of quality salmon habitat. The geomorphic assessment also found little evidence to suggest that sediment sources are primarily associated with deforestation, but rather attributed largely to a prominent fluvial terrace that underlies the entire watershed, the formation of which dates back approximately 10,000 years. Deep bedrock contact beneath the thick alluvial terrace creates conditions conducive to a loss of surface water to subsurface aquifers. This condition is further exacerbated by extended periods of low flow, a situation that is likely to be made worse during periods of drought and expected hydrologic impacts of climate change. Therefore, left unabated, the expected future conditions of Vance Creek are likely to be similar to that of today, if not worsened by future reductions in streamflow as a result of climate impacts.

To address the impaired geomorphic, hydrologic, and habitat conditions described in this report, as well as to address potential future flood impacts on valley residents, initial concepts have been developed to:

(1) Manage systemic sediment incision/erosion in the upper reaches.

(2) Attempt to reconnect sections in the middle reaches to shallow groundwater and provide perennial fish access and habitat to greater portions of Vance Creek.

(3) Provide more quality habitat for fish in the reaches they are likely to utilize the most, where cool groundwater re-enters the stream and perennial flow conditions currently exist.

(4) Reconnect or improve hydraulic connection to off channel areas in reaches supporting perennial flow.

(5) Use a high density of log jams in the lower reaches to constrict the channel and increase sediment transport capacity to move sediment through without aggrading the channel.

Treatment concepts are provided on a reach-by-reach basis and are described in Section 6. Treatment types are recommended to address the overarching physical impairments identified within Vance Creek, which include:

- Channel Form and Structure
- Off-Channel Habitat and Refugia
- Groundwater Separation and Channel De-watering
- Fish Access and Upstream Migration

5.1 Channel Form and Structure

Channel form describes the channel shape, pattern, and movements over time, which contribute greatly to the overall complexity of a stream, and is controlled by a combination of the underlying geology, the sediment regime, hydrologic regime, and the influence of large wood. Complex channel forms generally support greater ecological diversity (Beechie et al. 2006) and are representative of greater channel stability and balanced sediment regimes (Collins and Montgomery 2012). An anabranching and island-braided planform is of particular importance in defining the potential restoration trajectory in the upper reaches of Vance Creek, where a more self-sustaining braided and anabranching planform may aid in stabilizing channel position and reduce sediment transport to the lower reaches. Channel form therefore provides a metric to not only assess potential salmonid productivity within a reach, but also informs the trajectory and potential of actions to enhance structure and complexity, and provide long-term resiliency (Polvi and Wohl 2013). Channel form also has intrinsic linkages to hydraulic force distribution, flow pathways, and therefore flood potential.

5.2 Off-Channel Habitat and Refugia

The availability of off-channel habitat describes the lateral connectivity of the main channel of Vance Creek, areas offering low-velocity rearing habitat for juvenile salmonids. Disconnected off-channel habitat is generally characteristic of the lower study area, where channel modification in the riparian corridor is greatest. Aggradation and reduced lateral connectivity (i.e., from levees, revetments, dredging) have resulted in channel simplification and a loss of off-channel (high-flow) habitat and instream (low-flow) refugia. Dredging activity that has been performed in response to upstream sediment production further reduces the frequency of floodplain inundation for a given hydrologic regime, although that outcome is temporal. This loss of floodplain storage reduces peak flow attenuation, which in turn reduces the physical complexity within the main channel by reducing the residence time of wood, and thereby further driving channel incision and floodplain disconnection.

5.3 Groundwater Separation and Stream Dewatering

The geophysical survey revealed groundwater separation from the streambed to be as much as 20 feet in the upper reaches of the study area. Where groundwater tables are inferred to rise and fall seasonally, this upper zone of separation and streamflow loss is expected to persist throughout the year. During the winter, however, surface flows are sufficiently large that the losses cannot fully dewater Vance Creek. Taken together, the degree of groundwater separation and the persistence of the creek drying for nearly a century suggest that the tendency for creek dewatering is in large part due to the relationship between bedrock depth and aquifer thickness, likely resulting from glacial history and subsequent valley development. Approximately 20 cfs of streamflow is consistently infiltrated and lost to groundwater during a range of seasons. Even during small summer rainfall events, there was no corresponding increase in discharge at the USGS gage. This observation indicates that the rate of dewatering and shallow groundwater storage exceeded summer streamflow conditions, and dewatering is controlled primarily by the porosity of the streambed into the underlying unconfined alluvial aquifer. This seasonally persisting condition was only disrupted with the first fall rain, when the combined flow of Vance and Fir creeks exceeded 120 cfs.

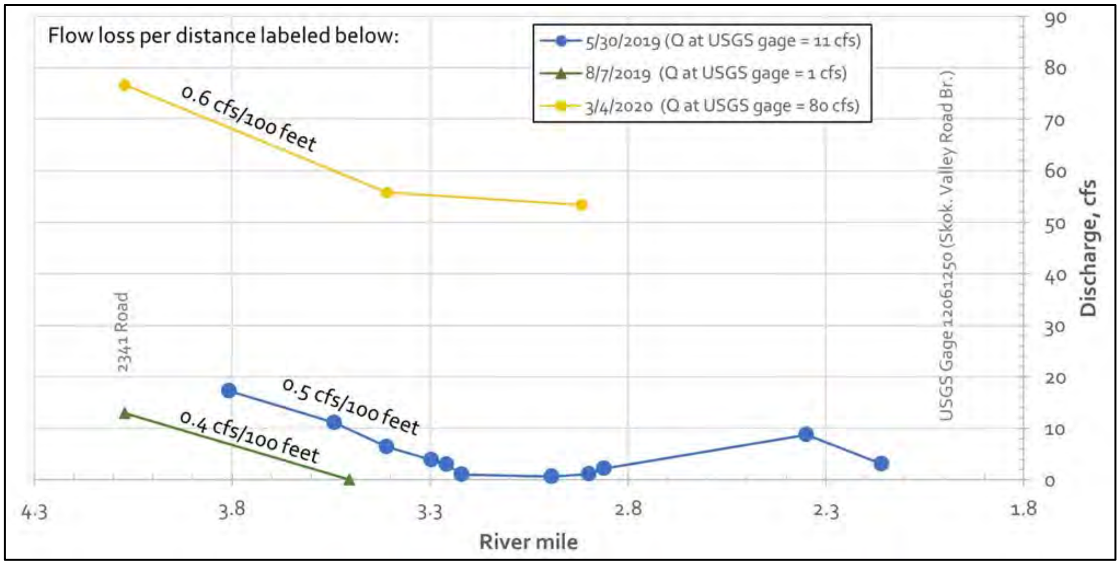

Figure 13. Measured Streamflow Loss Between RM 2.0 and RM 4.0

While this dewatering affects habitat accessibility and productivity in the upper reaches of Vance Creek, the resulting groundwater upwelling farther down-valley has been observed to reduce temperatures that may benefit aquatic ecology in downstream reaches. Groundwater separation generally leads to reduced hyporheic exchange where periodic downwelling of surface water supplies dissolved oxygen, nutrients, and organic matter to the ecological communities in the hyporheic zone (Boulton et al. 1998), and upwelling water may influence instream biota by enhancing the diversity of surface water habitat (Dent et al. 2000). The incubation of salmonid embryos has been found to depend on upwelling or downwelling of groundwater, a critical component of a functional stream habitat (Baxter and Hauer 2000).

5.4 Fish Access and Upstream Migration

The accessibility of habitat within the upper reaches of the study area remains a primary limiting factor due to localized channel dewatering, and lack of adequate flow depth during the adult salmonid upstream migration period. The dry channel conditions that occur in late summer and early fall affect the salmonid species differently because of varying life-stages. For fall Chinook salmon, the dry channel period coincides with adults returning to the river to migrate to upstream spawning areas. As a result, fall Chinook salmon adults are largely blocked from spawning in habitats upstream of the dry reach. Summer steelhead may be similarly affected.

The other species affected are coho salmon, winter steelhead, and coastal cutthroat trout. For these species, the dry channel periods occur when fish are rearing. Fish unable to move out of the reach will be stranded in isolated habitats. The only juvenile fish to survive are those that find deep pools that remain wetted. The dry reach has a limited number of large pools that are connected to cool groundwater, which makes existing pools in the upper study area vulnerable to drying out or overheating unless surface flows return again.

6 RESTORATION STRATEGY AND PRIORITIES

The restoration strategy is targeted to optimize near-term opportunities for improved habitat conditions balanced with the restoration of watershed-scale processes to support a more balanced, functioning, and self-sustaining river corridor over time. Restoration priorities (Table 3) are identified at the reach scale in this Plan to focus on multi-benefit actions that can be readily implemented to integrate process-based considerations with the creation of key habitat features. By identifying priorities at the reach scale, the recommended strategy supports multiple spatial scales that address immediate needs of salmonids, as well as the long-term benefits associated with balanced geomorphic processes in forming and sustaining natural habitats.

The reach-scale priorities shown in Table 3 directly address the physical impairments identified in Section 5 above. Following Table 3, three additional sections provide greater detail on (1) the linkages between the reach scale priorities and fish habitat improvement; (2) descriptions of various wood placement designs to support meeting reach scale priorities; and (3) a discussion of priorities and opportunities by reach.

Table 3. Reach-Scale Priorities within the Vance Creek Study Area

	Reach 1 (RM 0.0–1.2)	Reach 2 (RM 1.2–1.9)	Reach 3 (RM 1.9–3.0)	Reach 4 (RM 3.0–4.2)
Promote Planform Evolution			✓	✓
Stabilize Sediment Sources			✓	✓
Enhance Instream Habitat Complexity	✓	✓		
Increase Access to Off-Channel Habitat and Refugia	✓	✓	✓	
Mitigate Flood Extents and Duration	✓	✓		
Improve Groundwater Exchange			✓	
Improve Baseflow (Low-Flow Fish Passage)			✓	✓

6.1 Linkages Between Reach-Scale Priorities and Fish Habitat

- **Promote Planform Evolution**
  - Provides multiple beneficial habitat types for all salmonid life-stages.
  - Provides diverse habitats that benefit salmonids across range of flows experienced in the creek.
  - Provides immediate and long-term habitat creation and sustainability, including through large woody debris recruitment from stable planforms.
  - Benefits egg incubation survival by providing more stable habitats.
- S**tabilize Sediment Sources**
  - Reduces excessive fines that can negatively affect egg incubation survival.

  - Reduces burial of redds with incubating eggs.
- **Enhance Instream Habitat Complexity**
  - Provides multiple beneficial habitat types for all salmonid life-stages.
  - Provides diverse habitats that benefit salmonids across range of flows experienced in the creek.
  - Provides increased variability in depth, velocity, and substrate conditions throughout the reach, which provides varied preferred conditions for the various species and life-stages who use the habitats.
  - Increases availability of cover habitat preferred by juvenile and adult life-stages.
  - Improves connectivity between aquatic and riparian habitats, with benefits through shading and cover, as well as inputs of terrestrial prey (insects), organic matter (branches and leaves) to fuel aquatic invertebrate prey production, and large wood for habitat structure.
- **Increase Access to Off-channel Habitat and Refugia**
  - Off-channel habitats provide different habitat conditions and provide the same types of benefits described for enhanced instream habitat complexity.
  - Provides beneficial habitats for spawning and egg incubation through preferred substrate sizes and stable incubation conditions.
  - Provides beneficial habitats for juvenile salmonids, especially those species and life-stages preferring slower velocities and shallower depths than the mainstem (such as coho).
  - Access to deep pools, specifically those intercepting cool groundwater, is a vital refuge need in portions of the creek vulnerable to going dry in the summer. Rearing juvenile salmonids can survive in pools that remain wetted, cool, and with sufficient cover (through depth and/or structure) to avoid predators. Deep, cool pools can also provide refuge habitat for adult salmonids for holding during upstream migration, especially those species and runs that migrate upstream during warm summer conditions.
  - Provides lower energy habitats during high flow conditions, which enables juvenile salmonids to remain in the creek instead of getting carried downstream.
- **Mitigate Flood Extents and Duration**
  - Decreases risk of stranding through fish displacement out of channel and into areas with less direct connections for fish to return to the creek channel as flows recede.
  - Reduces effects of flooding on redd scour and juvenile mortality.
- **Improve Groundwater Exchange**
  - Provides cooler groundwater, which reduces surface water temperatures.
  - Promotes subsurface water flow, which is beneficial for egg incubation and can be an attractant for adult salmon choosing spawning locations.
- **Improve Baseflow**
  - Addresses most critical limiting factor in the creek by increasing the amount of aquatic habitat available and connectivity of instream habitats.

- Increases fish access to habitats by increasing water depths to allow fish to remain upright as they move.
- Improved thermoregulation of stream during warm summer months.
- Increases aquatic prey production by increasing the wetted area.
- Increases habitat availability by increasing the wetted area.

6.2 Wood and Engineered Log Jams as a Means to Meet Restoration Objectives

Various types of wood structures are effective in meeting the restoration objectives in Vance Creek. At this concept level, wood structures are divided into broad categories, each type designed to serve a particular purpose and address the physical impairments identified in the assessment. The main categories of wood structures presented in the concept plans (Appendix A) are described below.

6.2.1 Low-Profile Engineered Log Jams (ELJs)

Low-profile ELJs in lower Vance Creek are recommended to improve instream complexity in the vicinity of public and private infrastructure, with the intent of minimizing the potential effects of wood on channel migration or increasing the base flood elevation. Conceptually, these structures are not intended to significantly alter channel process or form, but will promote local hydraulic complexity and low-water refugia for salmonid species. Depending on their location, multiple rootwads or a greater volume of slash and woody debris may be placed to provide increased hydraulic interactions, cover from predation, organic inputs, and thermal diversity. When multiple structures are sequenced in close proximity, they function in concert to offset impacts of long-term sediment aggradation by promoting successive scour and channel deepening.

6.2.2 Meander Bend and Deflector ELJs

Meander bend and deflector ELJs are identified along the outside of meander bends and target areas of streambank erosion or areas of natural wood recruitment where pool formation is most likely to occur. Where these areas coincide with a shallow groundwater table, meander bend ELJs may be used to force localized scour conditions that support the area, depth, and frequency of pools. Additionally, these structures may be combined with bank stabilization designs that support moving erosion and scour potential away from the outside channel margins and reduce sediment inputs associated with the streambank. Structures would be designed to optimize interstitial spaces to offer the greatest potential for use by juvenile salmonids.

6.2.3 Bar Stabilization Complexes

Bar stabilization complexes promote planform evolution, stabilize sediment sources, and improve instream habitat. Conceptually, these complexes consist of multiple key pieces (60+ feet long and > 24 inches diameter at breast height) in an architecture that mimics natural wood formations observed on gravel bars. Complexes may be designed to be transient during high-flow events, not requiring mechanical anchoring or pile driving operations for installation. Alternatively, a force balance would be supported by hydraulic modeling used to evaluate wood layering designs that resist buoyant and drag forces during more frequent and less extreme flow events.

6.2.4 Augment and Stabilize Key Logs

Key log augmentation and stabilization describes opportunities to place wood with the intent of adding support and anchoring to existing wood recruitment in Reach 4. Similar to the design and function of bar stabilization complexes, key log stabilization would enhance natural recruitment processes and support sediment stabilization, planform evolution, and instream habitat objectives.

6.2.5 Flood Fencing

Flood fencing refers to the installation of vertical timber piles into the streambed, with the intent of emulating riparian zone roughness and encouraging further wood recruitment. This potential restoration action is identified between RM 1.9 and 2.5, where equipment access becomes more feasible. In contrast to installing ELJ structures, flood fencing would support more transient conditions but persist through multiple cycles of recruitment, reinforcing natural stream processes. Flood fencing would support multiple project objectives by promoting planform evolution, stabilizing sediment, and improving instream habitat and fish cover. Within Reach 3, flood fencing may be used to support the recruitment of additional wood, supporting multiple priorities identified upstream of the Skokomish Valley Road middle bridge.

6.3 Reach-by-Reach Priorities

The specific types of reach-scale priorities described below result from a greater understanding of the reach-by-reach variations in the geomorphic, hydrologic, and biological conditions along Vance Creek. For this planning-level effort, there is a benefit to classifying each reach based on a suite of high-level priorities. The outcomes of addressing these priorities will support watershed physical processes and address the biological needs of each reach to meet recovery goals. Priorities are sorted into seven main categories with similar treatment types (as listed in Table 3). As projects move forward from a conceptual basis, more in-depth engineering and analysis will be applied to site specific issues.

6.3.1 Reach 1 (RM 0.0 to RM 1.2)

From a practical standpoint, the position of this reach poses several challenges. Improving the hydraulic efficiency through the Skokomish Valley Road lower bridge just upstream of the confluence may reduce the rate of aggradation; however, upstream sediment supply will continue to reduce channel capacity and increase flooding throughout the reach and limit the overall effectiveness of treatments in the absence of addressing larger watershed-scale issues. Reach 1 also requires collaboration with and agreement form the greatest number of individual landowners; projects may also be pursued with multiple benefits, including flood mitigation or property protection for valley residents.

Enhancing instream habitat complexity and increasing access to off channel refugia are recommended as the priorities for this reach. The high degree of channel and floodplain modification limits the potential for site-specific actions to support long-term resiliency. However, recent meander development at the upstream end of this reach suggests that the channel is attempting to naturally adjust its geometry to a more sinuous planform that existed prior to channel manipulation. Using large wood as a stand-alone action to promote localized scour is unlikely to support sustainable pool development due to significant aggradation from upstream sediment loads, but may support near-term objectives for physical complexity in combination with opportunities to promote a sinuous planform.

6.3.2 Reach 2 (RM 1.2 to RM 1.9)

As in Reach 1, enhancing instream habitat complexity and increasing access to off-channel refugia are recommended as the priorities for this reach. Recent meander development in this reach suggests that the channel is attempting to adjust its geometry to a more sinuous planform that existed prior to manipulation. While it may not be possible to fully reestablish all of the abandoned channels due to current floodplain development, there are multiple opportunities to explore within this reach that support this objective.

One specific restoration opportunity is the confluence of Kirkland Creek (Figure 14), where historic side channels and floodplain terraces are observed near both streambanks. Kirkland Creek may be targeted as a strong opportunity to effectively encourage a single-thread meander to evolve toward a multi-thread channel. Farther upstream and downstream from the Kirkland Creek confluence, multiple side channels and historic floodplain terraces were observed using relative elevation mapping. These areas become inundated during between the 1- and 2-year events. Increasing the frequency and duration of utilization may be targeted to enhance the complexity of available habitat during periods of fish presence.

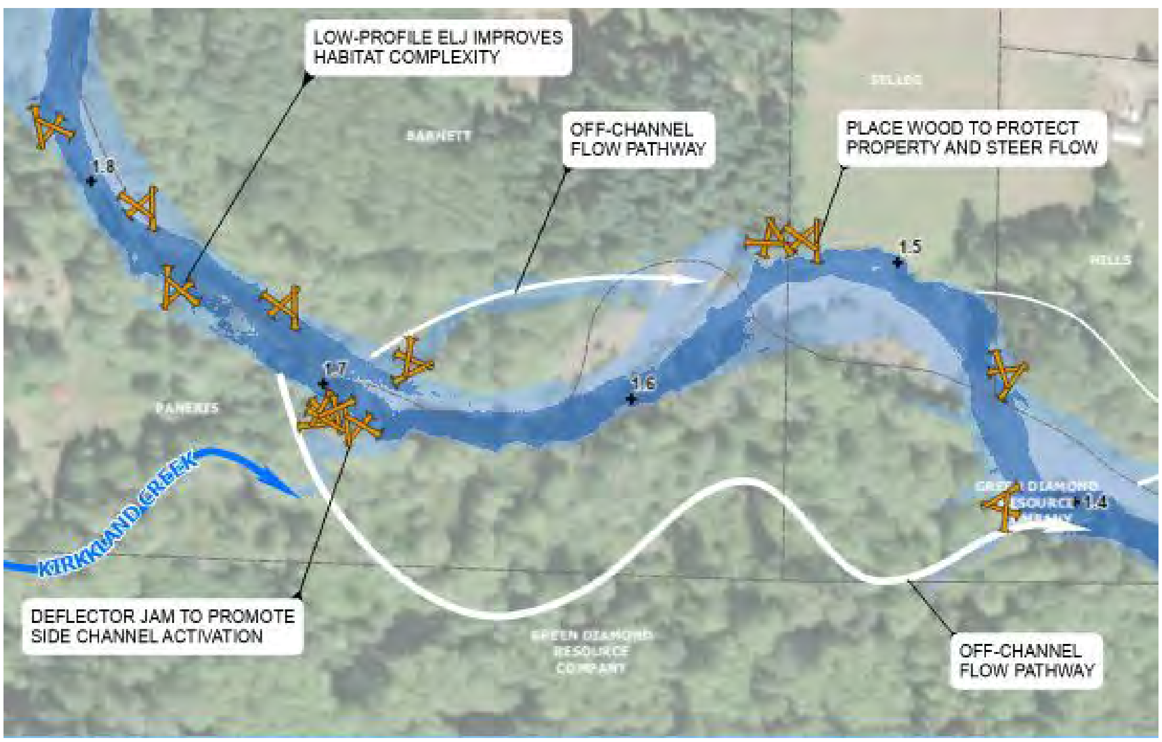

Figure 14. Reconnect Off-Channel Habitat at RM 1.7 Kirkland Creek

6.3.3 Reach 3 (RM 1.9 to RM 3.0)

From the standpoint of creating habitat, actions that help sustain baseflow and improve conditions for upstream fish passage will provide immediate access to high-quality upstream habitat. Within this reach, the groundwater table varies between 5 feet below ground surface and less. Maximizing upstream fish passage accessibility will provide immediate improvements to the overall quantity and diversity of available habitat in the watershed. The shallow groundwater table provides multiple opportunities to enhance baseflow conditions and hyporheic exchange by maintaining a low-flow thalweg and prolonging the presence and frequency of pools, which directly supports the reduction identified in the habitat limiting factors analysis.

Over the long term, the priority within this reach is promoting evolution toward a more stable channel form, which reduces the availability of instream sediment supply through riparian islands and stable bar development. Sediment budgeting supports this objective, indicating that this reach supplies a significant volume of sediment due to historic downcutting and erosion of glacial terraces. Several incipient vegetated islands between RM 2.2 and RM 3.1 have formed around woody debris and have grown in area since 1965. Natural evolution from past channel simplification suggests that recovery from anthropogenic disturbances has begun to some extent, supporting the objective of promoting a more complex planform.

Stabilizing Vance Creek at the RM 1.9 Skokomish Valley Road middle bridge (Figure 15) is identified as an opportunity to reduce risk for life and infrastructure as well as improve channel conditions for habitat productivity. Over the past few decades, the meander bend immediately upstream of the bridge has translated east toward Skokomish Valley Road and currently poses an increased risk to adjacent property and the bridge. Stabilization and reinforcement of the streambank at this meander bend are recommended to protect against further lateral channel migration. One potential alternative is using large wood to manipulate channel planform near RM 2.2, promoting riparian island development at this

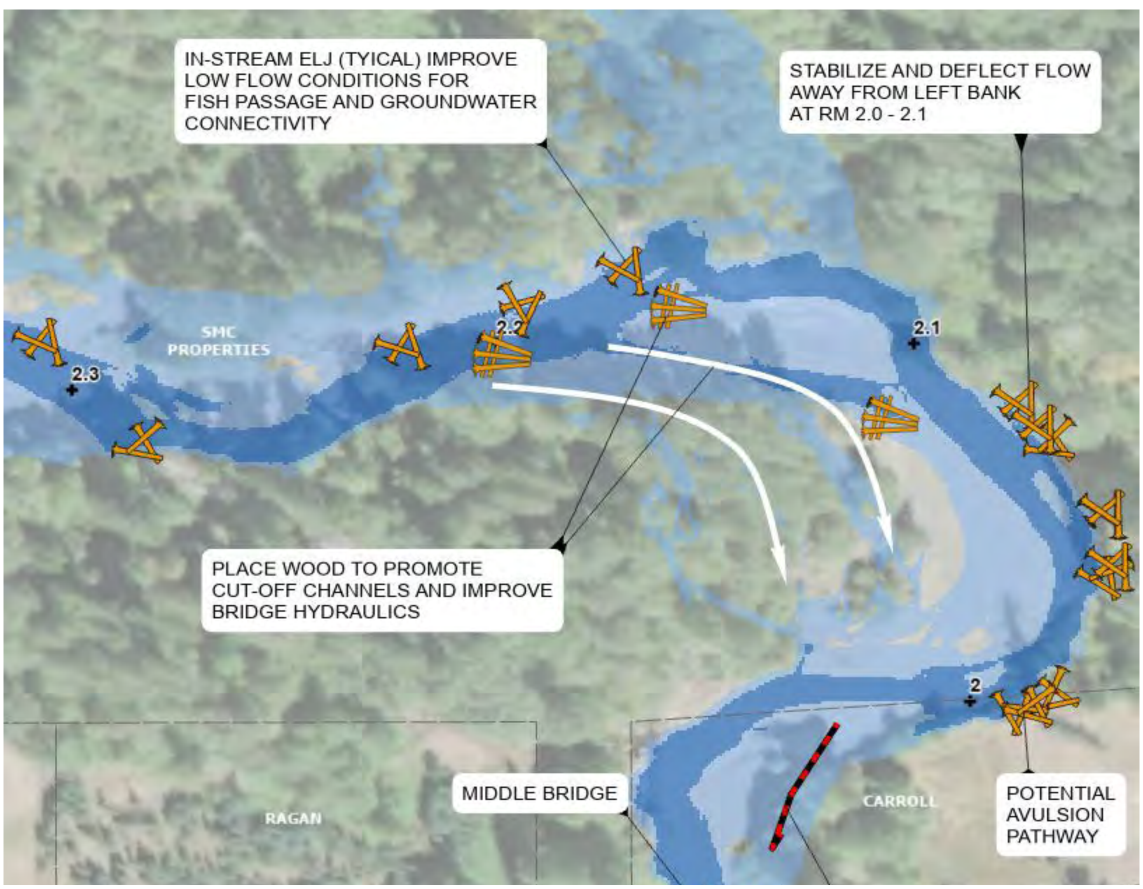

Figure 15. Stabilizing Vance Creek at RM 1.9 Skokomish Valley Road Middle Bridge

location. Re-aligning the channel upstream of the bridge through the use of large wood can protect from further bank erosion, create more effective hydraulic conveyance under the bridge, and create more suitable fish habitat. The wood placement can include rootwads and structural complexity to provide interstitial spaces that give salmon access to cover. The wood placement is much preferred to the alternative of riprap placement to protect the road.

6.3.4 Reach 4 (RM 3.0 to RM 4.2)

As in Reach 3, promoting planform evolution and stabilizing sediment sources are recommended as the priority within this reach, with the goal of improving channel stability and reducing the sediment transport capacity across point bars (Figure 16). Sediment budgeting supports these objectives, revealing that sediment flux within the lower watershed is primarily attributed to the long-term trend of in-bed degradation and erosion of upstream glacial terraces. Reducing sediment transport capacity in the upper study area will therefore have a direct impact on the resiliency and recovery trajectory for the lower watershed, within which channel simplification and floodplain development limit restoration opportunities.

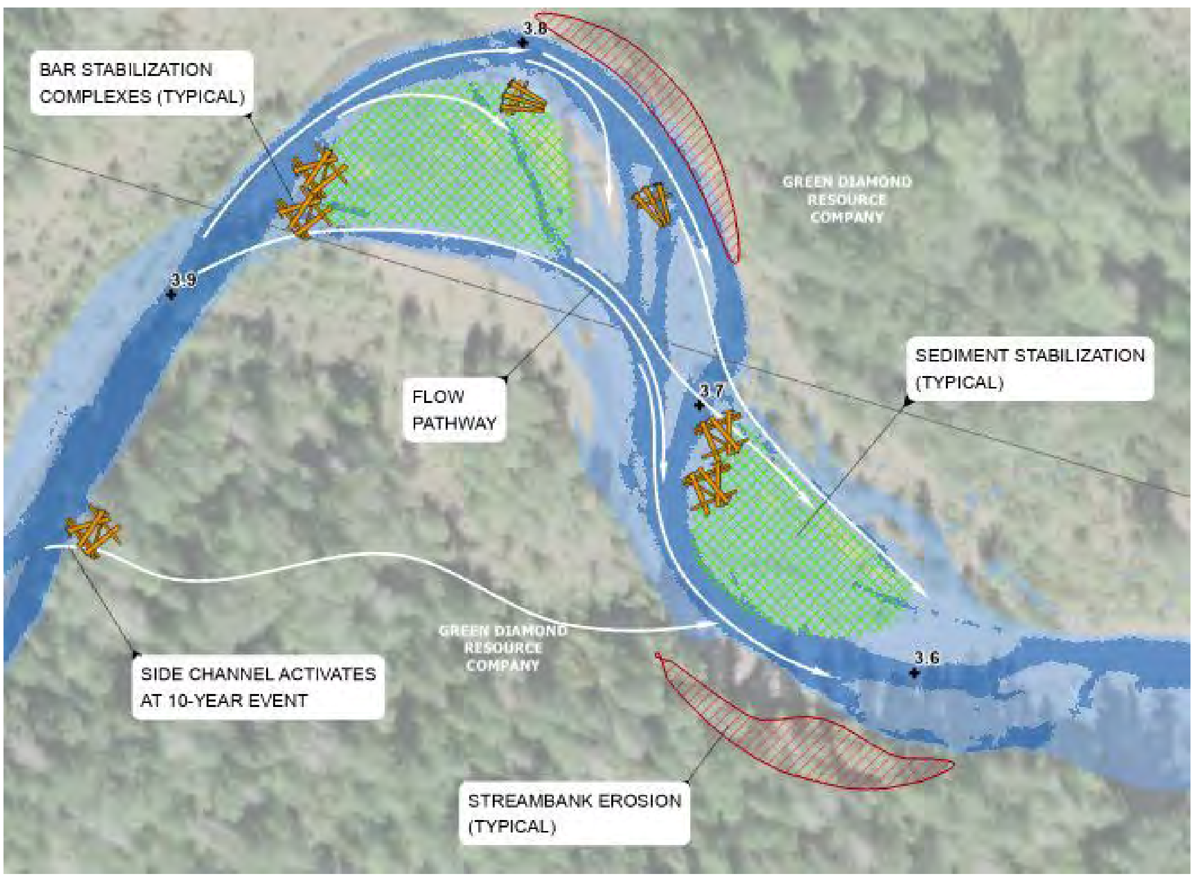

Figure 16. Using ELJs to Stabilize Vance Creek Planform and Sediment Sources at RM 3.8

Supporting the objective to promote planform evolution, a large riparian island has formed at the confluence of Fir Creek and is beginning to exhibit multiple threads (anastomosing planform). Island development was first observed within the 1995 aerial imagery, and substantial growth is observed within 2009 imagery. Promoting further planform evolution may be accomplishing by stabilizing existing key pieces (large wood) that have been naturally deposited around the vicinity of the island. Stabilizing and augmenting existing wood provides a low-tech action that can be implemented over a larger area without more labor-intensive construction techniques. Creating suitable habitat conditions at the confluence of Fir Creek further reinforces the potential ecological value for this area.

Due to the scale of groundwater separation and current seepage rates, targeting fish passage accessibility through pool development is not a recommended objective within expectations for a reach-scale response. Groundwater separation within the upper study area varies between 10 and 20 feet. Using large ELJs to reinforce pool development may improve conditions, but a trajectory toward full hydrologic recovery is likely not a realistic expectation. Based on the groundwater separation data, the downstream end of Reach 4 may be able to support pools that intercept groundwater and therefore maintain suitable refuge habitat for juvenile salmonids when surface water flows dry out. Otherwise, pools in the reach are highly unlikely to stay wetted throughout the later summer due to groundwater levels being so far below the creek bed.

7 HYDRAULIC PERFORMANCE OF RESTORATION CONCEPTS

Hydraulic modeling was completed for a subset of the restoration concepts to test the validity of design approaches at meeting key design assumptions and performance expectations. The existing conditions HEC-RAS 2D model was modified to simulate the presence of log jam features depicted on Sheets 2, 4, and 7 of Appendix A. Specific restoration features were evaluated to determine the likelihood of success and to identify opportunities to improve designs in the next phase of work. Below is a brief summary of the hydraulic performance assessment.

7.1 Bar Stabilization Complexes

Reach 4 is identified for the placement of large, bar stabilization log jam features. The design objective of these complexes is to stabilize gravel deposits and promote the evolution and maturation of riparian forests on these gravel deposits, thereby creating stable multi-branch channel forms that manage the transport of sediment from the upper basin over time and also create high-flow refuge for aquatic species. The hydraulic effect that creates this response is a large reduction in velocities and stream power, which leads to sediment deposition. The hydraulic modeling output shown on Sheet 2A depicts the reduction in shear stress (which is a measure of force in lbs./square foot) associated with a simulation of the structures shown on Sheet 2. The results show large reductions in shear associated with the complexes, giving high confidence in the ability of these structures to meet project objectives. The size, dimensions, and orientation of these structures need further refinement, but initial modeling suggests a high likelihood of success.

7.2 Deflector and Meander Jams

In Reach 3, a series of log jams are recommended to constrict the channel and force pool formation and scour. Figure 4A shows the hydraulic modeling results for shear stress changes associated with the jams. The jams force concentrated flow at key locations, thereby increasing stream power in areas identified for pool development. Scour analysis was completed to test the hypothesis that these structures can force bed scour to intersect the shallow groundwater table beneath the surface. Scour calculations demonstrate that these features do indeed create enough force to form and sustain pools adjacent to log jams. These pools should provide an immediate lift to fish habitat in reaches with shallow groundwater by intersecting cool hyporheic flow resources and also providing pools at a spacing and frequency that can support over-summering fish.

7.3 Low-Profile Wood Structures

In Reach 1, a series of low-elevation wood structures were evaluated for potential changes in flood response. Sheet 7A shows the mild, yet clear, potential flood impacts associated with the placement of wood in this reach. Minor elevation increases are seen throughout the reach as a result of wood jam placement. This impact may potentially be countered by excavation of the channel bed near log jams or by incorporating some of the off-channel reconnection opportunities identified upstream or downstream of these areas. This analysis should be a focus of future design and modeling efforts.

8 NEXT STEPS

MCD will lead stakeholder outreach efforts to seek input on the recommendations made in this report. Stakeholders will include valley residents, Mason County, fisheries co-managers (WDFW and Skokomish Indian Tribe), and the Skokomish Watershed Action Team (SWAT), among others. Projects may be prioritized according to need and funding opportunities, and then pursued by project sponsors. We recommend a continuation of hydrologic data collection as feasible and incorporation of both physical and biological monitoring metrics into any projects to track channel and fisheries response to restoration activities.

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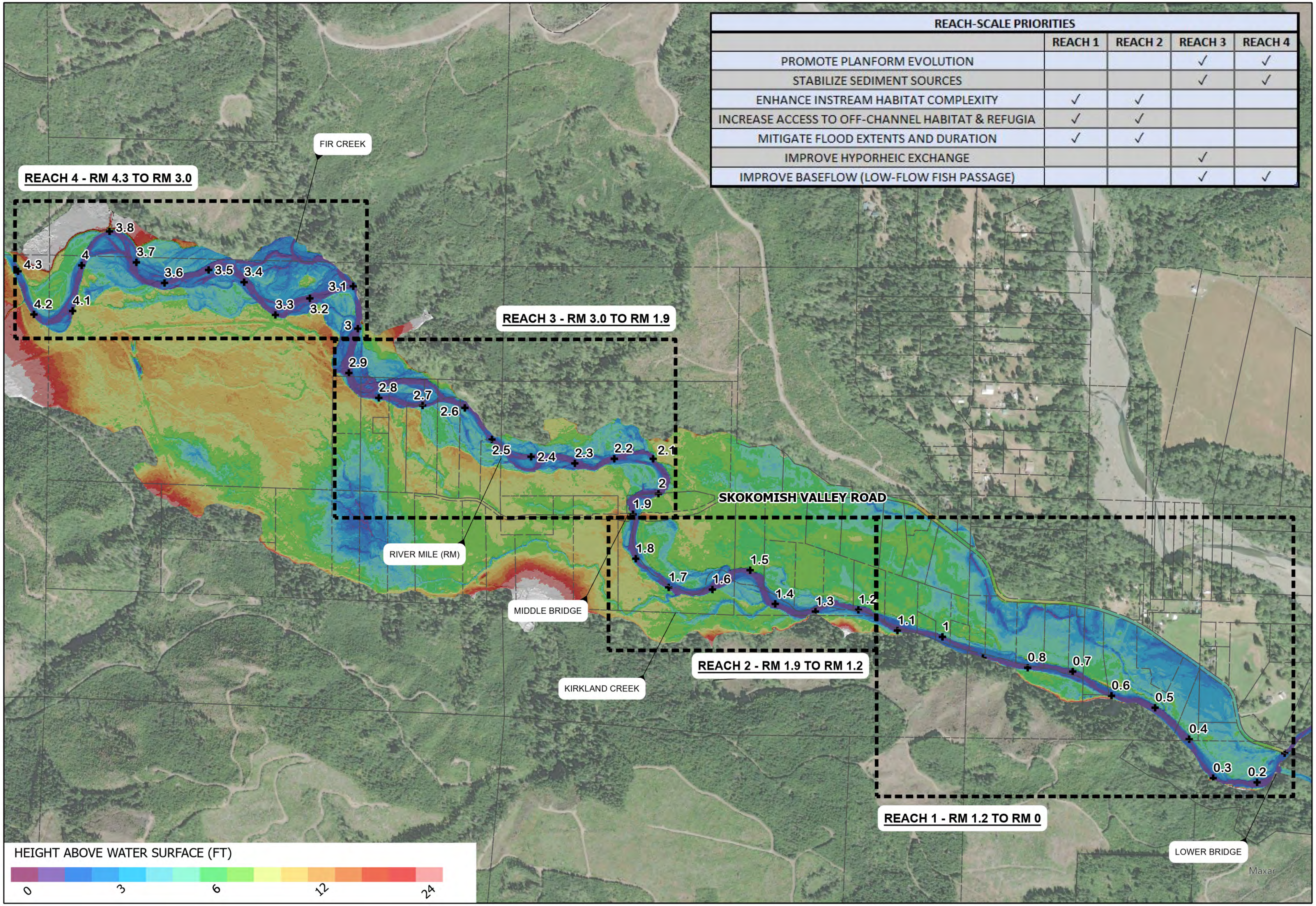
APPENDIX A. CONCEPTUAL RESTORATION MAPS

REACH-SCALE PRIORITIES

	REACH 1	REACH 2	REACH 3	REACH 4
PROMOTE PLANFORM EVOLUTION			✓	✓
STABILIZE SEDIMENT SOURCES			✓	✓
ENHANCE INSTREAM HABITAT COMPLEXITY	✓	✓		
INCREASE ACCESS TO OFF-CHANNEL HABITAT & REFUGIA	✓	✓		
MITIGATE FLOOD EXTENTS AND DURATION	✓	✓		
IMPROVE HYPORHEIC EXCHANGE			✓	
IMPROVE BASEFLOW (LOW-FLOW FISH PASSAGE)			✓	✓



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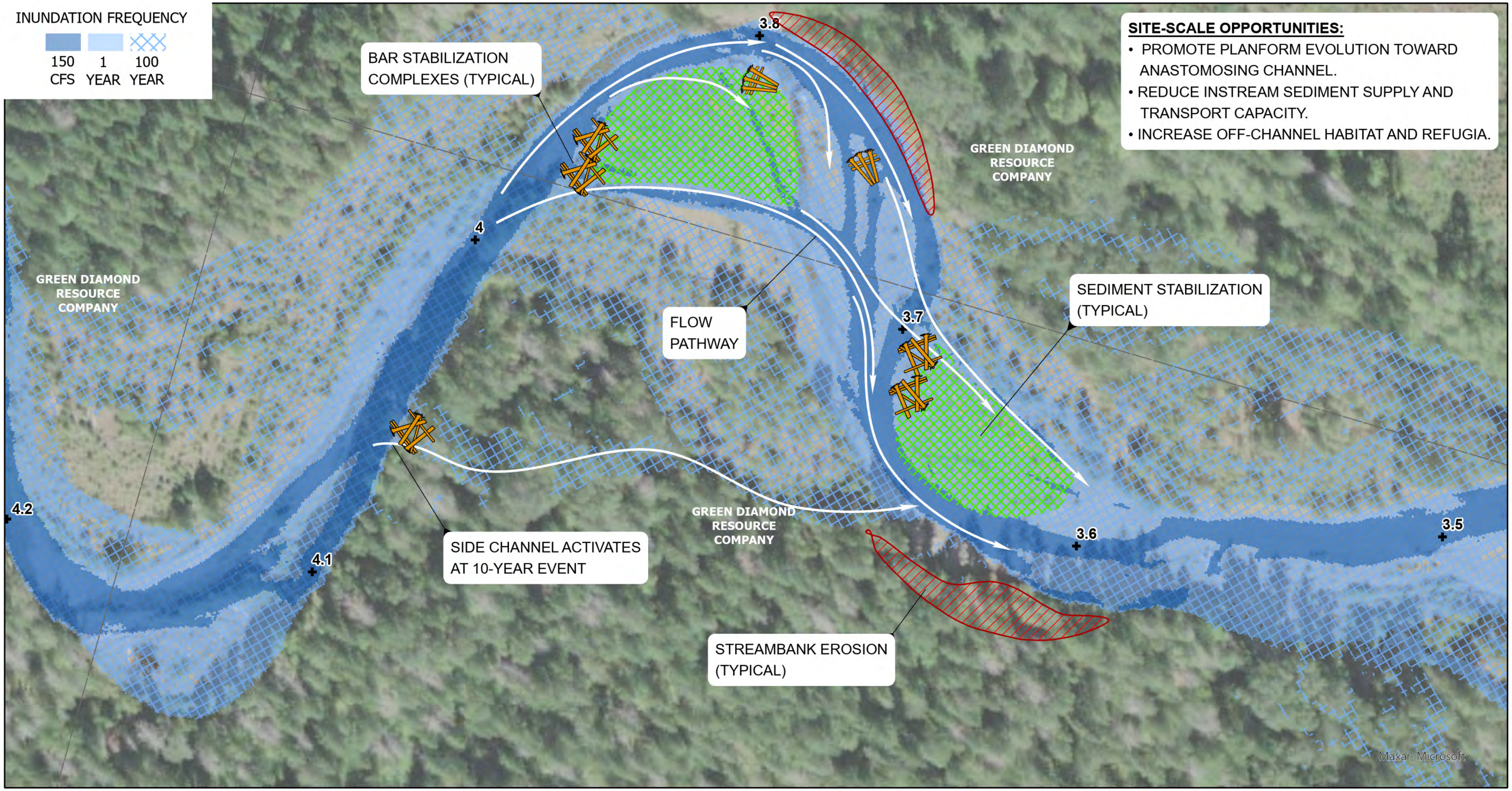
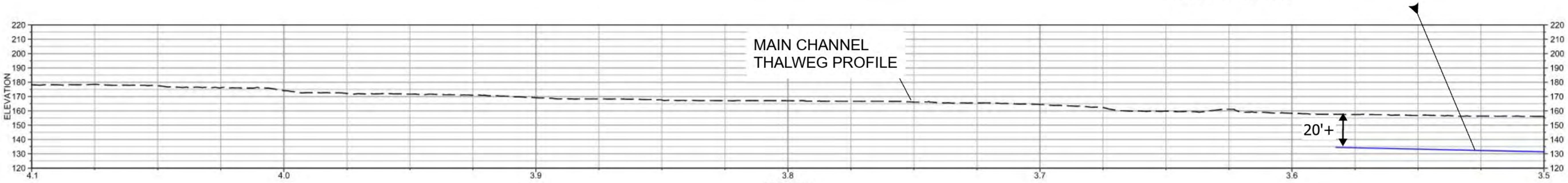
VANCE CREEK WATERSHED ASSESMENT OVERVIEW MAP



REACH 4 (RM 4.3 - RM 3.5)

LOW FEASIBILITY TO INCREASE BASEFLOW & GROUNDWATER CONNECTIVITY.



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VANCE CREEK WATERSHED ASSESMENT
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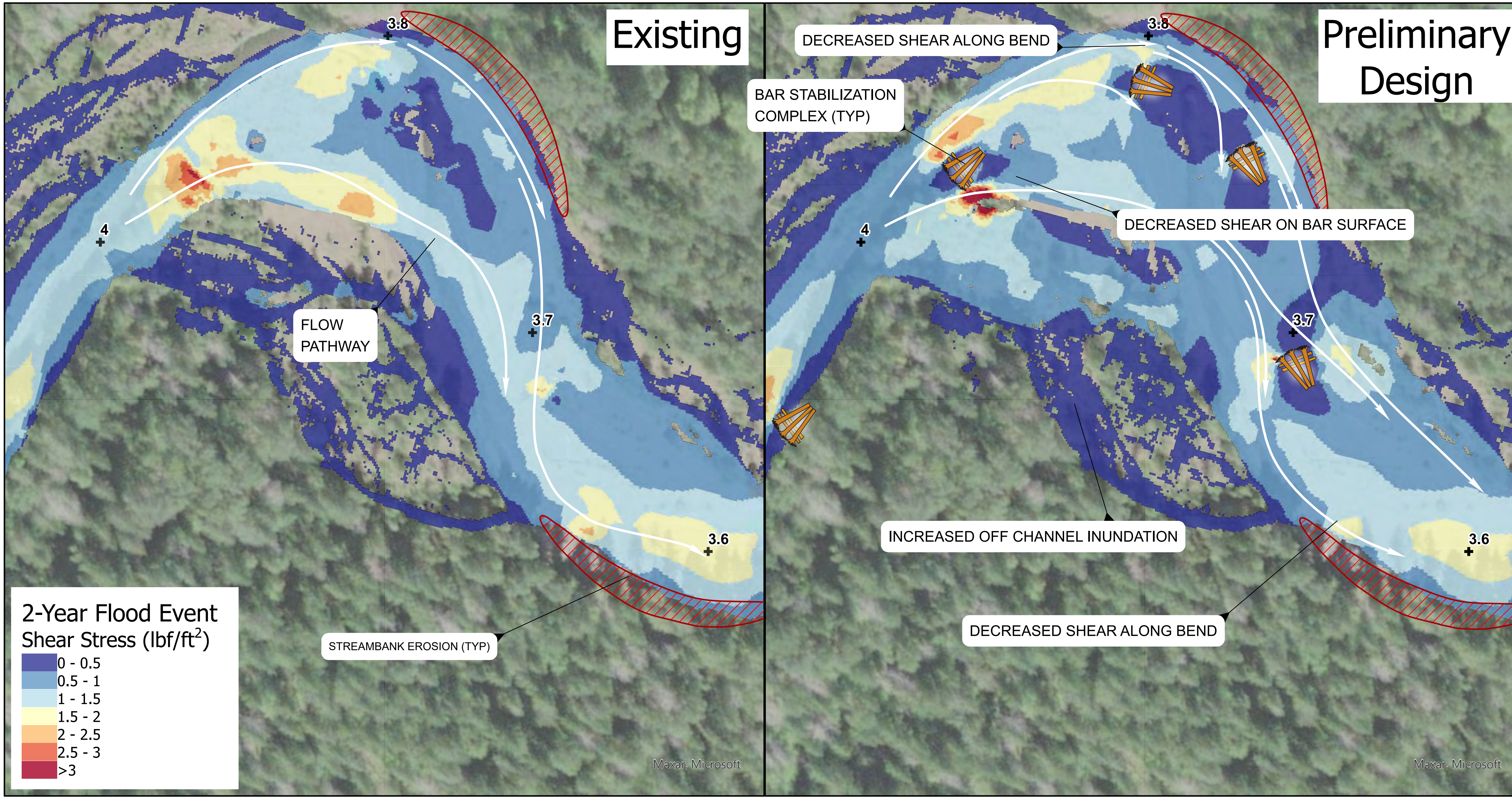
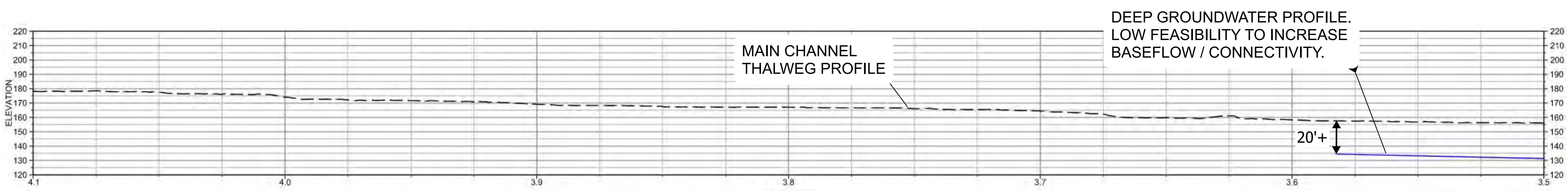


REACH 4 (RIVERMILE 4.2 - 3.5)



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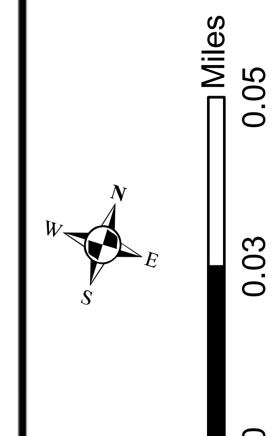
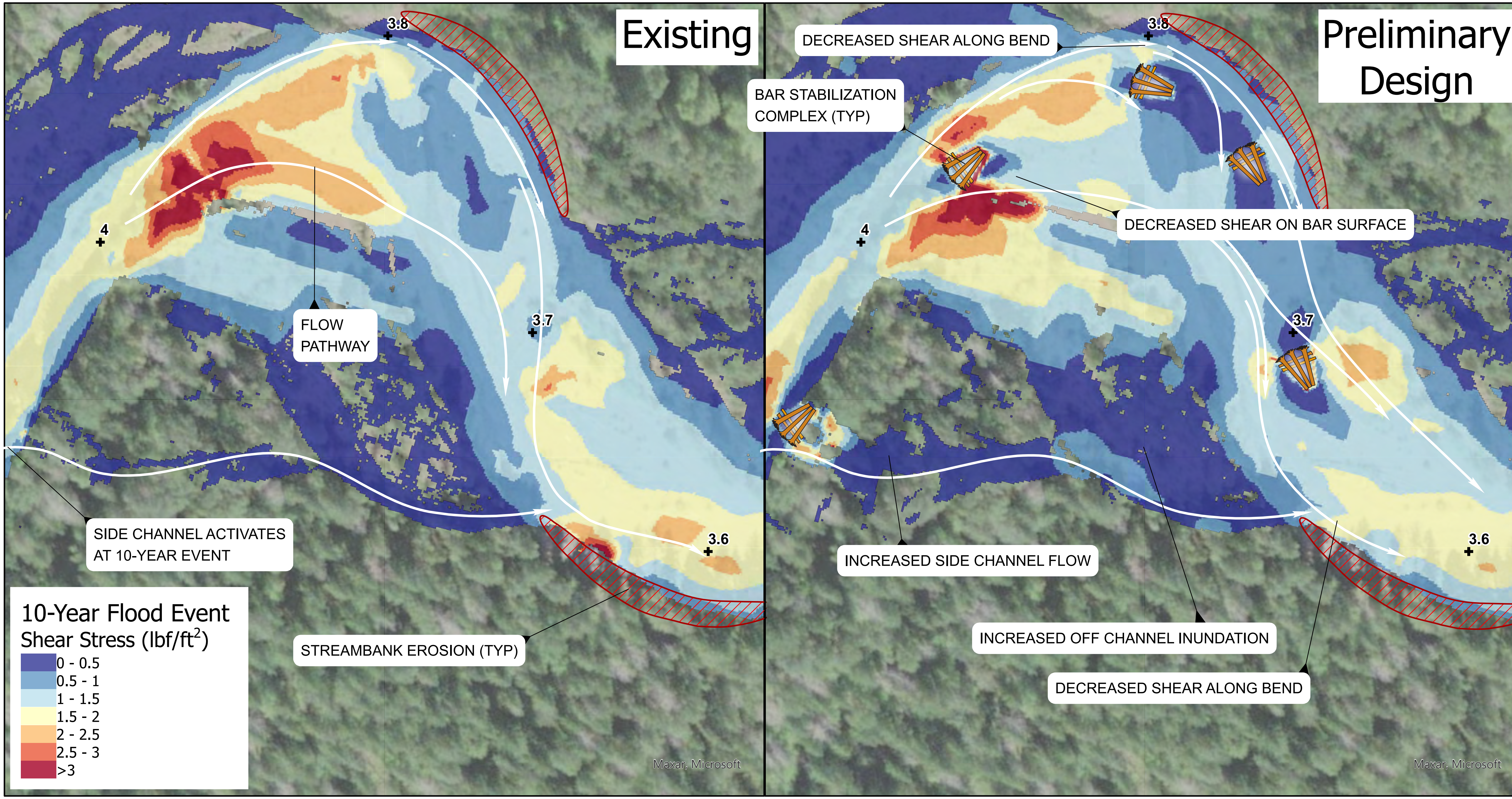


VANCE CREEK WATERSHED ASSESMENT
REACH 4
HYDRAULIC PERFORMANCE ASSESSMENT

2A OF 9



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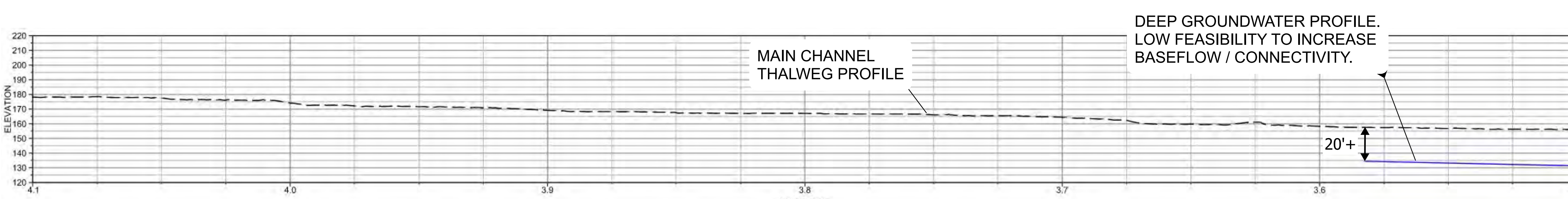

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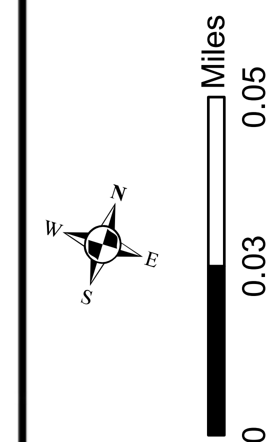

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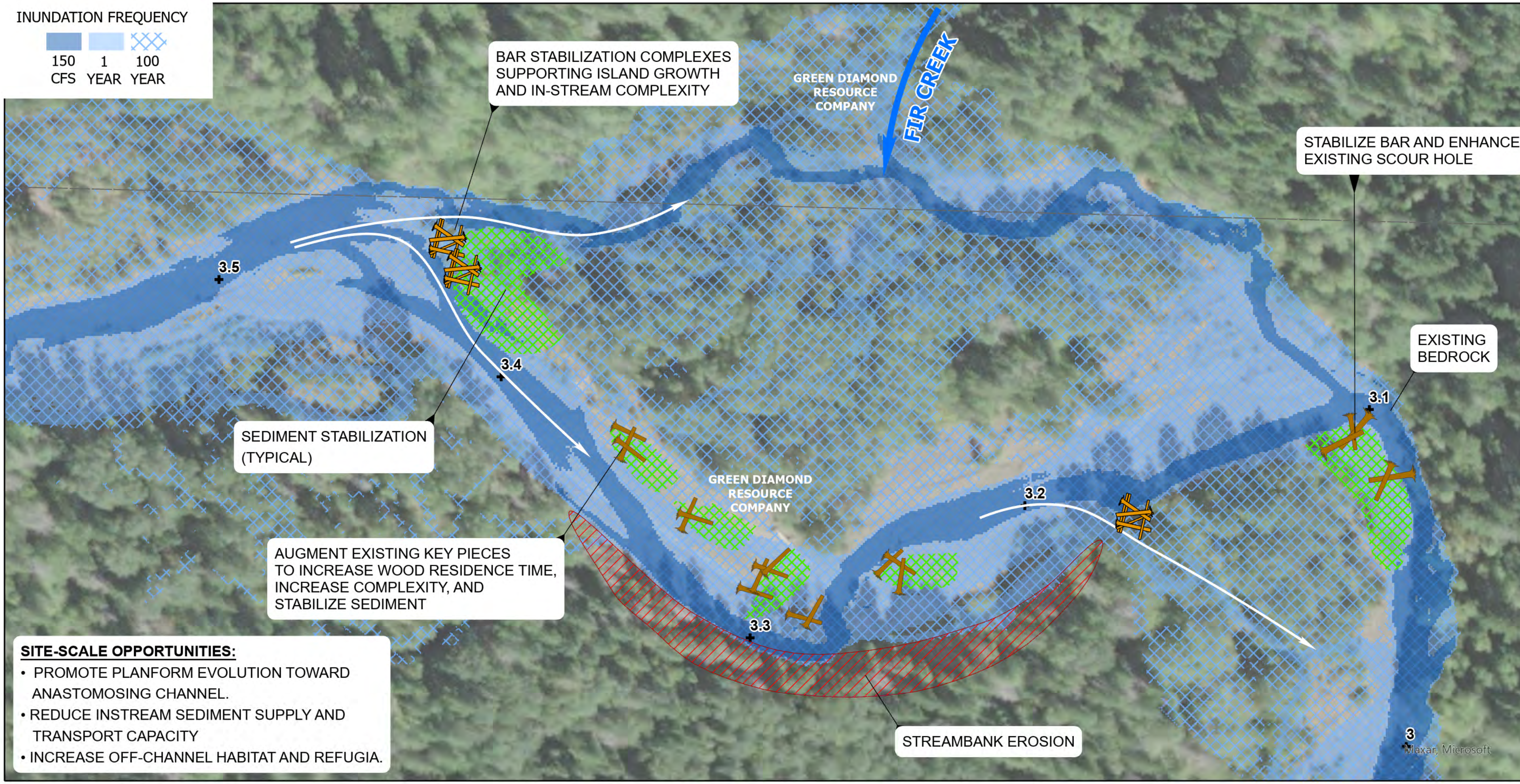
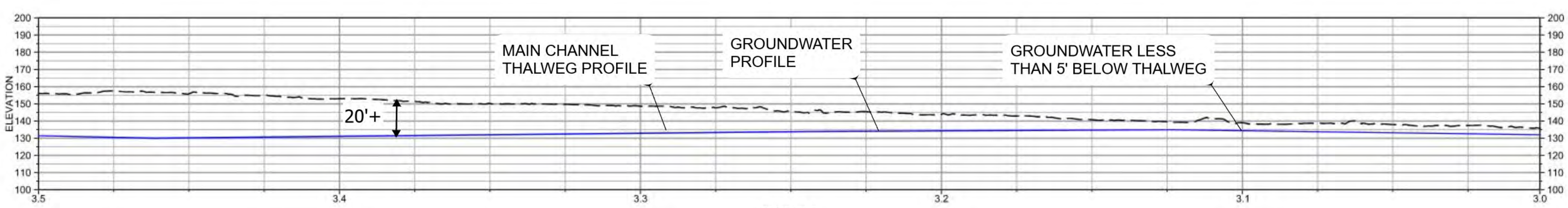
REACH 4
HYDRAULIC PERFORMANCE ASSESSMENT

2B OF 9



REACH 4 (RM 3.5 - RM 3.0)



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VANCE CREEK WATERSHED ASSESMENT
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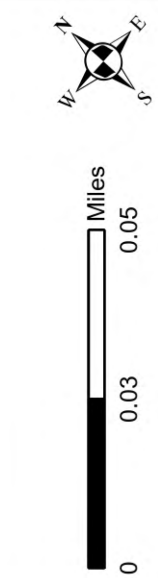

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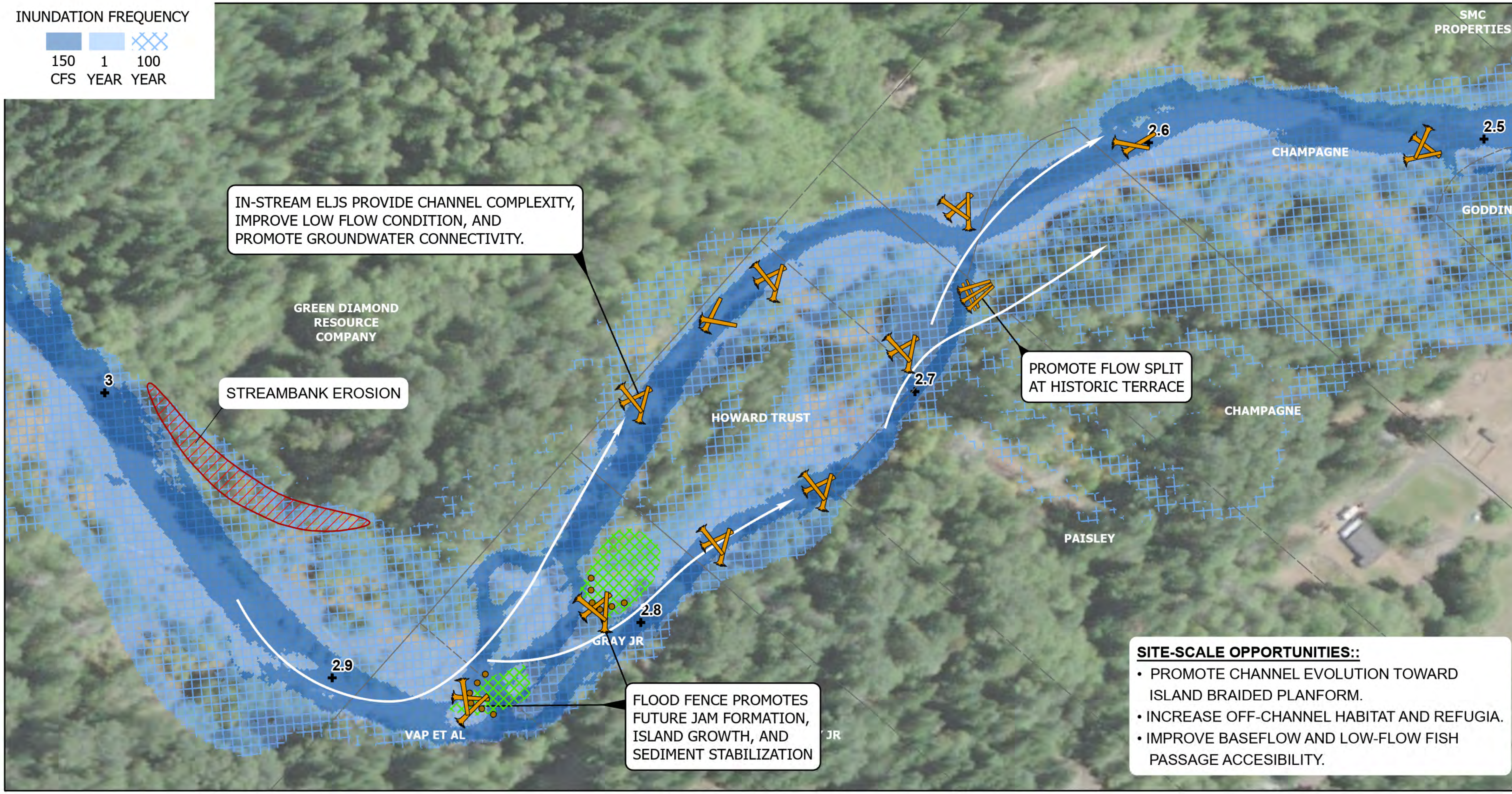
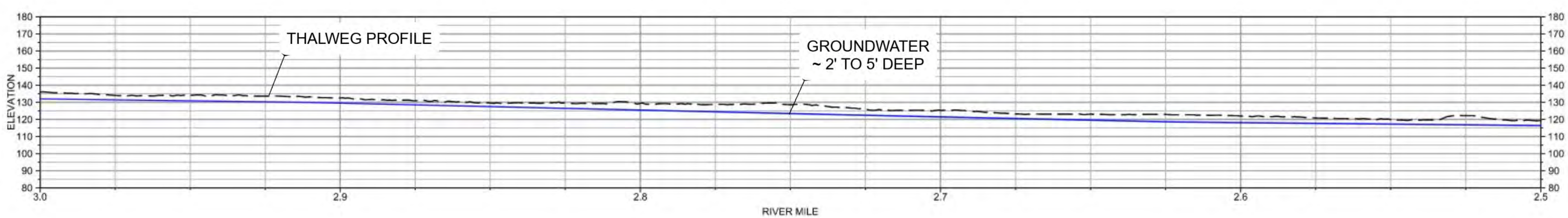
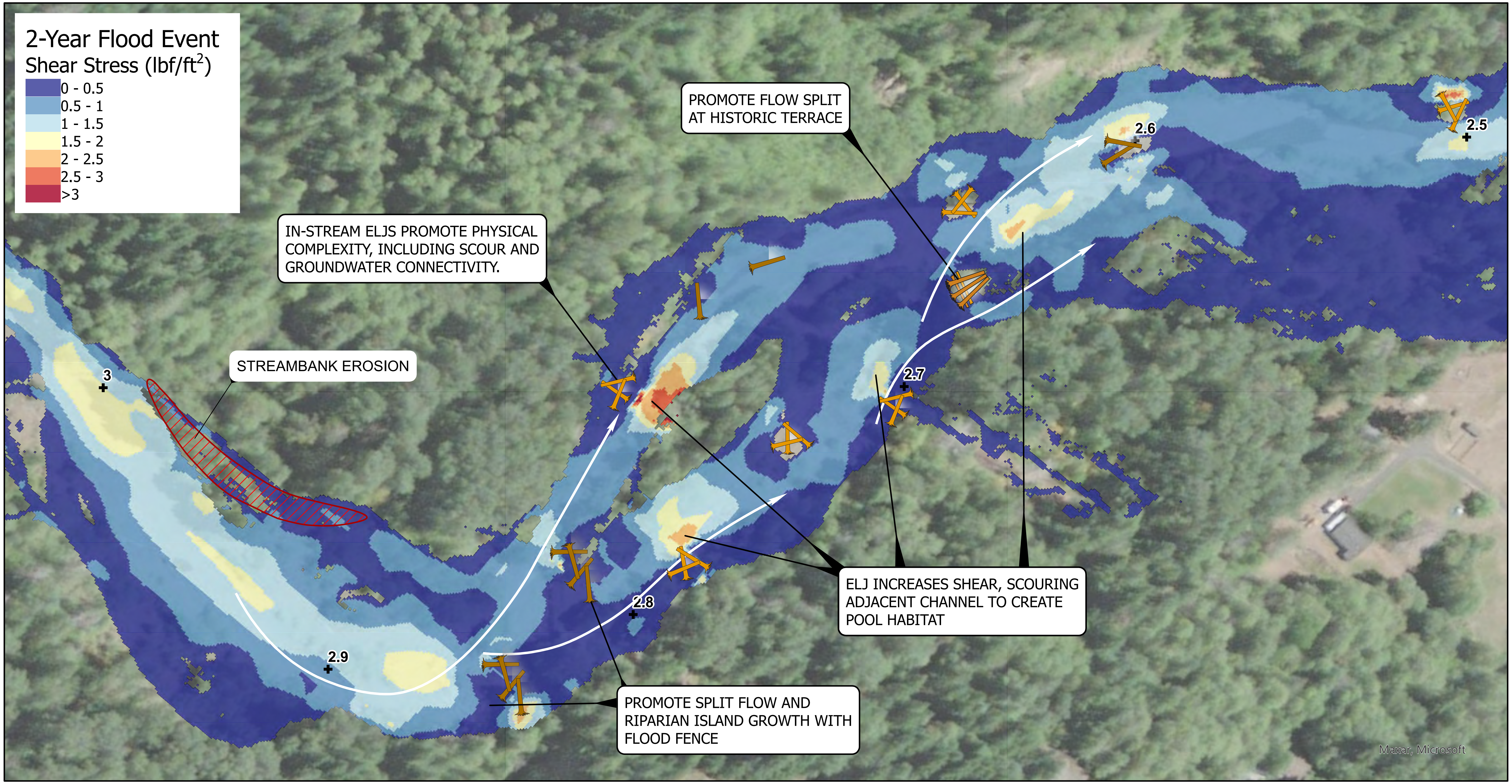
REACH 3

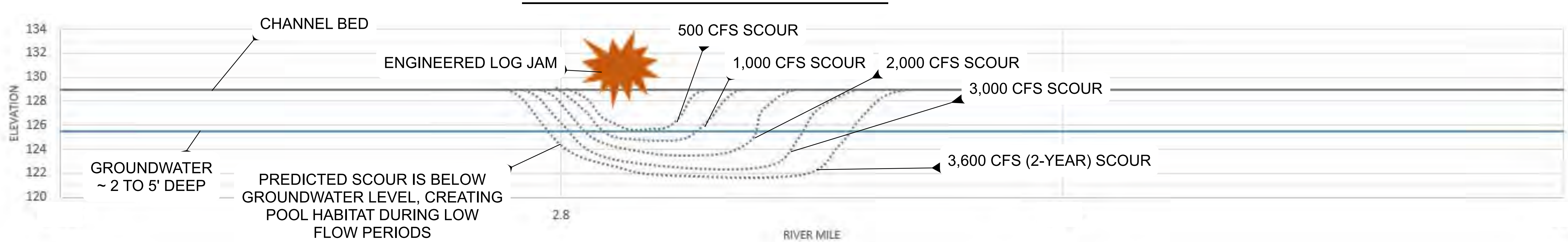


REACH 3 (RM 3.0 - RM 2.5)





REACH 3 - RIVERMILE 3.0 TO 2.5



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VANCE CREEK WATERSHED ASSESMENT
REACH 3
HYDRAULIC PERFORMANCE ASSESSMENT

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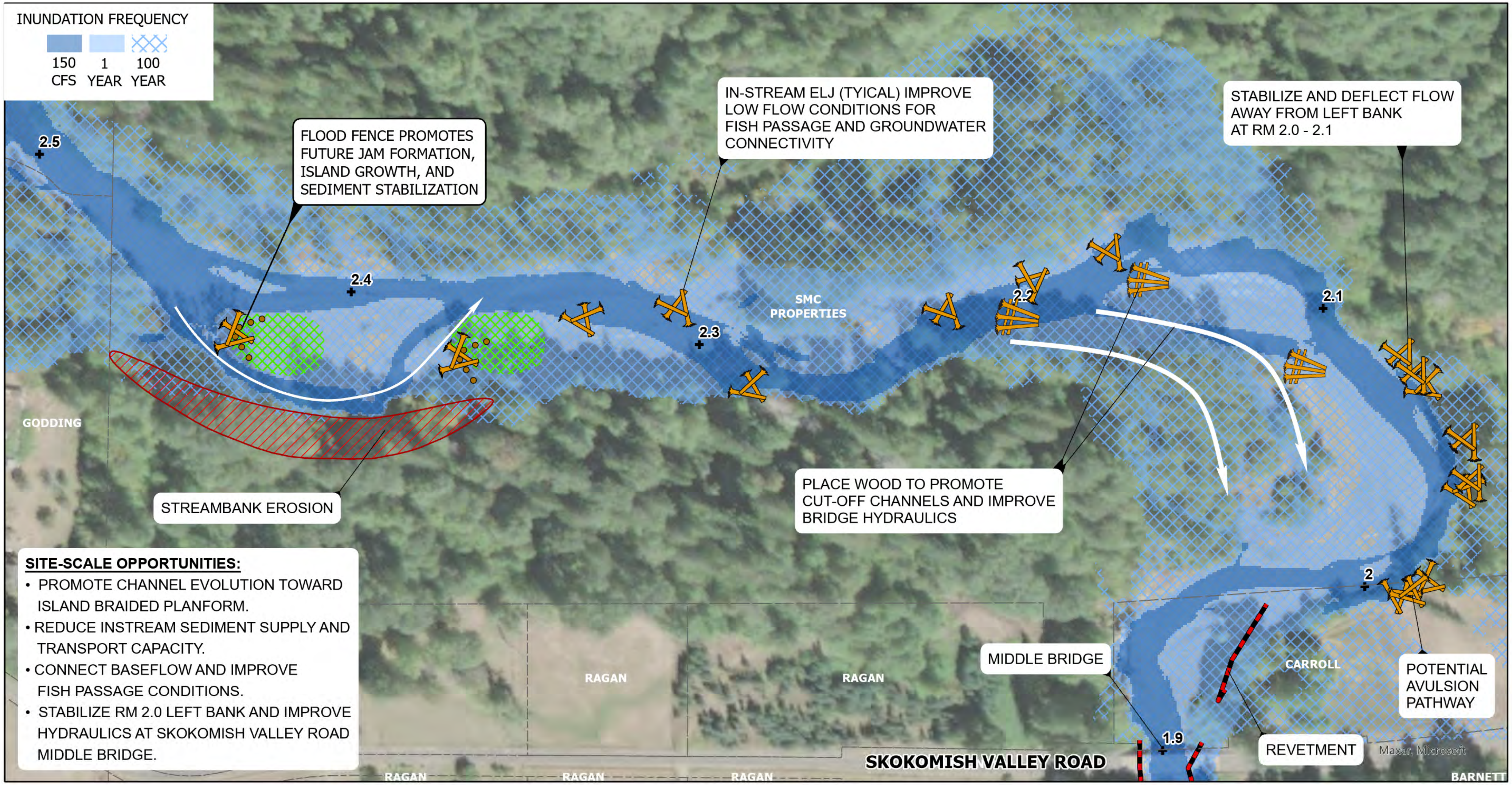

SITE-SCALE OPPORTUNITIES:

- PROMOTE CHANNEL EVOLUTION TOWARD ISLAND BRAIDED PLANFORM.
- REDUCE INSTREAM SEDIMENT SUPPLY AND TRANSPORT CAPACITY.
- CONNECT BASEFLOW AND IMPROVE FISH PASSAGE CONDITIONS.
- STABILIZE RM 2.0 LEFT BANK AND IMPROVE HYDRAULICS AT SKOKOMISH VALLEY ROAD MIDDLE BRIDGE.

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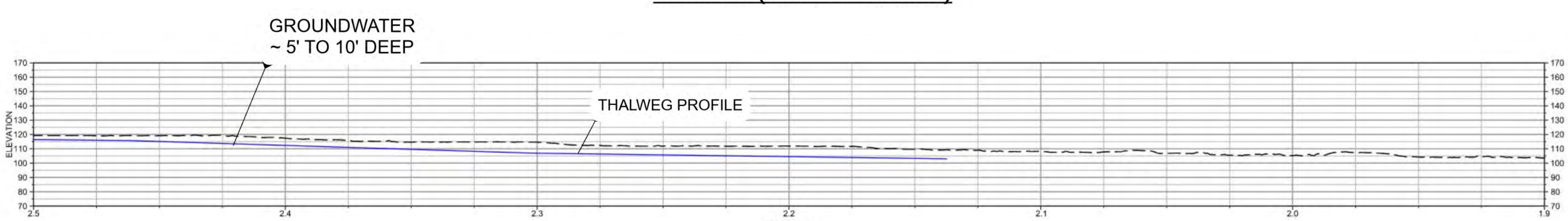
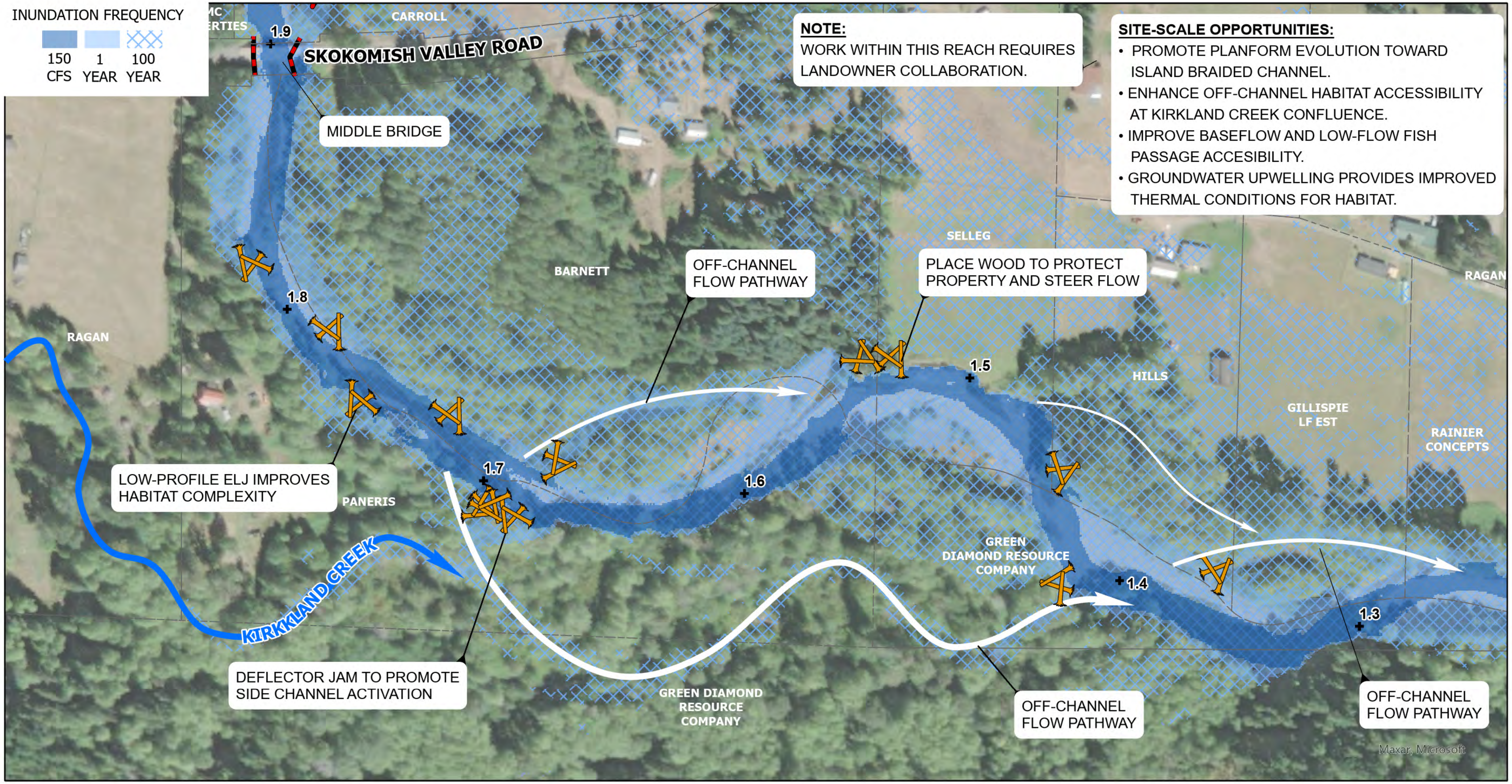
REACH 3 (RM 2.5 - RM 1.9)



VANCE CREEK WATERSHED ASSESMENT
REACH 3



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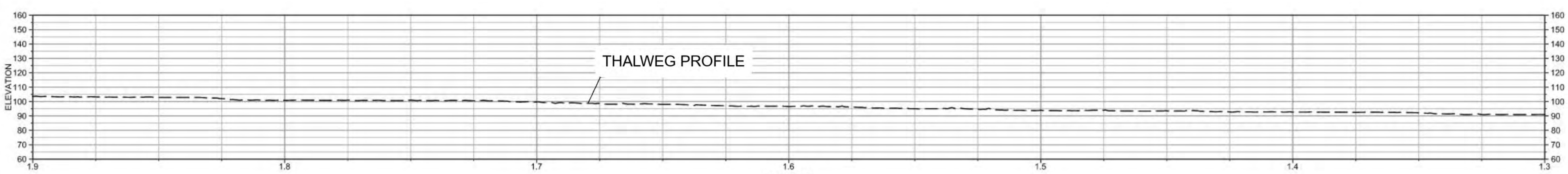

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VANCE CREEK WATERSHED ASSESMENT
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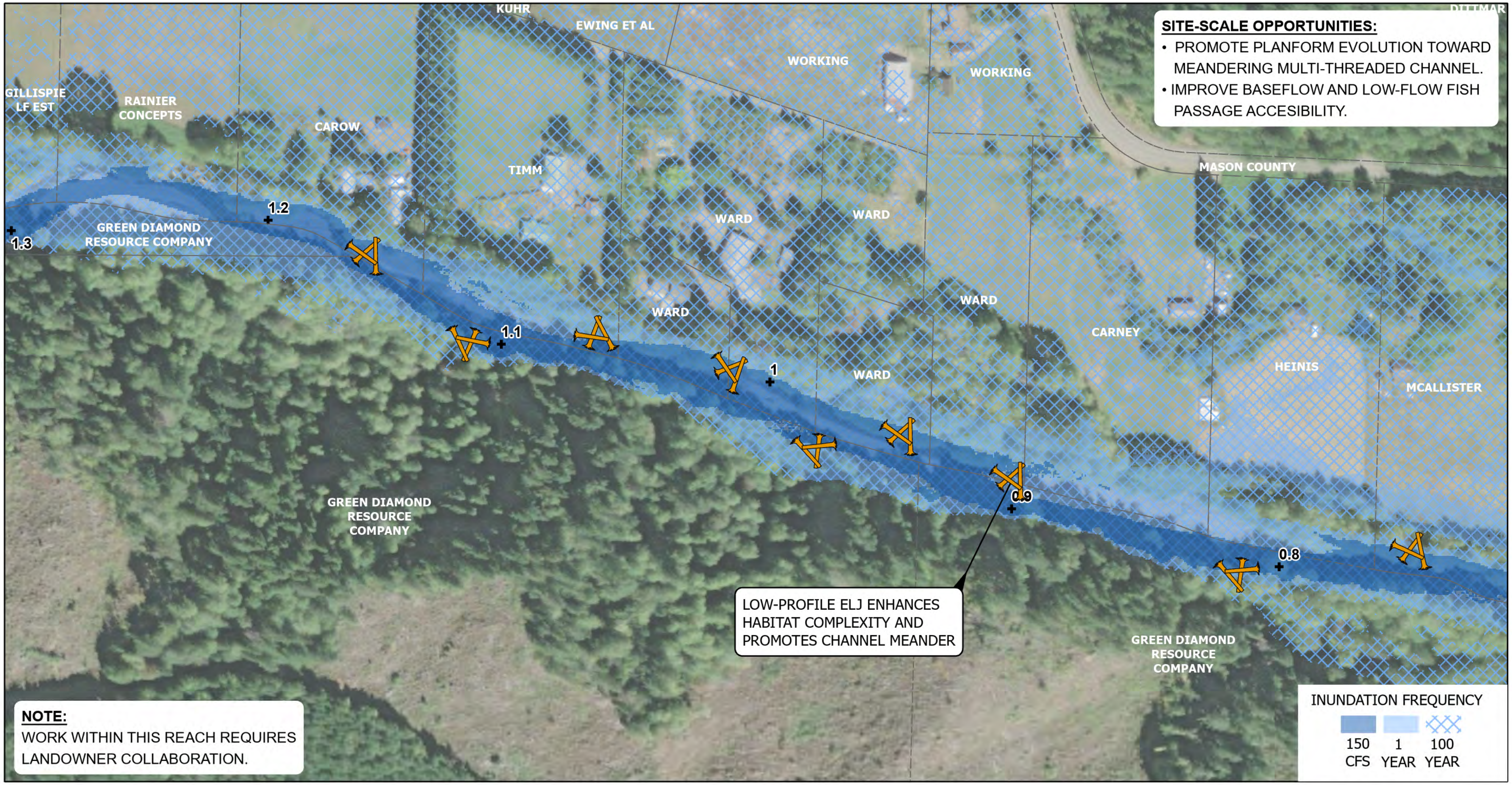
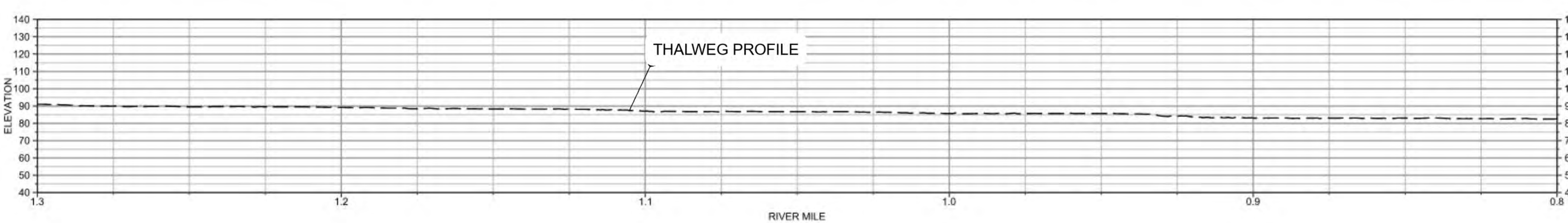


REACH 1 (RM 1.3 - RM 0.8)



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VANCE CREEK WATERSHED ASSESMENT
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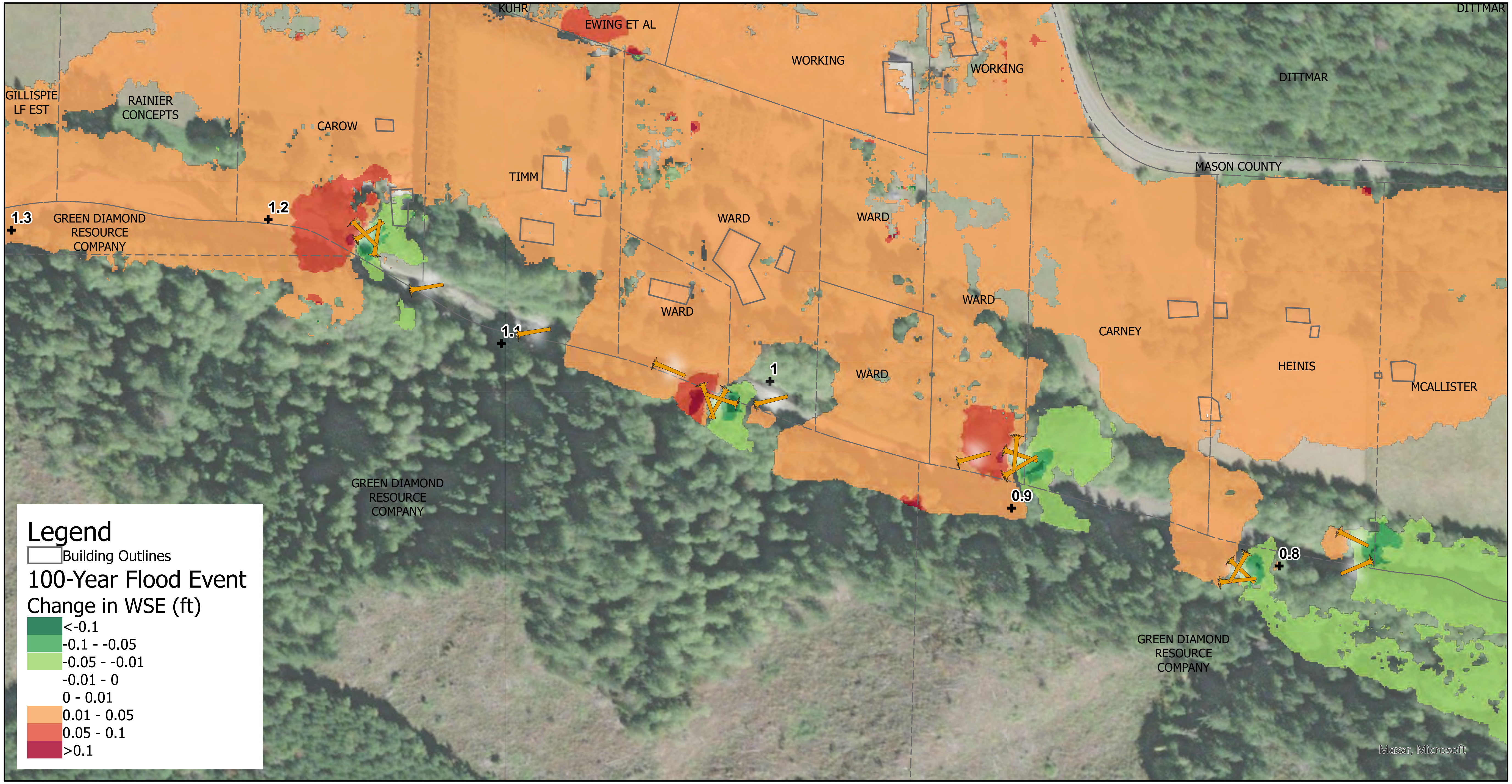
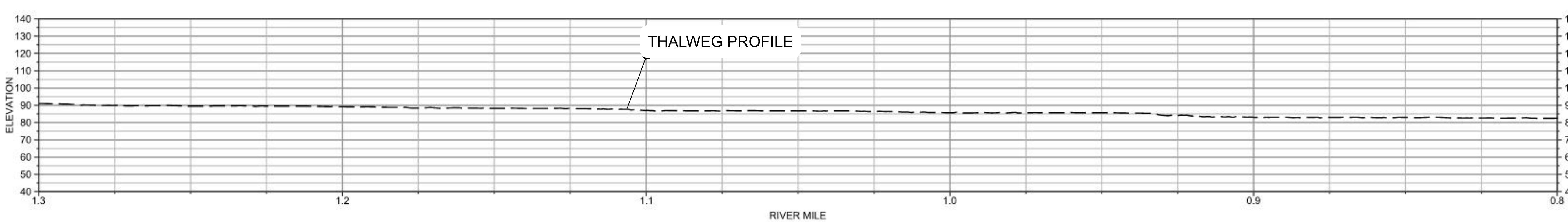


REACH 1 - RIVERMILE 1.3 TO 0.8



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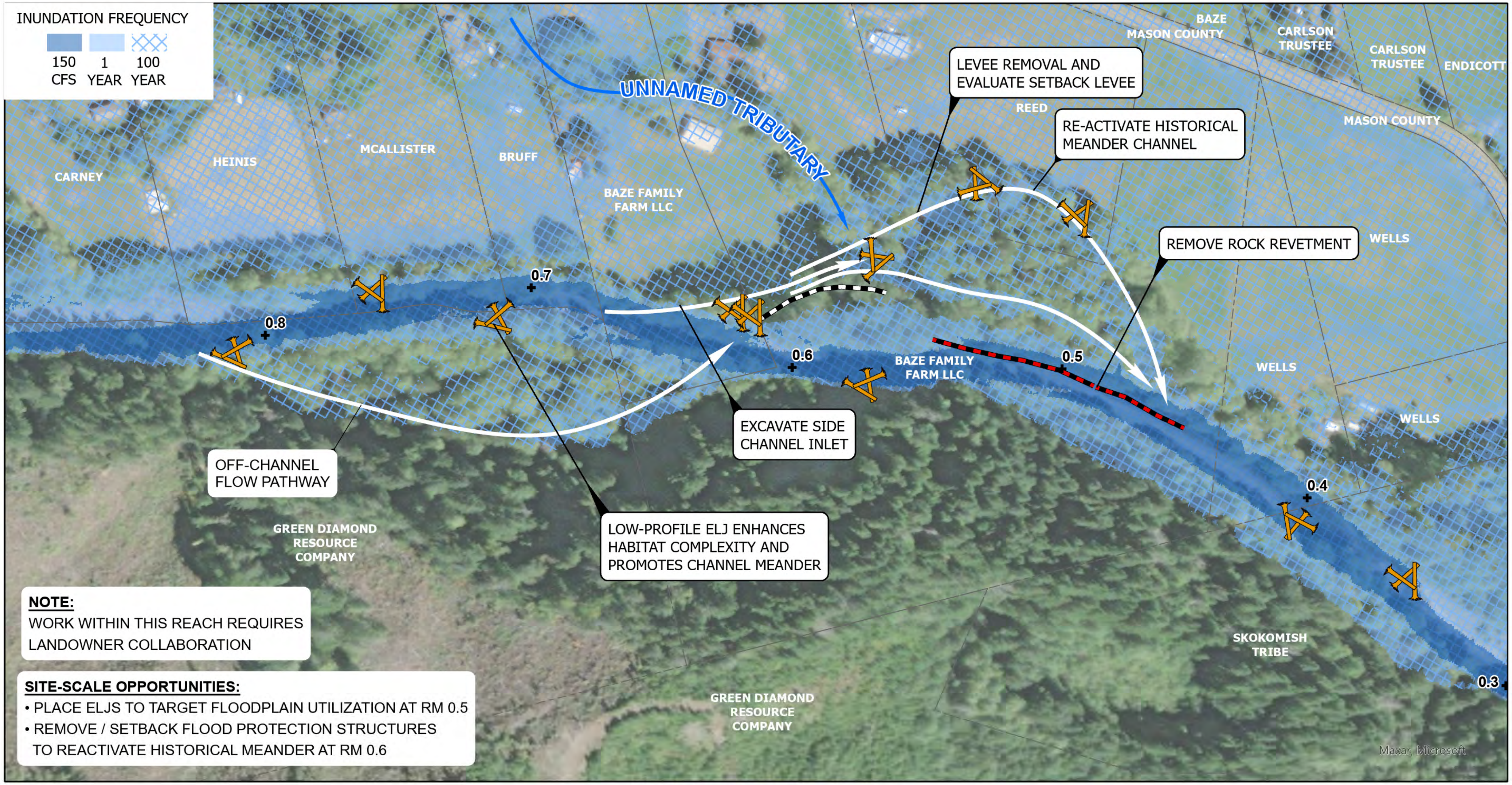
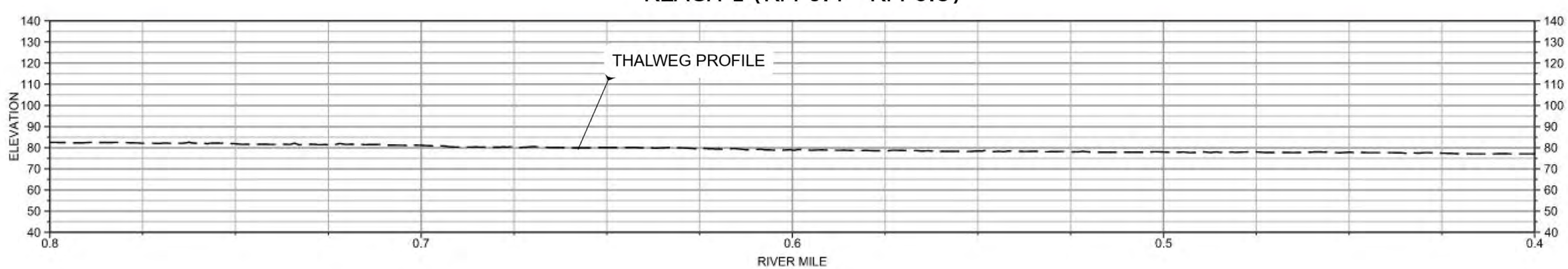


NOTE:
WORK WITHIN THIS REACH REQUIRES LANDOWNER COLLABORATION

SITE-SCALE OPPORTUNITIES:

- PLACE ELJS TO TARGET FLOODPLAIN UTILIZATION AT RM 0.5
- REMOVE / SETBACK FLOOD PROTECTION STRUCTURES TO REACTIVATE HISTORICAL MEANDER AT RM 0.6

REACH 1 (RM 0.4 - RM 0.8)



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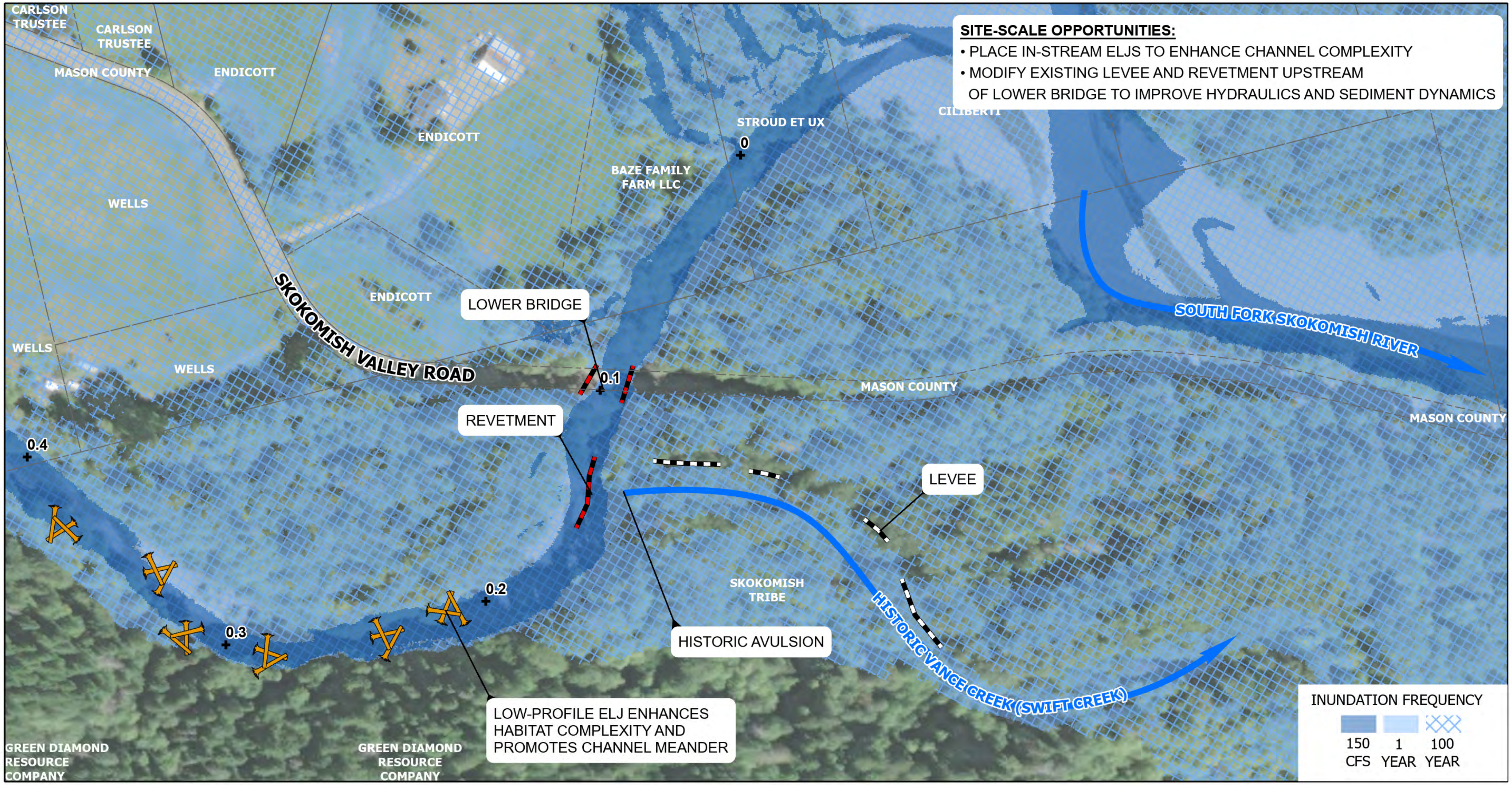
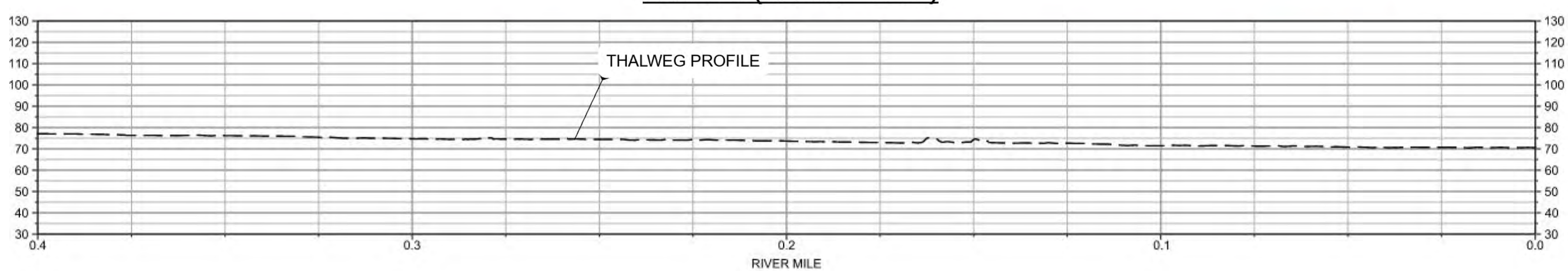


REACH 1 (RM 0.4 - RM 0)



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VANCE CREEK WATERSHED ASSESMENT
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APPENDIX B. GEOMORPHIC ASSESSMENT AND SEDIMENT BUDGET

Technical Memorandum

Date:	March 5, 2021
To:	Evan Bauder (MCD), Jon Ambrose (ESA)
From:	Nick Legg, LG
Project:	Vance Creek Watershed Study
Subject:	Geomorphic Assessment and Sediment Budget

1. Introduction

This memorandum (memo) summarizes the geomorphology and sediment budget of Vance Creek, a major tributary of the South Fork Skokomish River (SFSR) in Mason County, Washington (Figure 1). The primary project area includes the lower most 4.2 miles of Vance Creek, a high-priority reach for key salmon species. The reach is thought to suffer from multiple aspects of habitat degradation relating to watershed- and reach-scale sediment and geomorphic issues. With this effort, we assess the geomorphology and sediment budget to provide an understanding of natural processes and anthropogenic factors that inform potential restoration strategies and recovery timescales.

This assessment was completed as part of a broader project led by Mason Conservation District (MCD). Wolf Water Resources (W2r) partnered with Environmental Science Associates (ESA) and Cardno to undertake the technical aspects of the project. MCD supported this technical effort with significant field data acquisition and analysis. In addition, the US Geological Survey (USGS) collected streamflow and sediment data and provided general input. We thank all for their contributions and support with this effort.

Attached to this memo are two project area maps (terrain and aerial photography versions) showing features discussed in this memo.

Project Area Description

The project reach includes the lower 4.2 miles of Vance Creek extending from the confluence with the South Fork Skokomish River upstream to the point where Vance Creek emerges from a steep canyon. Below RM 4.2, the valley is broad and developed with rural residences and small farms in the lower 2-2.5 miles, and private timber lands in the upper portions. Bridge crossings provide key longitudinal landmarks throughout this memo. Those bridge crossings include one by the 2341 Road (private timber owned) at river mile (RM) 4.2 and two crossings by the Skokomish Valley Road at RMs 1.95 and 0.2.

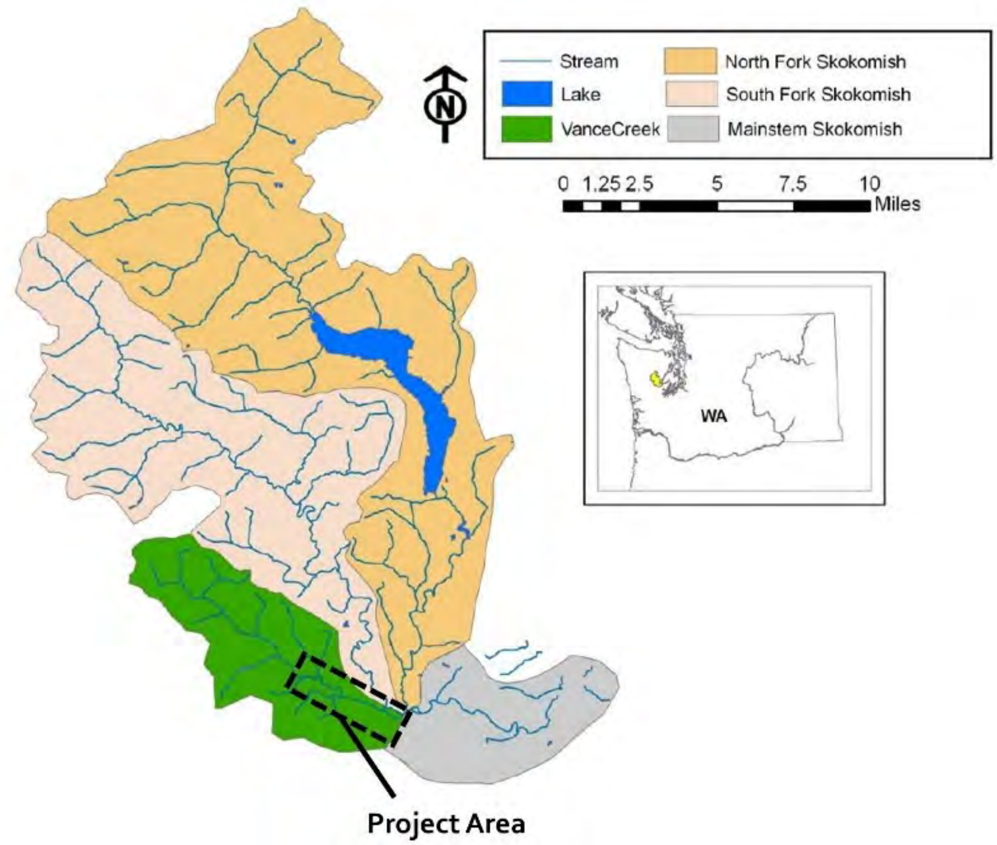

Figure 1 Overview map of project area (figure source: BOR, 2011)

Goals and Objectives

Sediment delivery and geomorphology are major considerations in the restoration and flood-risk reduction efforts in the broader Skokomish River watershed. This study capitalizes on new terrain, sediment, and hydrologic data to build upon previous studies of geomorphology to inform watershed restoration opportunities in Vance Creek and the downstream areas along the Skokomish River to which Vance Creek contributes.

Additionally, several specific forms of habitat degradation and flood risks are known to exist in Vance Creek. Those specific issues include:

- Simplified and over-widened Vance Creek channel
- Suspected high sediment loads resulting from historic logging
- Losses in floodplain reconnection via historic creek and floodplain manipulation
- Sediment aggradation and avulsion dynamics near the Vance Creek mouth

In the context of these factors, objectives were to understand longitudinal patterns in fluvial geomorphology, reach- and sub-reach scale sediment dynamics in terms of sources, fluxes, and patterns of erosion and deposition, and temporal changes in stream dynamics. Together these topics inform the potential impacts and recovery rates from anthropogenic disturbances.

2. Previous Studies

Multiple past studies of Vance Creek geomorphology provide a baseline for this assessment.

Washington Department of Natural Resources (1997) completed a broader watershed analysis of the South Fork Skokomish watershed which included detailed estimates of landslide-derived sediment delivered to Vance Creek from 1946-1995. They tabulated volumetric sediment inputs by sub-watershed, five of which covered the Vance Creek watershed. Here we tabulated their volumes (Table 1) by summing volumes estimated for sub-watersheds (including sub-watersheds named Upper Vance, Middle Vance, Aristine Creek, and Fir Creek) above and contributing to the current USGS gage and sediment measurement location in this project reach. Together these data indicate landslides contributed about 2,600 cubic yards (CY) per year for the DNR study period from 1946-1995.

Table 1 Summary of landslide inputs to Vance Creek mapped and estimated by DNR for the sub-watersheds above the Vance-Fir Creek confluence (~RM 3.2 of Vance Creek).

Photo Interval -->	1946-1956	1956-1965	1965-1978	1978-1985	1985-1995	1946-1995
# yrs -->	10	9	13	7	10	49
Volumetric Inputs, cy	14,400	33,500	30,600	0	52,500	130,900
Average Input Rate, cy/yr	1,440	3,722	2,354	0	5,250	2,671

Because the DNR study period generally coincided with the most intense logging in the watershed (which is discussed below), their mapping through time in Vance Creek does not directly inform changes in landsliding rates as a function of logging. However, DNR's broader mapping in the SF Skokomish River watershed estimated that landslides were about 210% more frequent in logged areas as compared to unlogged areas.

In 1999, Skillings-Connolly Inc. and Simons and Associates conducted a geomorphic and hydraulic assessment of Vance Creek and the South Fork Skokomish River. The study characterized hydraulics and geomorphology in the creek. Notably, the study identified a large landslide from the northern valley wall that had occurred in the late 1990s at about RM 2.4. Additionally, the study noted a high avulsion potential along the historic Vance Creek alignment currently occupied by Swift Creek.

In 2011, the US Bureau of Reclamation (BOR) assessed the geomorphology and hydraulics of the project area to better understand restoration opportunities. Their assessment broadly characterized geomorphic conditions through geomorphic mapping, radiocarbon dating of river terraces, historic air photo mapping, characterization of instream sediment gradations, and hydraulic/sediment transport modeling (1D). Overall, the study provided a detailed account of the watershed history, existing geomorphic conditions, and recent channel changes. From these assessments, BOR provided a restoration strategy to address habitat simplification but also recommended additional monitoring to address gaps in understanding related to hydrology and sediment fluxes through the project area. With greater terrain and flow/sediment monitoring available, the present study has addressed those gaps more directly to provide better context for effective future restoration actions.

3. Watershed Geology and Glacial History

Vance Creek drains the southeastern Olympic mountains, a range and setting affected by both active tectonics and a history of continental glaciation. Together, these geologic conditions and history provide context for sediment delivery and dynamics in the watershed. According to mapping by

Logan (2003), the Vance Creek watershed comprises two broad geological domains with a transition at the upper end of the project reach (Figure 2). Above this point is steep and largely bedrock-dominated terrain of the Olympic Mountains and foothills, and where Vance Creek runs through a confined valley. In contrast, deposits laid by continental glaciers and more recent deposits lie below this transition and throughout the project reach.

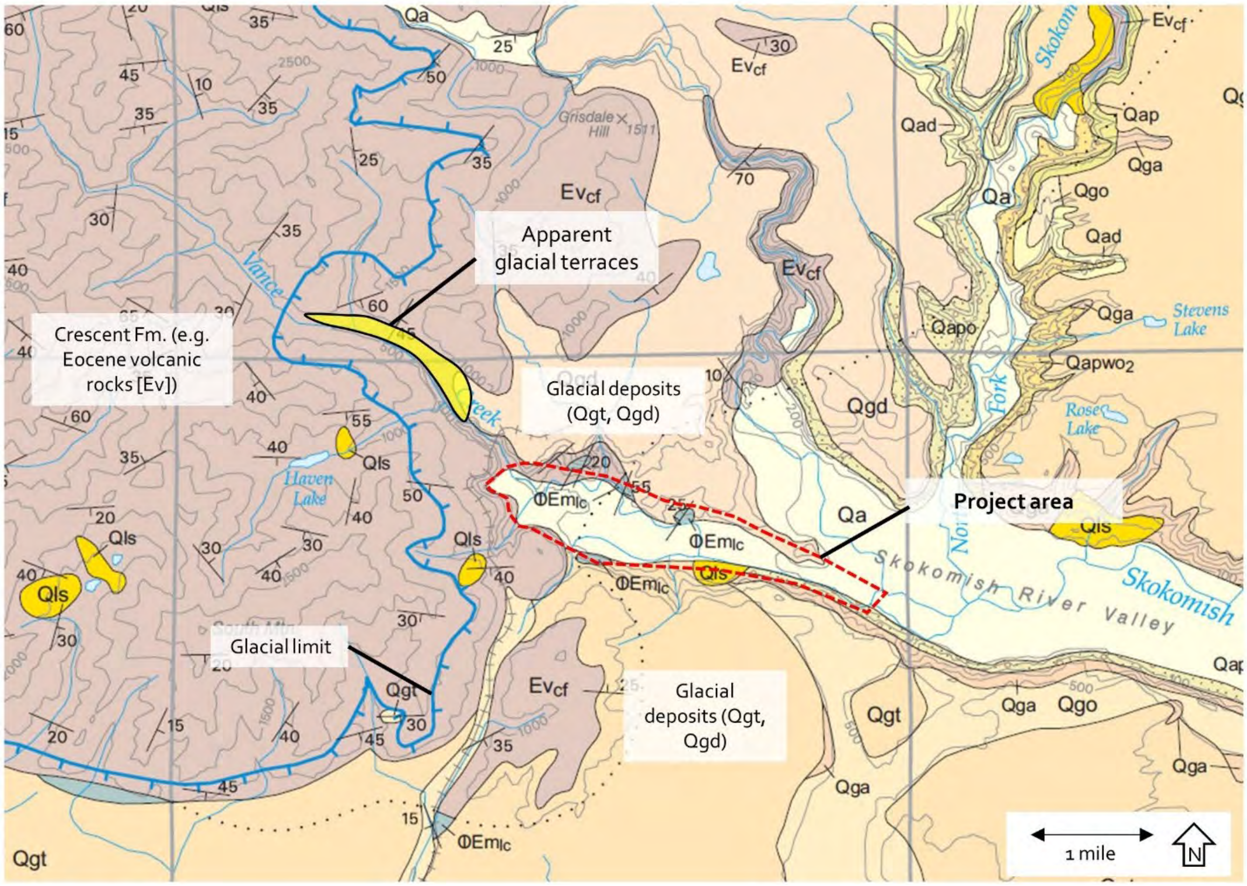

Figure 2 Annotated geologic map (Logan, 2003) of the Vance Creek vicinity.

As represented by the maroon areas in Figure 2, the relatively steep foothills of the Olympic Mountains in upper watershed are predominantly underlain by volcanic rocks (basalt flows and volcanic breccias) of the Crescent Formation, erupted roughly 40 million years ago (Logan, 2003). Tectonic uplift of the Olympic Mountains is known to be relatively rapid (Pazzaglia and Brandon, 2001), and while rates are typically greater toward the central range, they nonetheless tend to contribute to steep terrain and high sediment production in watersheds similar to the upper watershed of Vance Creek.

Adjacent to and within the project reach, geologic mapping shows a history of continental glaciation and subsequent valley formation. Continental glaciation occurring during the Vashon stade from ~16-17 thousand years before present (Porter and Swanson, 1998). During this period, a continental ice sheet flowed southward through the Puget Lowland and, at its maximum, extended from British Columbia south to Chehalis, just to the south of the project area. Mapping by Logan shows that the maximum glacier extent not only covered the entire project area but extended about two miles upstream into the canyon (Figure 2). Although he did not map significant glacial deposits upstream of the project area, examination of LiDAR terrain reveals apparent glacial terraces (~400 feet high above present day creek level) extending into the upper valley to roughly the mapped glacier limit. Similar glacial terraces have been associated with high sediment loads in the South Fork Skokomish River (Collins et al., 2019) as river channels migrate into and induce landsliding off the face of these terraces of unconsolidated material.

Along the project reach, glacial deposits constitute a large proportion of the valley walls (Figure 3) and adjacent high terraces, whereas the valley bottom is mapped as more recent alluvium (Qa in Figure 2). These deposits and their relative positions on the landscape indicate that the creek has incised into those glacial deposits and widened its valley since retreat of the glaciers, which is a common history for several rivers in the Puget Lowlands (Collins and Montgomery, 2011).

Figure 3 Example glacial outwash deposit along the southern valley wall (RM 1).

4. History of Development and Timber Harvest

The history of the Vance Creek watershed provides context to potential watershed degradation and recovery trajectories considered in this assessment. The BOR study provides a comprehensive history compiled from several sources. From that timeline, we have compiled an abbreviated timeline of logging in the headwaters and settlement (land clearing, river manipulation) in the lower Vance Creek valley.

- 1877: First documented European settlement of Vance Creek valley
- 1898: Lower Vance Creek valley mapped as being cleared of forests (Rakine and Plummer, 1898)
- 1929: Railroad bridge was built across Vance Creek gorge in upper watershed. Railroad line was reportedly built to support timber operations (DNR, 1997).
- 1938: Aerial imagery of the lower valley shows localized clearcuts on adjacent slopes and a cleared valley bottom.
- 1940: Lower creek was improved and dredged.
- 1949: Mainline roads constructed in the upper watershed heralded a period of intense timber harvest (DNR, 1997).

- 1949-1973: Sediment and debris removal of unknown volume from lower creek by Mason County (Skillings-Connolly, Inc. and Simons and Associates 1999)
- Late 1950s: Vance Creek confluence with the South Fork Skokomish River shifts upstream to its approximate current position.
- 1956-1986: Private levee and bank revetment projects in approximately the lowermost mile of the creek, where flooding is known to be most prevalent (BOR, 2011).

US Forest Service (USFS) tree age mapping (2016) provide additional information on the timing and intensity of logging in the upper watershed. These data were clipped to the Vance Creek watershed boundary and inverted to construct an inferred timeline of logging (Figure 4). They show that the most intense period of logging occurred from the mid-1950s to mid-1990s. The onset of intense logging is also consistent with the timing of railroad and road building in the upper watershed. From the tree age mapping (Figure 4), we can see that the remaining unlogged areas are generally localized along the creek.

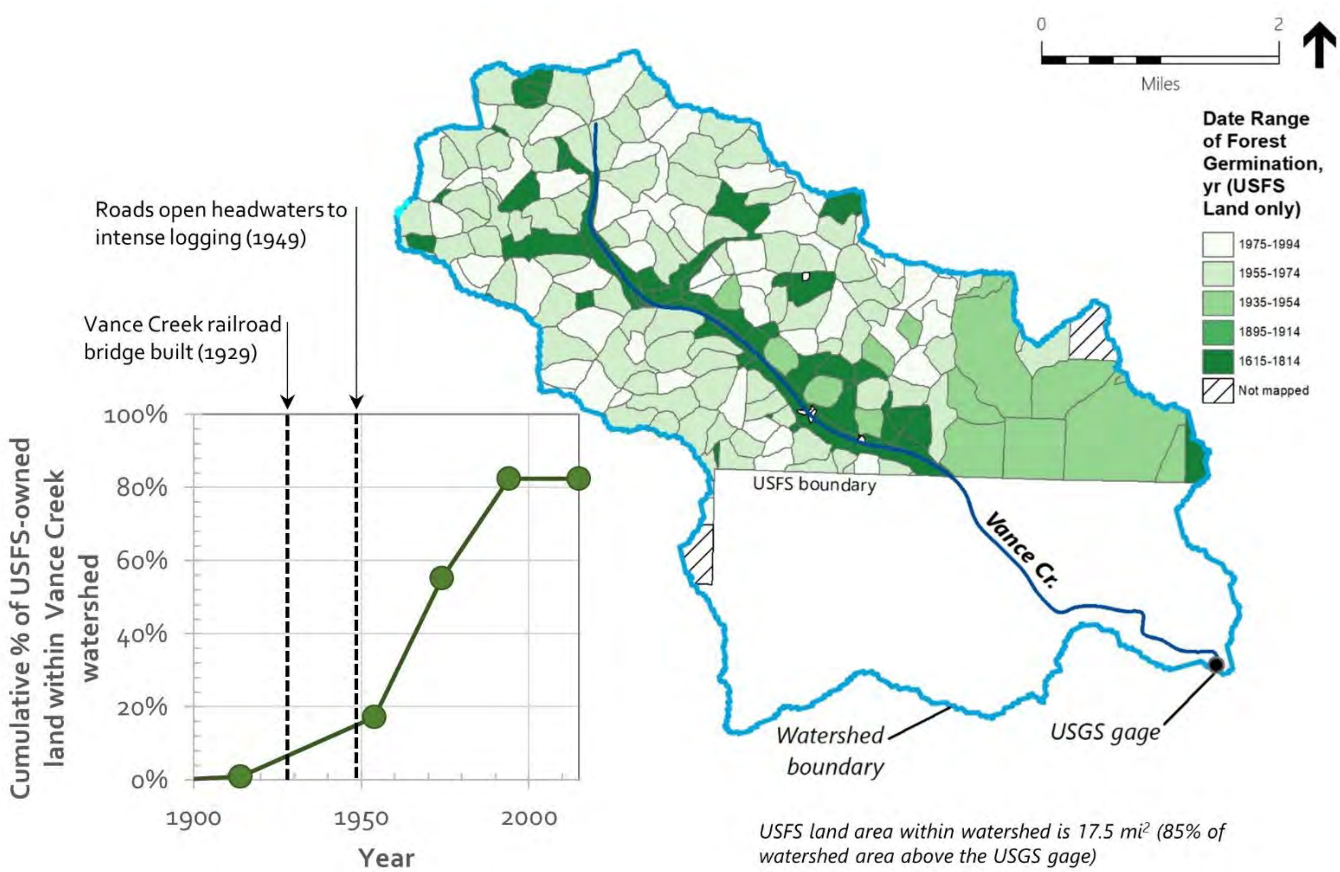

Figure 4 Inferred timeline of logging extent in lands owned by the USFS in the upper Vance Creek watershed. Data source: USFS, 2016

5. Technical Approach

This study included the following information and efforts:

- Broad characterization of reach geomorphology through field, GIS, and hydraulic model related outputs
- Estimate rates of stream incision and aggradation along the project reach using multi-temporal terrain sources including dated landforms
- Bedload measurements by USGS, rating curve development, and estimation of annual bed load flux
- Sediment budget using a combination of morphologic budgeting techniques (derived from LiDAR based geomorphic change detection) and USGS measurement-based estimates of bedload

6. Data Sources and Processing

Data

The study utilized sediment flux measurements collected by the USGS at their gage station (12061250) located at the upper Skokomish Valley Road Bridge (RM 1.95). The USGS measured bedload sediment flux on seven occasions (often with multiple samples per trip) during a range of winter high-flow conditions from 2018-2020.

To characterize stream bed size gradations, several pebble counts were collected using Wolman (1954) methods by MCD with guidance by W2r.

Multiple surveyed and LiDAR terrain datasets informed the geomorphic change analysis:

- Channel survey by BOR in summer 2009 (as part of 2011 study). Surveyed thalweg elevations were primarily used for this study.
- LiDAR data collected by the Puget Sound LiDAR consortium in 2002 (6′ resolution grid, collected on March 3 at an estimated flow of 150 cubic feet per second [cfs]).
- Topo-bathymetric LiDAR data collected by Quantum Spatial Inc. for MCD in 2016 (3′ resolution grid, collected on September 28).

Terrain Data Pre-Processing

A major component of the geomorphic change assessment involved the differencing of terrain datasets, which involved varying pre-processing steps depending on the nature and quality of the data being compared. We made two primary terrain comparisons, from 2002 to 2016 (LiDAR to LiDAR) and 2009 to 2016 (survey to LiDAR). The simplest comparison was from 2009-2016, where thalweg elevations at given river station were compared. Comparison of the LiDAR datasets involved multiple preprocessing steps due to the mix of LiDAR terrain quality, vertical bias between datasets, and LiDAR type (traditional v. bathymetric). Those steps involved corrections for:

- *The quality of terrain representation*: The 2002 LiDAR dataset had notable data artifacts where the channel was wetted at the time of acquisition (usually these were obvious high points not true to reality). In order to remove these artifacts, we extrapolated the adjacent water surface elevations to these artificial high points, effectively removing them according to adjacent creek elevations. Although removal of data artifacts improved suitability for terrain comparison, imperfections undoubtedly remained. The remaining error is challenging to quantify, however.

- *Vertical bias:* Vertical bias was simply measured and averaged along centerlines of paved roads in the project area, which are assumed to be relatively stable. This analysis found that the 2016 dataset averaged 0.16 feet below the 2002 LiDAR dataset. A corresponding correction was applied to all volumetric measurements.
- *Inundated area:* Traditional LiDAR methods capture the water surface at the time of acquisition. To remove the volume represented by water, project partner Cardno ran hydraulic models at the estimated stream discharge during LiDAR acquisition (estimated to be about 150 cfs at the time of the 2002 LiDAR capture). Because the modeling was run on the 2016 topobathymetric terrain, the 2002 terrain surfaces could not be directly "corrected". Rather, flow volumes were segmented by longitudinal analysis bin and applied to volumetric calculations outside of the geospatial environment.

Together these efforts were deemed to improve the volumetric analysis, but unavoidable uncertainty remains and is considered further in the context of results below.

To analyze longitudinal trends in geomorphic change, we mapped out 400-foot-long spatial bins (i.e., slices) of the combined active channel areas at the time of two LiDAR datasets. Net volumetric changes were then measured within each bin. Additionally, volumetric changes were parsed into those associated with bed changes and bank erosion.

7. Reach Geomorphology

The project reach is situated in a broad unconfined and post-glacial valley as the creek transitions from the steep headwaters to its confluence with the South Fork Skokomish River. Through this reach, the stream is apparently transitional in its character, as tracked through longitudinal patterns in valley geomorphology, stream profile, channel planform, and apparent sediment dynamics.

Valley Geomorphology

Vance Creek and its active floodplain occupy a relatively small portion of its broader post-glacial valley. The active geomorphic floodplain varies in width from roughly 200-800 feet, which compares to a broader valley bottom width of 1000-3000 feet (generally wider in the upper 2 miles). For much of the valley length (especially above RM 1), the portion of the valley bottom outside of the active floodplain is characterized as a continuous a river terrace roughly 10 – 12 feet above the active channel. The terrace surface has limited channel scars and has a least one relatively large alluvial fan built onto it from the southern valley wall. Hydraulic modeling indicates this terrace surface stands above the 100-year flood. Together these observations suggest that the terrace is disconnected from the river at present, and has been for many decades or centuries.

Moving downstream, this terrace is continuous, but reduces in relief relative to the active channel (requiring that the slope of the terrace is steeper than the active channel). By RM 2 (just upstream of the upper crossing of Skokomish Valley Road) hydraulic modeling indicates the terrace experiences limited surface flow at the 10-year flood.

At RM 1, the broader valley and floodplain changes in character. This point in the valley marks the end point of the high glacial terrace separating the floodplains of Vance Creek and South Fork

Skokomish River. The floodplain is also lower relative to the stream than those found upstream, with elevations almost entirely less than 5 feet above the active channel (and typically less). Hydraulic modeling correspondingly shows broad inundation of the floodplain at the 2-year flood. The floodplain also slopes gently away from the bank tops of the active channel, which is common where overbank sediment deposition preferentially occurs near the creek (Figure 5). This lower mile of floodplain is also the only portion of Vance Creek with notable artificial (now apparently ineffective) push-up levees visible in LiDAR.

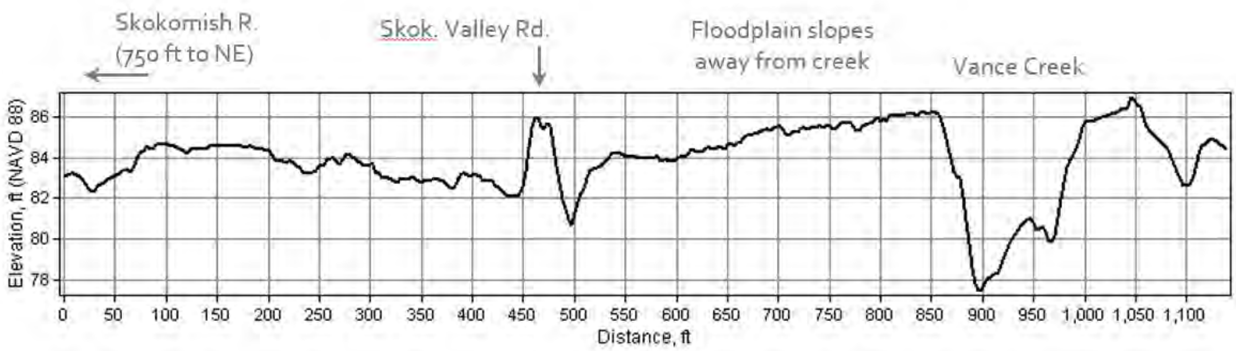

Figure 5 Cross section at RM 0.78, cut from topo-bathymetric LiDAR (2016). Looking downstream.

The character of hillslopes along the project reach are also notable for the prevalence of landslide scars and steepened valley toes. These features appear to be most common where valley walls are comprised of glacial material (Figure 2) and where the active channel and floodplain impinge against the valley margin (notably from RM 2.1-3.2), suggesting toe erosion by the creek plays a role. This is consistent with the large landslide of the late 1990s noted on the same segment of valley wall by Skillings-Connolly, Inc and Simons and Associates (1999).

Stream Profile

The stream profile of Vance Creek (Figure 6) is notably concave up, with slopes decreasing from ~0.8% to ~0.1% over the course of the reach. These declines in slope are continuation of slope declines from the canyon reach upstream of RM 4.2, where grades exceed 2.5% (BOR, 2011). With only a 1.5-fold gain in drainage area along the project reach (from 16 to 24 mi^2), the roughly 8-fold decline in gradient indicates a roughly 80% reduction in overall stream power. Although this stream power calculation is simplistic, it does suggest a reduction in sediment transport capacity and tendency for sediment deposition. These longitudinal declines in stream power also suggest the reach is likely to function as a “response” reach, which are reaches that are naturally dynamic and responsive to watershed disturbances (as described by Montgomery and Buffington, 1997).

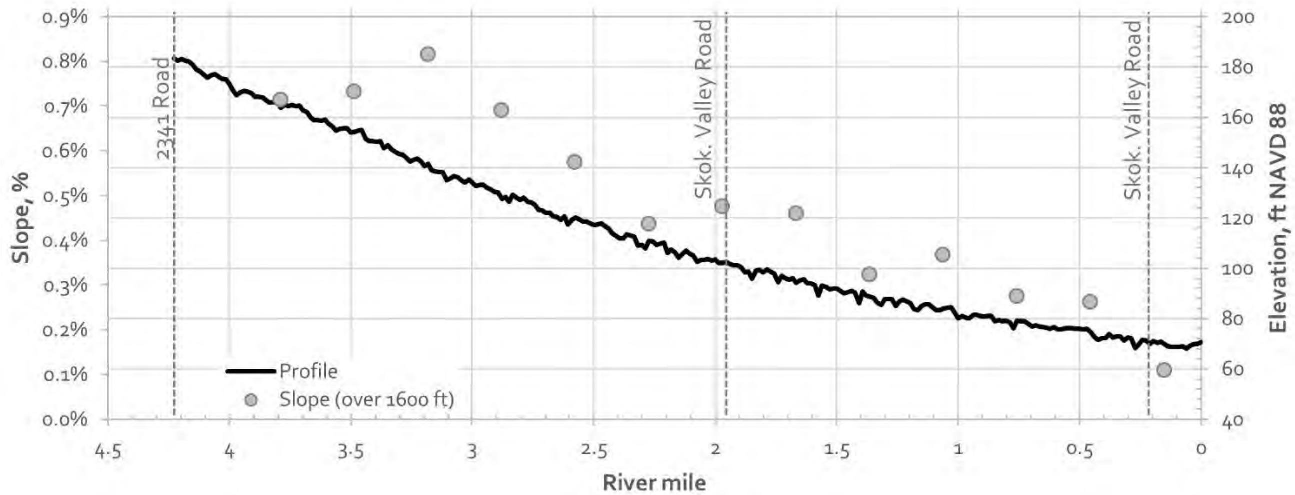

Figure 6 Longitudinal profile of the project reach as extracted from the 2016 topobathymetric LiDAR.

Sediment Size and Transport Capacity

Longitudinal patterns in sediment size and transport conditions were assessed through field measurement of grain sizes and basic modeling of sediment competence. Pebble counts (Wolman, 1954) collected at 18 gravel bars along the creek reveal that bed material size distributions fall largely in the medium gravel to fine cobble size ranges. Median diameters (D50s) are typically coarse gravel. Longitudinally, sizes are relatively consistent with exception of apparent fining in the lowermost mile of creek (Figure 7).

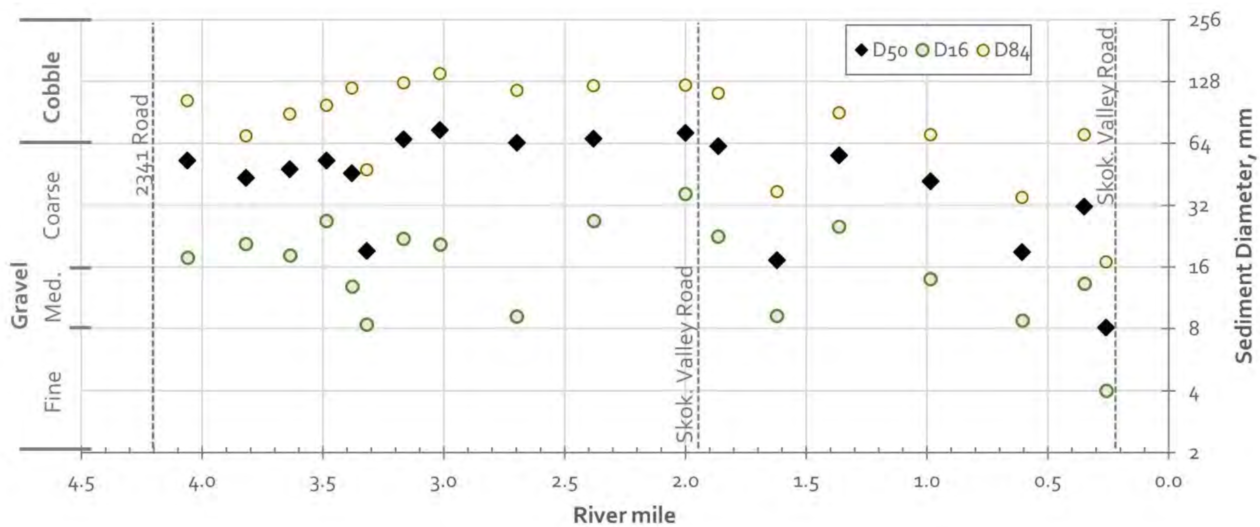

Figure 7 Measured sediment diameters on gravel bars along the reach. Wolman (1954) methods were used.

Hydraulic modeling by Cardno for this study informed the relative competence of Vance Creek to carry sediment of varying grain sizes. Using the shear stresses output from the model for the 2-year flood flow, combined with the Shields criteria for incipient motion, we calculated the size of gravel just beginning to move based on modeled hydraulic conditions (this result is often referred to as the “critical diameter”).

The results (Figure 8) show critical diameters that generally decline downstream through the reach, as would be expected given the declining slopes noted above. From the upper to lower limits of the project reach, the modeled critical diameters decline by roughly 70%, which compares well with calculated reductions in total stream power. The modeled values also compare reasonably well with the observed grain sizes along the creek. A possible exception to this agreement occurs in the channel segment from RM 3.3 to 4.2, where the bed is finer than modeled critical diameters. The finer bed in this location may be explained by a particularly high tendency for sediment to deposit as the creek emerges from the canyon just upstream (Buffington and Montgomery, 1999).

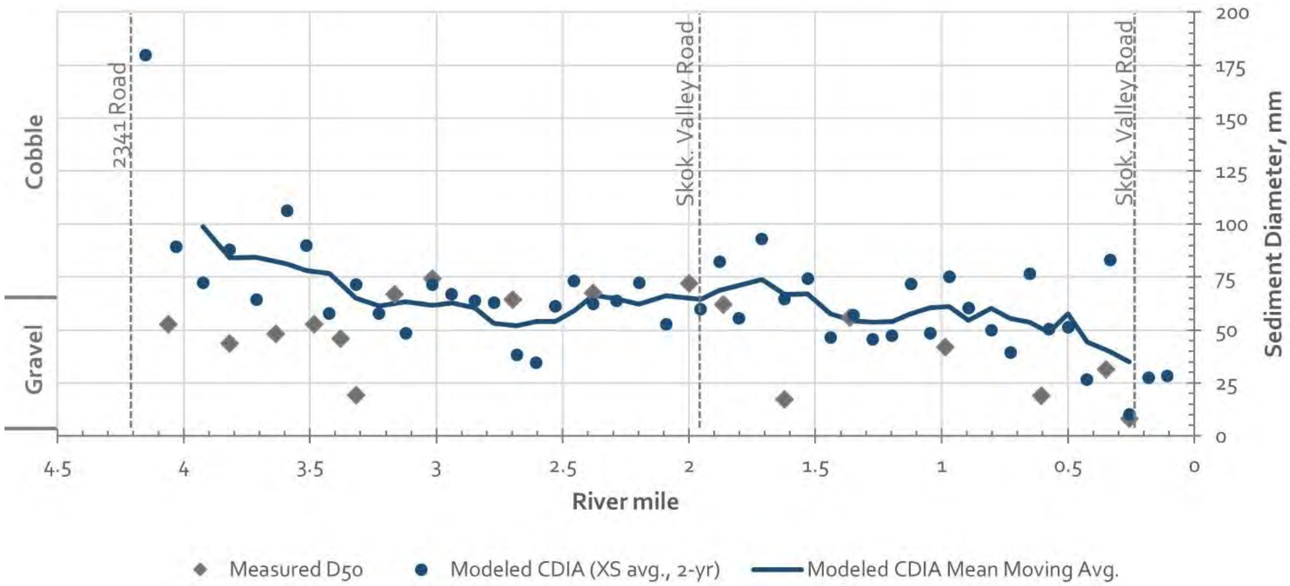

Figure 8 Modeled critical diameters (CDIA) at the 2-year flood based on 2D hydraulic modeling by Cardno for this watershed study. Critical diameters experiencing incipient motion were calculated assuming a Shields parameter of 0.03. Average values correspond with those values measured along cross-sections spanning the mapped active channel.

Channel Planform

The channel pattern also transitions over the course of the reach. One indicator of channel pattern is active channel width, which is the width of the channel defined by the sum of wetted channel plus adjacent gravel bars. Broad active channel widths are found just below the canyon mouth, with steady declines in width toward the mouth (Figure 9). Sinuosity also decreases downstream, with values of ~1.5 and ~1.2 in the upper and lower halves of the project reach, respectively (although BOR [2011] notes some degree of historic straightening in the lowermost creek) as well as major changes in the confluence location as discussed below.

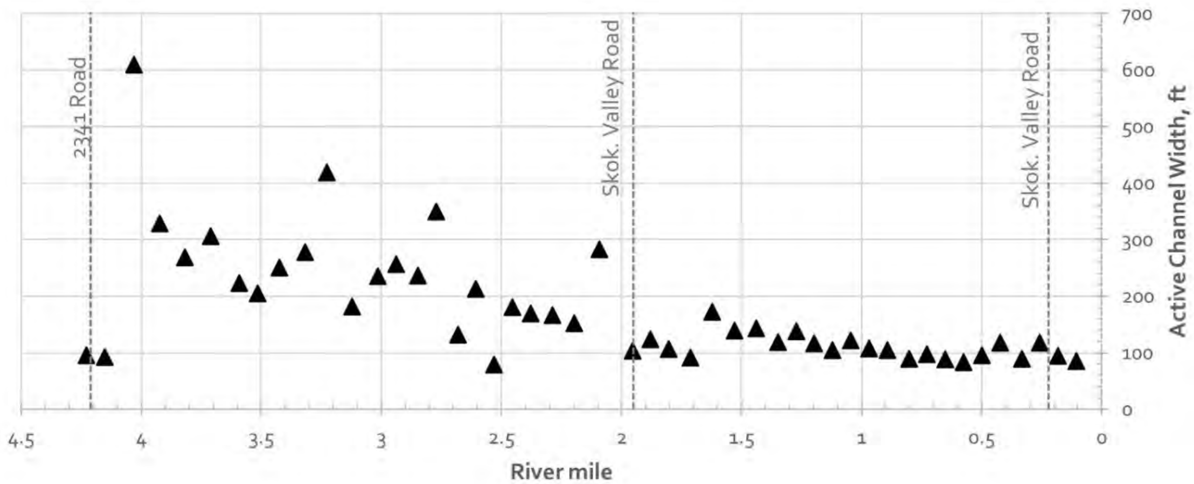

Figure 9 Active channel widths (2016) along the project reach.

The classification of planform pattern is of particular interest for habitat and restoration considerations, particularly with respect to multi-threaded island braided (anabranching) streams which historically were more prominent in Pacific Northwest streams prior to logging and large wood removal. Of the four main pattern types (straight, meandering, island braided, and braided) noted by Beechie et al. (2006), island braided channels have been shown to support some of the highest instream and floodplain habitat quality.

For the most part, the existing channel pattern ranges from straight in the lowermost reach to meandering in the uppermost reach. However, the stream segment from RM 2-3.5 has incipient features of an island braided stream, where several young, vegetated islands are present and appear to be nucleating around logjams. Mapping by BOR (2011) indicates that the islands in this segment have indeed been increasing since 1965, whereas vegetation island area in other portions of the reach have had no discernable trend. Because the existing planform is surmised to have transitioned away from its historic condition due to anthropogenic disturbances, we plotted the reach relative to regional channel pattern domains developed by Beechie et al. (2006) (Figure 10). The portions of the reach above about 0.4% slope, or roughly the upper half of the reach, plot within the island braided domain. In contrast, the lower two miles plot within the domain of straight and meandering patterns.

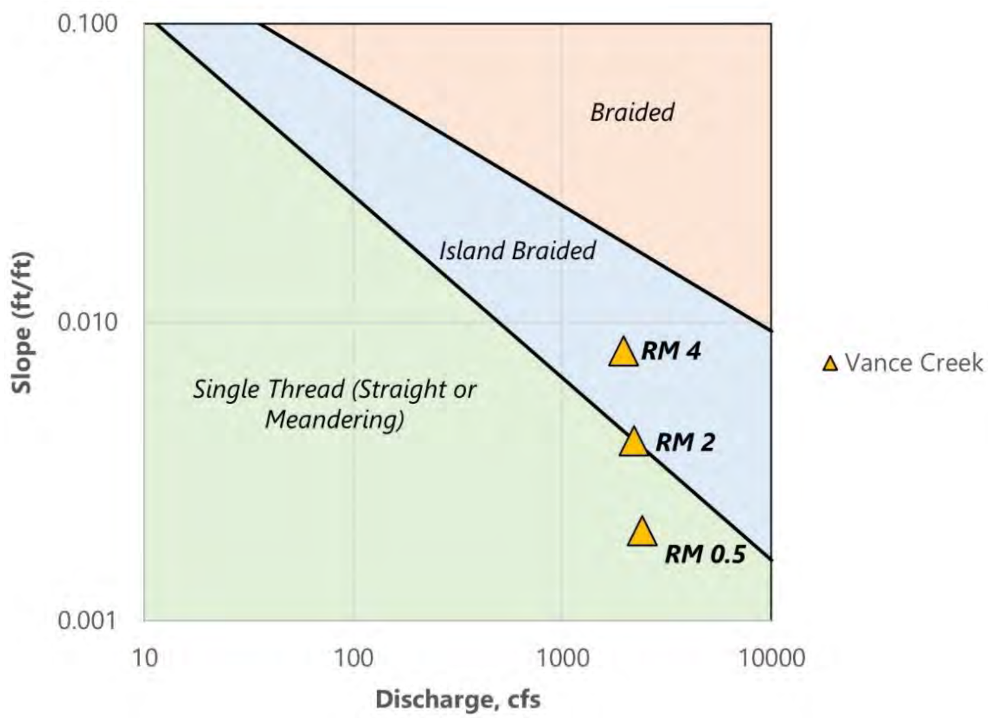

Figure 10 **Slope-bankfull discharge plot showing the range of slopes found in the project reach relative to planform pattern domains defined by Beechie et al. (2006).**

8. History of Stream Elevation Changes

Patterns and histories of stream incision and aggradation are key to the sediment dynamics and watershed responses to potential disturbances (natural and anthropogenic). To the degree possible, we estimated rates of vertical channel change on varying timescales to understand broader trajectories in the project reach and how they may have changed through time.

Landform-Based Interpretations

In the absence of detailed accounts or historical measurements, valley-bottom landforms provide context on the nature and approximate rates of stream evolution over periods that pre-date European settlement in Vance Creek. In the study reach, BOR's (2011) geomorphic mapping, radiocarbon dating, and historical channel mapping in combination with terrain information provide a foundation to assess landform relationships and their relative ages over these longer timescales.

The broad terrace covering a large proportion of Vance Creek's valley (as noted in Section 7 above) represents one marker for longer-term stream bed changes. For much of the valley length (roughly the upper ¾ of the project reach), this terrace covers 60-80% of the valley width and is roughly 8-12 feet above the river channel and active floodplain. In multiple instances along the valley, small ephemeral tributary channels flow across this terrace surface and are either perched as they emerge into the active Vance Creek channel, or flow across steep headcuts just upstream. Together these relationships suggest the terrace has indeed been disconnected from the creek via subsequent channel incision.

BOR's (2011) radiocarbon dating of multiple exposures of alluvial material along this terrace (4 separate samples between RM 1.5 and 4) provide a measure of terrace deposition. Dates of these samples range from ~500-1300 years before present (locations are shown in the attached map). Because the radiocarbon samples were collected from fluvial deposits, the ages suggest that Vance Creek ran over this surface from before 1300 years to at least 500 years before present. Therefore, the period of incision that separated the terrace from the active creek probably occurred within the last 500 years. This suggests terrace abandonment may have occurred in the Little Ice Age (a cooler period in the Pacific Northwest from roughly 1550-1850 AD; Burbank, 1981). Together, the height and probable age (assumed 500 years) of the terrace suggest a minimum average incision rate of about 2 feet per century (if the onset of incision occurred more recently, the rate would be greater than 2 feet per century).

Inset within this broader terrace are subtler abandoned floodplain levels that provide a more recent record of stream incision. One set of abandoned floodplains, which are shown to be largely dry during the modeled 100-year flood, are present on the right and left banks from RM 3.5-3.7 (see attached maps). These terraces sit about 1 foot above the active floodplain level and were abandoned by the creek in about 1980 (based on channel mapping BOR, 2011). Channel mapping further indicates the adjacent active floodplain was formed in about 2000, suggesting that 1 foot of incision occurred in the intervening time period. This produces an estimated incision rate of about 0.5 foot per decade for that period from 1980-2000.

At RM 1.9, an aerial photograph captured in 1938 shows an abandoned oxbow channel devoid of vegetation, suggesting it had just recently been abandoned by Vance Creek (Figure 11). Based on LiDAR terrain, relative elevations of preserved and present-day point bar tops at this location are separated by about 2 feet. Together these data indicate an average incision rate of 0.2-0.3 ft/decade over the last ~80 years.

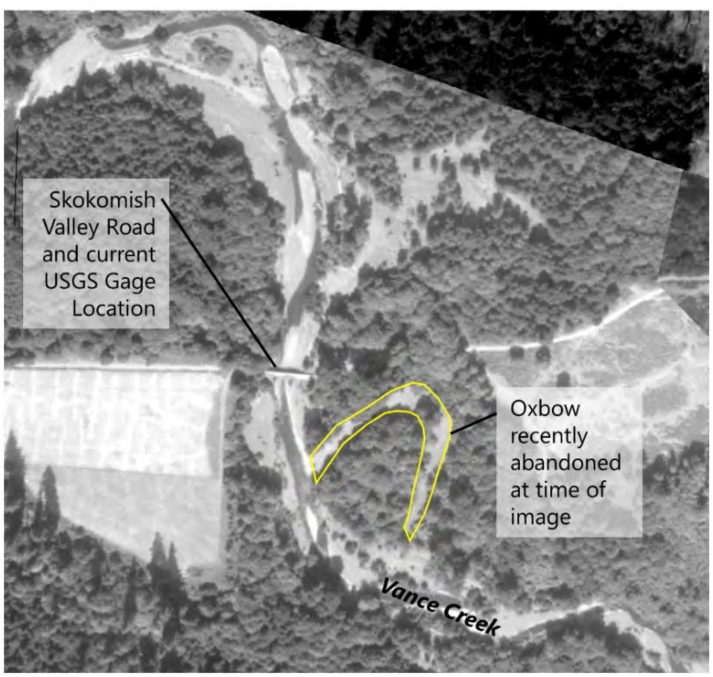

Figure 11 Aerial photograph captured in 1938 showing a channel oxbow that apparently had been recently abandoned by the creek.

The change in floodplain character and topography at RM 1 (as noted in Section 7) from the pronounced fluvial terraces upstream to the low convex floodplain signals a longitudinal shift in erosional regime (Figure 5). Convexities in floodplains of this nature are commonly formed by streams experiencing net sediment deposition through time. In aggrading reaches, channels build alluvial ridges, which in turn promotes flooding that builds levees sloping away from the channel (Nanson and Croke, 1992). Incidentally, the lower reach has historically been the focus of flood control efforts in Vance Creek, with several small informal levees visible in LiDAR and noted in the historical analysis by BOR (2011).

Measured Bed Elevation Changes (Recent Decades)

Bridge Inspections

Mason County bridge inspection measurements at the two Skokomish Valley Road bridge crossings provide direct measurements of recent bed trends at single points in the stream. These surveys show contrasting trends at the two locations, with incision at the upper bridge of about 1.5 feet per decade, and aggradation at the lower bridge of 4.5 feet per decade (Figure 12).

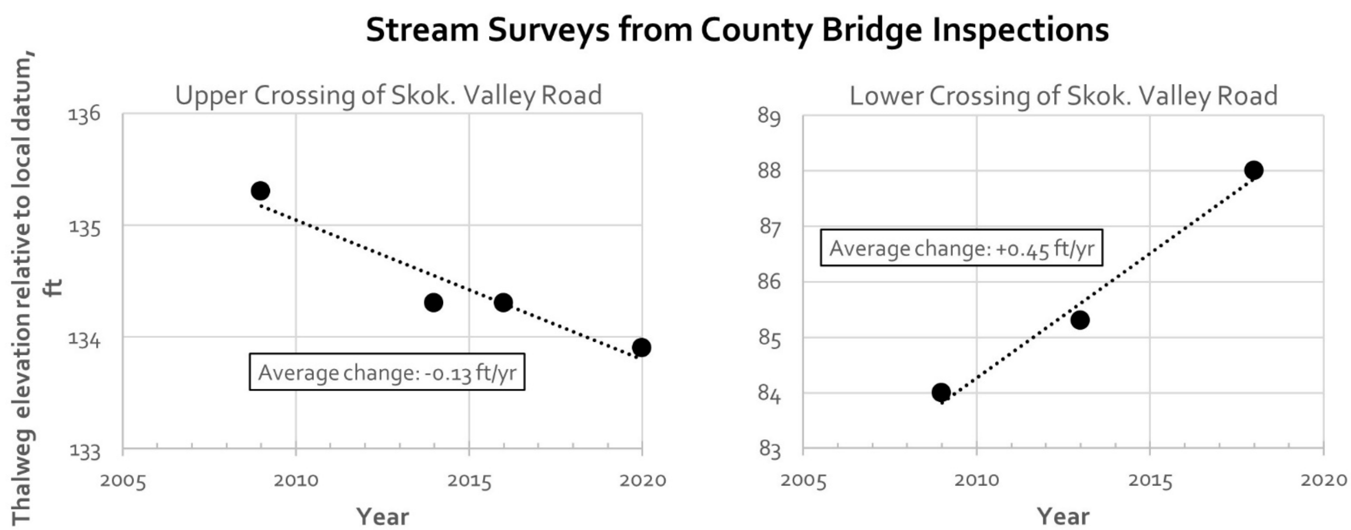

Figure 12 Thalweg elevations surveyed during bridge inspections of the upper and lower Skokomish Valley Road crossings (Mason County). The lower crossing is referred to the "Vance Creek Divide" bridge in Mason County engineering records.

Longitudinal Thalweg Change (2009-2016)

Comparisons of thalweg elevations from 2009-2016 (comparing surveyed thalwegs by BOR and LiDAR based measurements) provide a longitudinal picture of bed elevation changes (Figure 13). These data show general stability in the upper most reach (above RM 3.5), net incision of ~1-3 feet (1.5-4 feet per decade) in middle portion of the project reach (~RM 3.5-1), and a downstream trend toward aggradation in the lowermost mile. In this lowermost mile, the maximum aggradation rate of about 4.5 feet per decade occurs at and just downstream of the Skokomish Valley Road bridge (no data points are below this point). These results generally agree with inspection related measurements at each of the bridges.

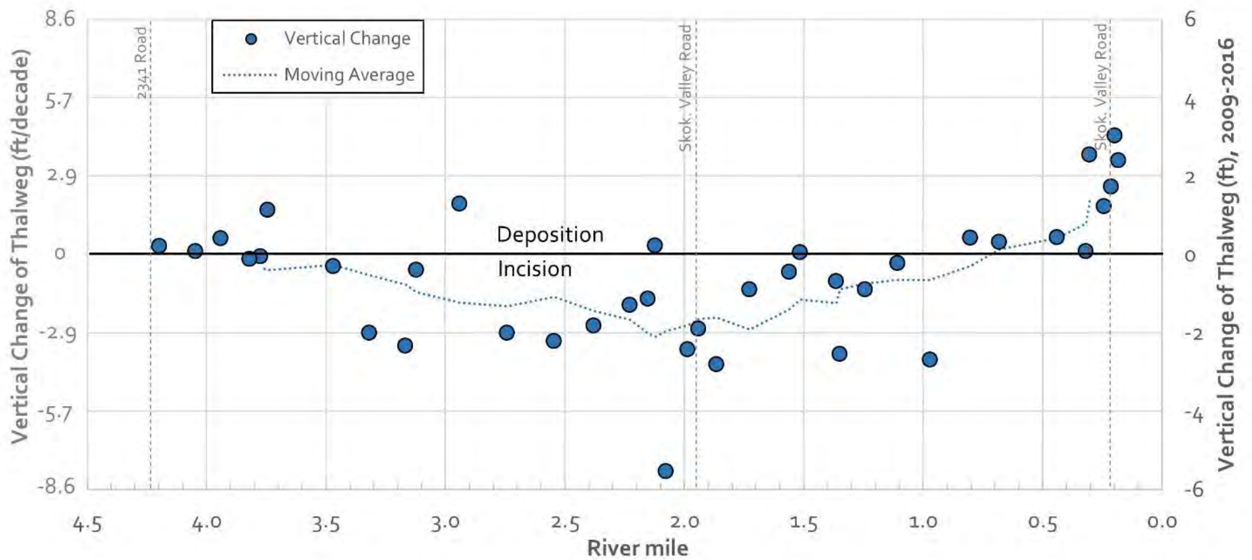

Figure 13 Longitudinal measurements of vertical thalweg change from 2009-2016. Elevations are taken from topographic survey (BOR, 2009) and topobathymetric LiDAR (Quantum Spatial, 2016). Road crossings are shown.

Average Bed Elevation Change (2002-2016)

Bed elevations were also compared for the 2002-2016 period using the corresponding LiDAR data. Because the LiDAR data collected in 2002 did not capture areas below the water surface, thalwegs could not be compared directly as with previous datasets. However, average elevations of the broader active channel were compared after undertaking the terrain processing and binning steps outlined in Section 6. Figure 14 shows the average vertical change in each one of these longitudinal bins.

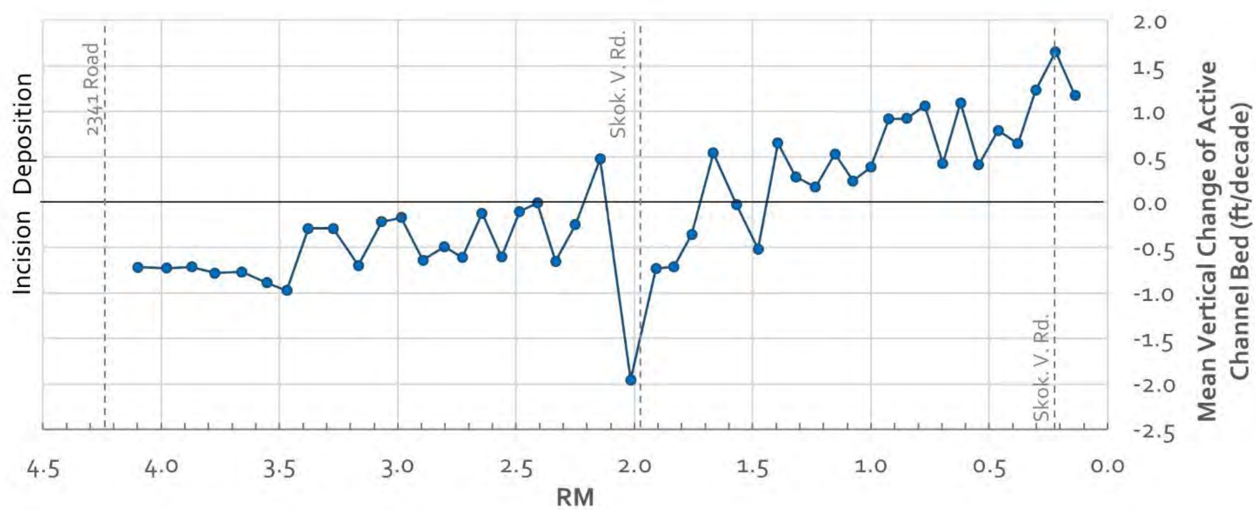

Figure 14 Average rates of bed elevation change in the active channel area as measured for periods between 2002 and 2016 LiDAR flights. Individual data points represent the average change within 400-foot longitudinal slices of the active channel area, after accounting for the eroded volumes on banks.

The LiDAR comparison shows a general trend from incision to aggradation moving downstream, with most of the reach experiencing net incision. From these results, the lowermost 1-1.5 miles of the reach is shown as having experienced net deposition. The LiDAR comparison also shows broadly similar longitudinal patterns but lesser rates of change than those measured at thalwegs. The latter may simply indicate that thalwegs experience faster rates of change than the broader active channel. The 2002-2016 LiDAR comparison period also contained a major flood in 2007 (and the 2009-2016 period did not), which may lead to some of the pattern differences.

Dynamics at the Creek Mouth

The mouth of Vance Creek has experienced multiple historic and ongoing changes which have relevance to present dynamics in the lowermost creek. The first of these changes involves multiple significant upstream shifts in the confluence location. The South Fork Skokomish River is also actively aggrading at the current confluence (Collins et al., 2019). This increasing bed elevation at the confluence impacts the slope and sediment transport capacity of Vance Creek. Specifics of each are described below.

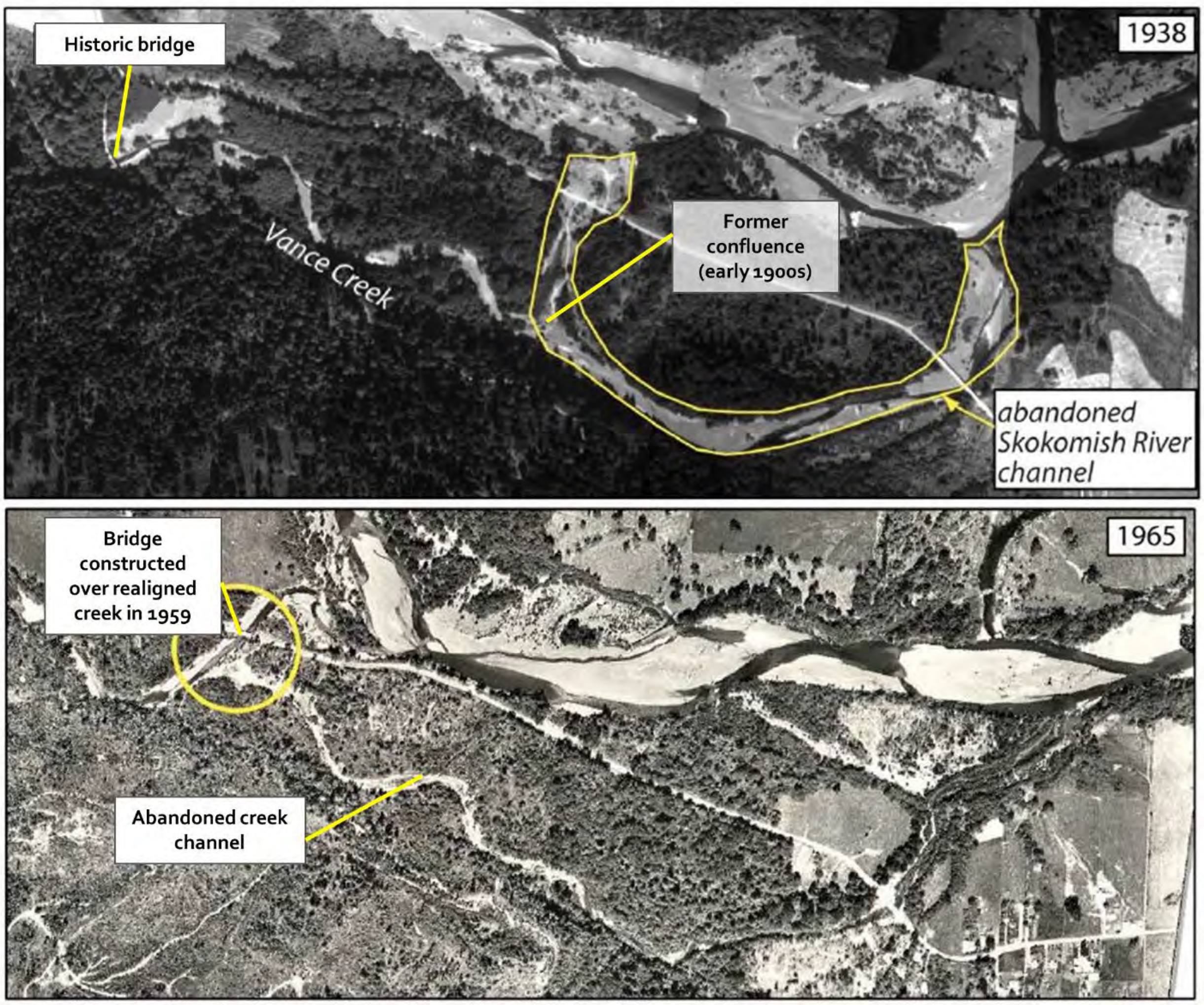

Figure 15 Historic change in the location of the Vance Creek confluence with the South Fork Skokomish River as recorded through historic aerials (modified from BOR, 2011).

In the early to middle 20th century, Vance Creek's confluence with the South Fork Skokomish River experienced two major shifts. The first shift (Figure 15) moved the confluence downstream when a cutoff of the SFSR occurred sometime in the years prior to the 1938 aerial image (BOR, 2011). The second shift, which happened in the 1950s, resulted in the confluence moving to its approximate current position with the present-day crossing location of Skokomish Valley Road (RM 0.2). The specific timing has some uncertainty but probably occurred just before or at the time of bridge construction in 1959 (a date reflected in engineering plans provided by Mason County). BOR cites multiple historic reports that indicate somewhat conflicting causes for this latter realignment, which include diversion by a major landslide from the southern valley wall and artificial diversion to improve runoff. Given the lack of a major landslide observed in Figure 15, the anthropogenic realignment is more likely. The historic (pre-1959) Vance Creek channel is still visible today and currently diverges from Vance Creek just upstream of the Skokomish Valley Road bridge at about RM 2 (Figure 16).

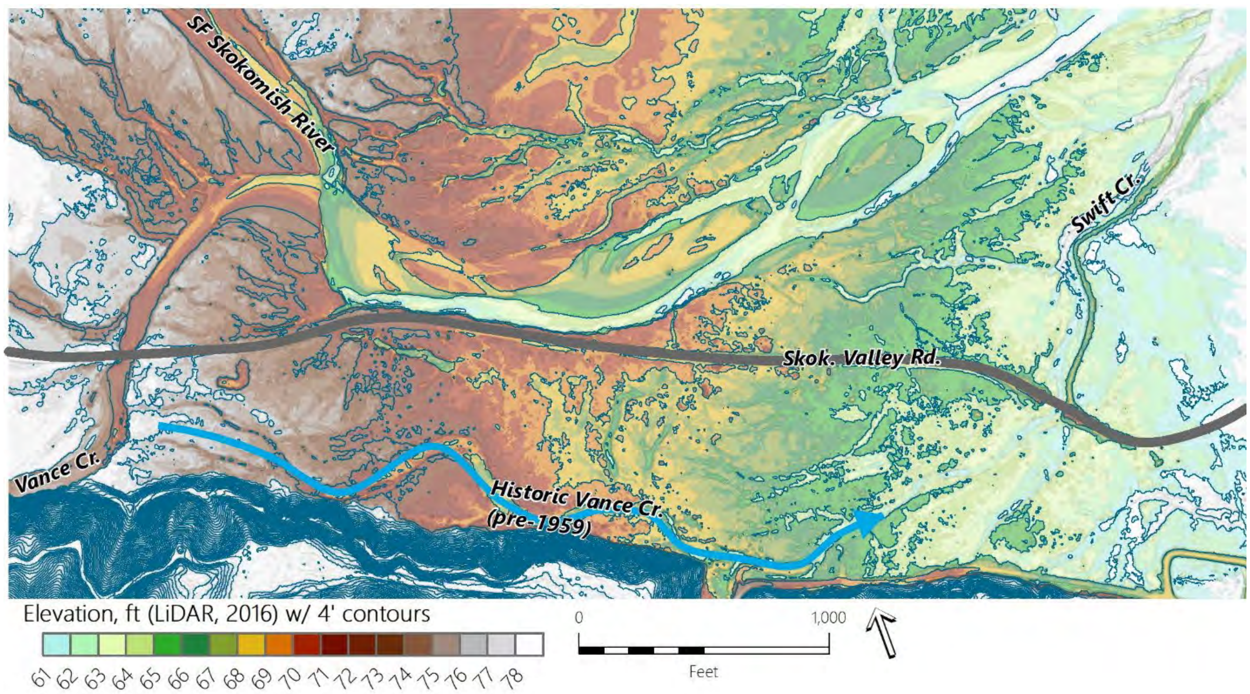

Figure 16 Terrain map of Vance Creek mouth and vicinity. Historic Vance Creek channel (which is still visible in terrain) is shown.

The potential implications historic confluence changes for sediment transport in the lowermost reaches of Vance Creek of these include:

- Realignment to a cross-valley orientation may have reduced channel slope directly.
- The historic (pre-1950s) channel acts as a significant off-take of flood flows that have no clear return to the creek, effectively reducing stream power in the channel itself (Figure 16).
- Based on low observed clearance, the Skokomish Valley Road bridge constructed in 1959 probably acts as a constriction causing backwater effects upstream (HEC-RAS modeling results show this, but the current modeling does not fully represent the bridge geometry).

In recent decades, aggradation of the South Fork Skokomish River at Vance Creek's mouth has been significant, which is demonstrated by repeat cross-section data assembled by Collins et al. (2019)

(Figure 17). Most recently from 2007-2016, cross-sections at the Vance Creek mouth show the South Fork Skokomish River has aggraded roughly 1.5-2.5 feet per decade. Broader reach averages (see bars associated with the 1994-2007 and 2007-2016 periods) show that this aggradation at the Vance Creek mouth has probably increasing through time since the mid-1990s. Together, these rising elevations at the mouth require that Vance Creek's gradient is also becoming less through time.

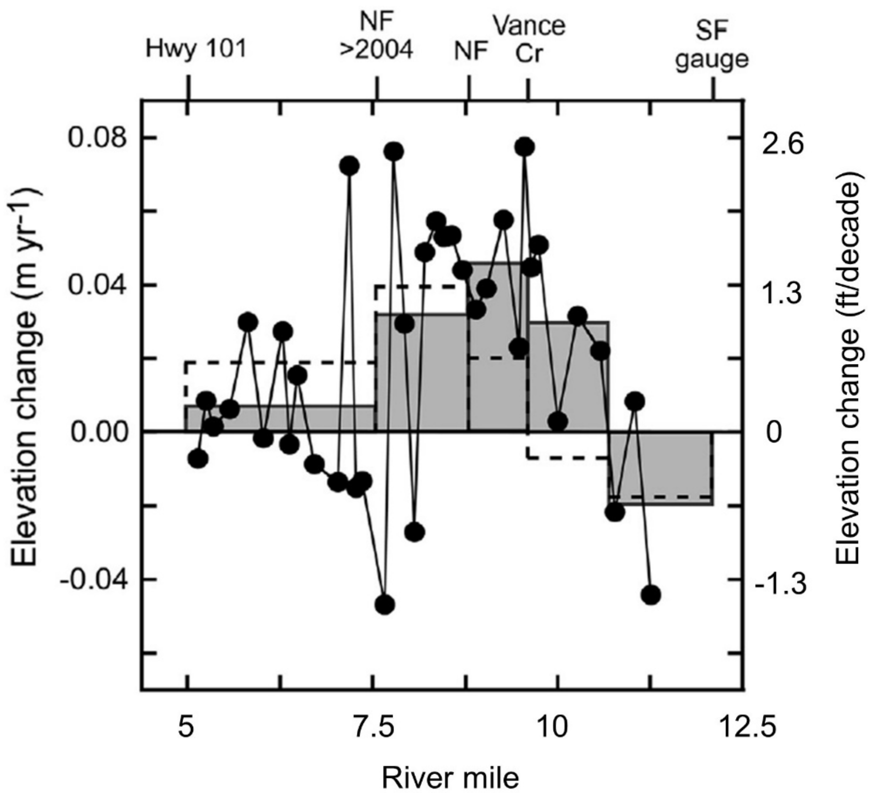

Figure 17 Historic elevation change along the reach of the South Fork Skokomish River including the Vance Creek confluence. Data points show average elevation change from 2007-2016 at surveyed cross-sections. Bar graphs (grey) show average elevation changes for river segments. Dashed bars show averages for the same segments based on surveys from 1994-2007. Figure was modified from Collins et al. (2019).

Together, conditions related to the historic confluence changes plus recent and significant aggradation in the South Fork Skokomish point to an enhanced tendency for sediment deposition in the lowermost creek (beyond what might be expected from the broader decline in sediment transport capacity discussed in Section 7).

It is also worth noting that past studies have called out the historic Vance Creek alignment (Figure 16) as being a potential pathway down which Vance Creek could avulse (e.g. Skillings-Connolly, Inc and Simons and Associates 1999). Sediment deposition in this segment of creek has potential exacerbate that potential.

Summary of Bed Changes

The history of bed changes compiled here (Table 2) includes a broad domain of primarily bed degradation from RM 1-4 and aggradation from RM 0-1.

Degradation in the upper segment has apparently been active for several centuries, with more variability in bed changes apparent in the last century. Within the last century, estimates point to a possible period of stability from about ~1940-1980, and then relatively rapid incision (~0.5-1.5 ft/decade) from 1980 to present. In general, the relative confidence of these estimates is best in more recent periods, and with longer-term averages estimated from the broad terrace. There is relatively less confidence in the 1940-1980 period where estimates are based on relative rates estimated from landforms located in different locations along the river.

The lower mile of Vance Creek appears to have experienced net aggradation over both longer time scales as well as recent decades. Although direct rate estimates are not available for longer time periods, valley bottom landforms (a lack of terraces as well as natural levee deposits along the channel) are suggestive of net deposition over several decades to centuries. Additionally, historical records noted in the BOR (2011) report indicate that the lower creek was a focus of dredging in the early part of the century. The recent measurements since 2002 show net aggradation that increases downstream with notably rapid rates (up to 4.5 ft/decade) at the Skokomish Valley Road bridge and just downstream approaching the mouth. These rapid rates near the mouth appear to be a result of historic confluence changes and the rapid aggradation rates of the South Fork Skokomish River at the confluence.

Table 2 Timeline of estimated incision and aggradation rates by reach

RMs	Time Period	Method or Physical Marker	Incising or Aggrading?	Estimated Rate (ft/decade)	Notes
1.5-4	Last ~500 years	Terrace radiocarbon ages (BOR) and heights (RM 1.5-4)	Incising	0.2	Represents a minimum average rate
1.5-4	~1940-1980	Abandoned oxbow ~ RM 1.9	Balanced (?)	~0	Calculation: net lowering (2’) from 1940-present minus estimated 2’ lowering from 1980-present.
1.5-4	1980-2000	Abandoned floodplains	Incising	0.5	
1.5-4	2000s	LiDAR change, surveys, bridge inspections	Incising	0.5-1.5	Thalweg elevations appeared to have changed more rapidly than active channel. Rate estimates from active channel were selected
0-1.5	Centuries (?)	Inferred from noted floodplain convexity and channel super-elevation	Aggrading	NA	
0-1.5	2000s	LiDAR change, surveys, bridge inspections	Aggrading	1-4	Rate increases downstream toward confluence

9. Bedload Flux Measurements and Yields

USGS bedload measurements allow for direct estimates of flux through time. These bedload fluxes not only are key to understand the sediment budget, but also put Vance Creek into context with other streams in the Skokomish River watershed.

The workflow to assess annual bedload fluxes involved development of a bedload rating curve (relating bedload transport rate to stream discharge), development of bedload predictions based on recorded or estimated stream flows, and summation of daily bedload flux calculations to develop estimates over a key study period from 2002-2016. In order to assess the impact of short-term bedload variability on longer term flux estimates, a Monte Carlo simulation approach was also used to generate the range of likely bedload fluxes over key time periods.

Figure 18 shows the bedload data and rating curve relative to stream discharge developed using the USGS measurements. The rating curve, which was developed using least squared regression approaches, predicts bedload flux (Q_s) relative to stream discharge (Q). For prediction purposes, the rating curve requires application of a bias correction factor (BCF), which was calculated as 1.14 (using methods of Newman [1993]). Additionally, a threshold of initial bedload movement was estimated visually at 500 cfs (on days with flow below 500 cfs, the bedload flux was assumed to be zero).

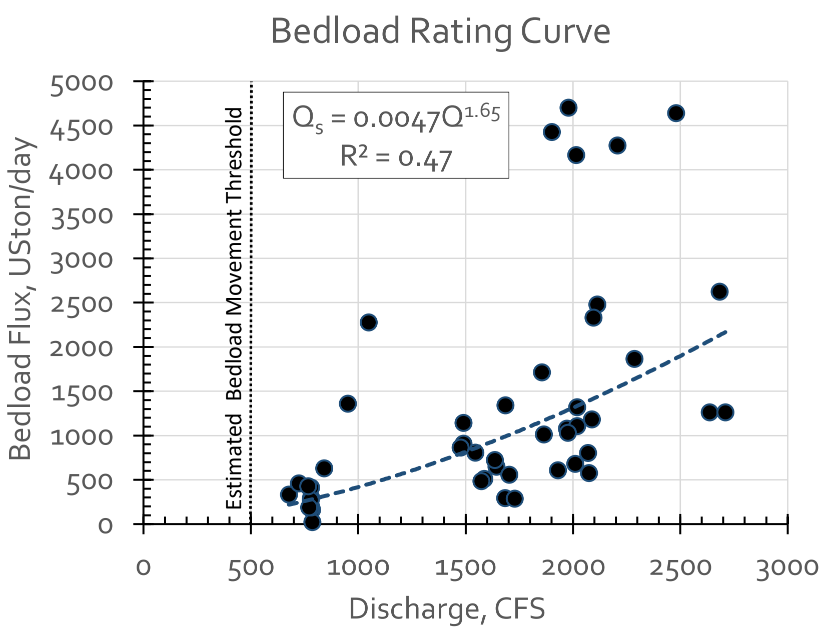

Figure 18 Bedload rating curve developed with USGS measurements (2018-2020) at the gage located at RM 2 (USGS 12061250). The threshold of bedload movement of 500 cfs was visually identified based on the data trends. Prediction of bedload flux using the regression equation shown requires multiplication by a bias correction factor (BCF) of 1.14 (developed using methods by Newman [1993]). The standard error of y (standard deviation of residuals) for log-transformed values was calculated 0.33 and used to define the normal distribution of error for the Monte Carlo simulation.

The rating curve and flow record in Vance Creek together allow us to estimate a history of bedload flux for the period of interest. This first required estimation of daily discharges at the Vance Creek gage prior to the USGS beginning operation in October of 2018. Flow estimation took a simple regression analysis between coincident Vance Creek and SF Skokomish River flows (see associated report by ESA). The resulting record of daily flows and bedload fluxes are shown in Figure 19.

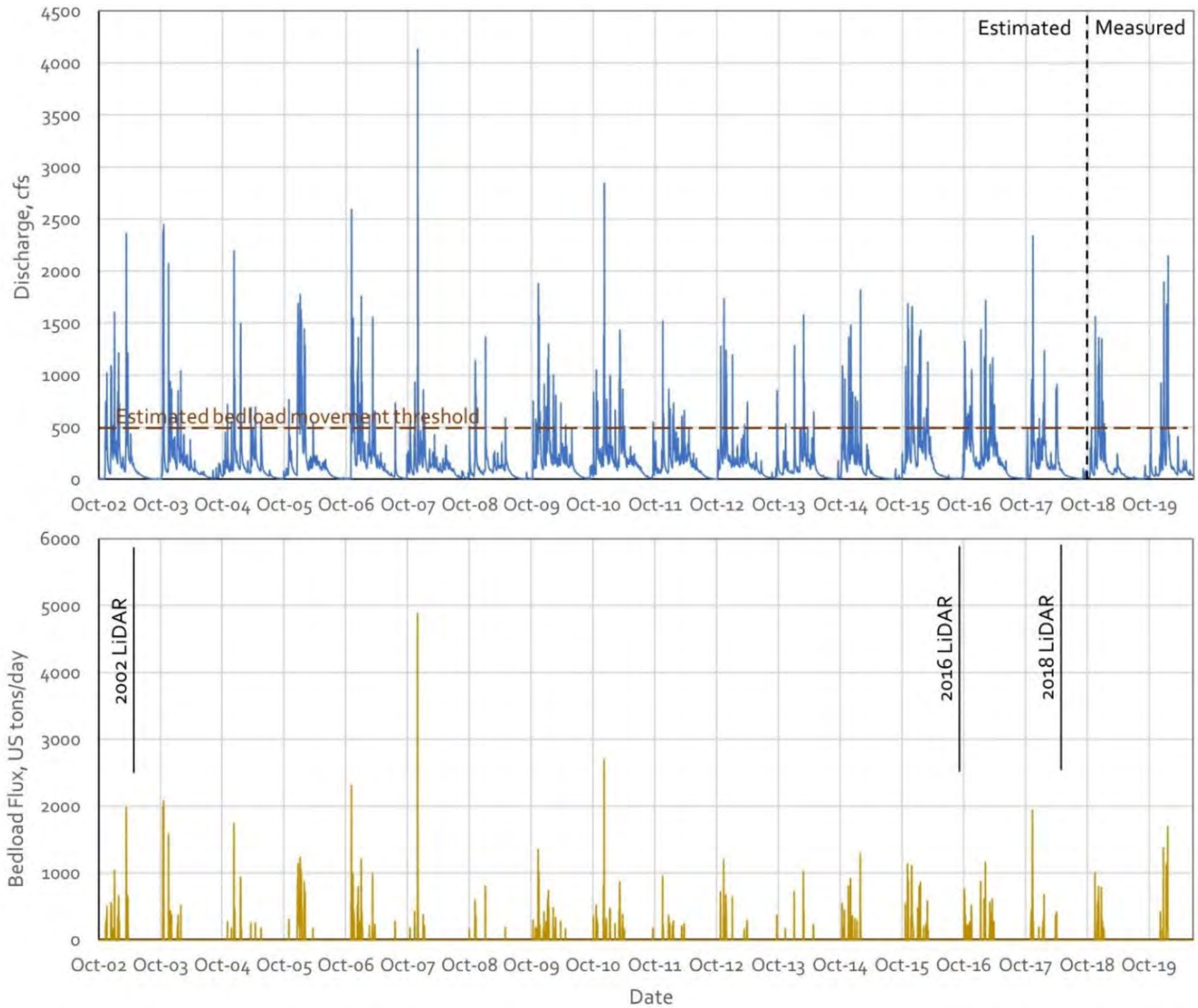

Figure 19 **Mean daily streamflow and bedload flux in Vance Creek (USGS gage 12061250) from 2002-present.**

Summation of predicted daily bedload fluxes shown in Figure 19 is the simplest and most direct way of estimating total bedload flux over a given period. However, this approach ignores the significant variability in the actual bedload movement as seen in Figure 18. Given this variability and scatter in the data, we instead employed a Monte Carlo simulation approach which incorporates this known variability. For each daily estimate of bedload flux, this approach generated a bedload flux estimate based on a randomly generated error value normally distributed (assuming the measured standard deviation of error of the least squares regression fit) around the bedload rating curve. We then iterated this process 1000 times, and recorded the average annual flux (through summation of the randomly generated values) for the 2002-2016 period in each iteration of the Monte Carlo routine.

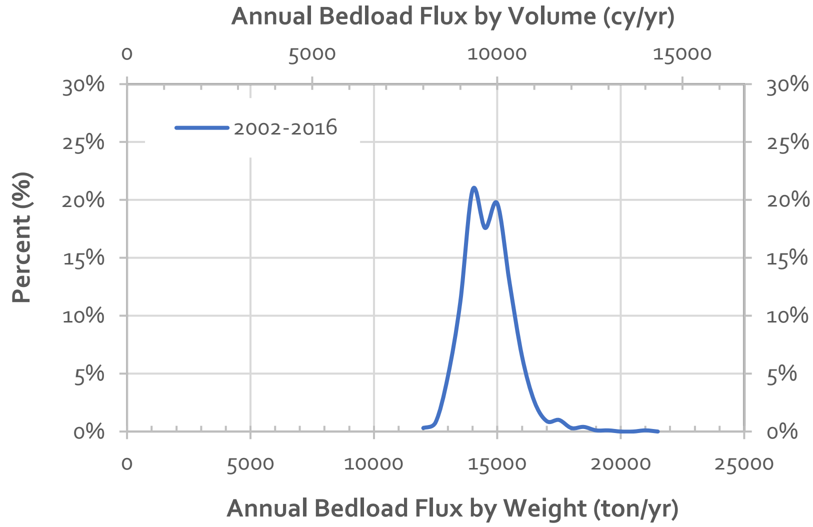

Figure 20 Estimated annual bedload flux as simulated for key analysis periods using a Monte Carlo approach. The graph shows the probability density function of annual bedload flux for 1000 Monte Carlo simulations.

Figure 20 shows the distribution annual bedload flux for the 2002-2016 time period bracketed by LiDAR flights, with a mean value of 14,400 tons per year (9600 cubic yards [cy]/year), with statistics shown in Table 3. Average calculated bedload yields (flux per unit watershed area) equate to about 700 ton/yr/mi^2, which has reasonable agreement with the estimate of 590 ton/yr/mi^2 estimated by Collins et al. (2019) for the mainstem Skokomish River.

Table 3 Summary of annual bedload fluxes as estimated using a Monte Carlo simulation approach.

	Annual bedload flux (percentile)				
Time period	5%	25%	50%	75%	95%
2002-2016 (tons/yr)	12,950	13,700	14,340	14,990	16,160
2002-2016 (CY/yr)	8,630	9,140	9,560	10,000	10,770

10. Sediment Budget

Approach

A combination of LiDAR-based geomorphic change and bedload flux measurements allowed for detailed budgeting of relative sources, sinks, and fluxes of sediment in the project reach over recent decades. A key component of the analysis is a morphologic sediment budget developed using the geomorphic change measured from 2002-2016, which quantifies local changes in the project reach itself. The bedload fluxes estimated for the same 2002-2016 period using the USGS measurements (described in Section 6) inform the total flux derived from both local and upstream sources (i.e., the upper watersheds of Vance and Fir Creeks). Together, these approaches allow us to parse out sediment sources from the upper watershed versus those in the lower valley, which together speak to the broader processes of sediment transfer on a watershed scale.

The morphologic sediment budget included three main types of sediment sources and sinks in the project reach. Within the active channel, we measured changes in sediment storage on the bed in the banks. Because of spatially variable erosion and deposition, the bed acts as both a net source and sink of sediment along the reach. We assumed 100% of the change on the bed was transported as bedload. In contrast, bank erosion is always net source of sediment to Vance Creek. From visual estimation at eroding banks (generally alluvial material with mixed fines, as shown in Figure 21), it was assumed that the eroded bank material partitioned and transported downstream as 70% bedload and 30% suspended load. Discrete hillslope sources were the third type of sediment mapped. These were mapped where discrete and significant areas of erosion were visible adjacent and connected to the active channel. Visual examination of material composition was not conducted, but given the glacial origin of these deposits, it was assumed this material was transported downstream as a 50-50 mix of bedload and suspended load.

A key step in the morphologic budgeting process converted geomorphic change volumes (as measured in bins along the channel) to downstream fluxes of sediment. This calculation involves a summation of all volumetric changes measured upstream of a given point (bin) in the stream. By the simple assumption of downstream movement, this approach allowed us to calculate sediment fluxes sourced from within the reach at each point (bin) along the stream. With this approach, net erosion (i.e., reduction in sediment storage) in a given bin translates to a positive flux downstream; and conversely, deposition represents a net reduction of flux moving downstream.

Figure 21 Example eroding banks in the reach.

Sediment Budget Results

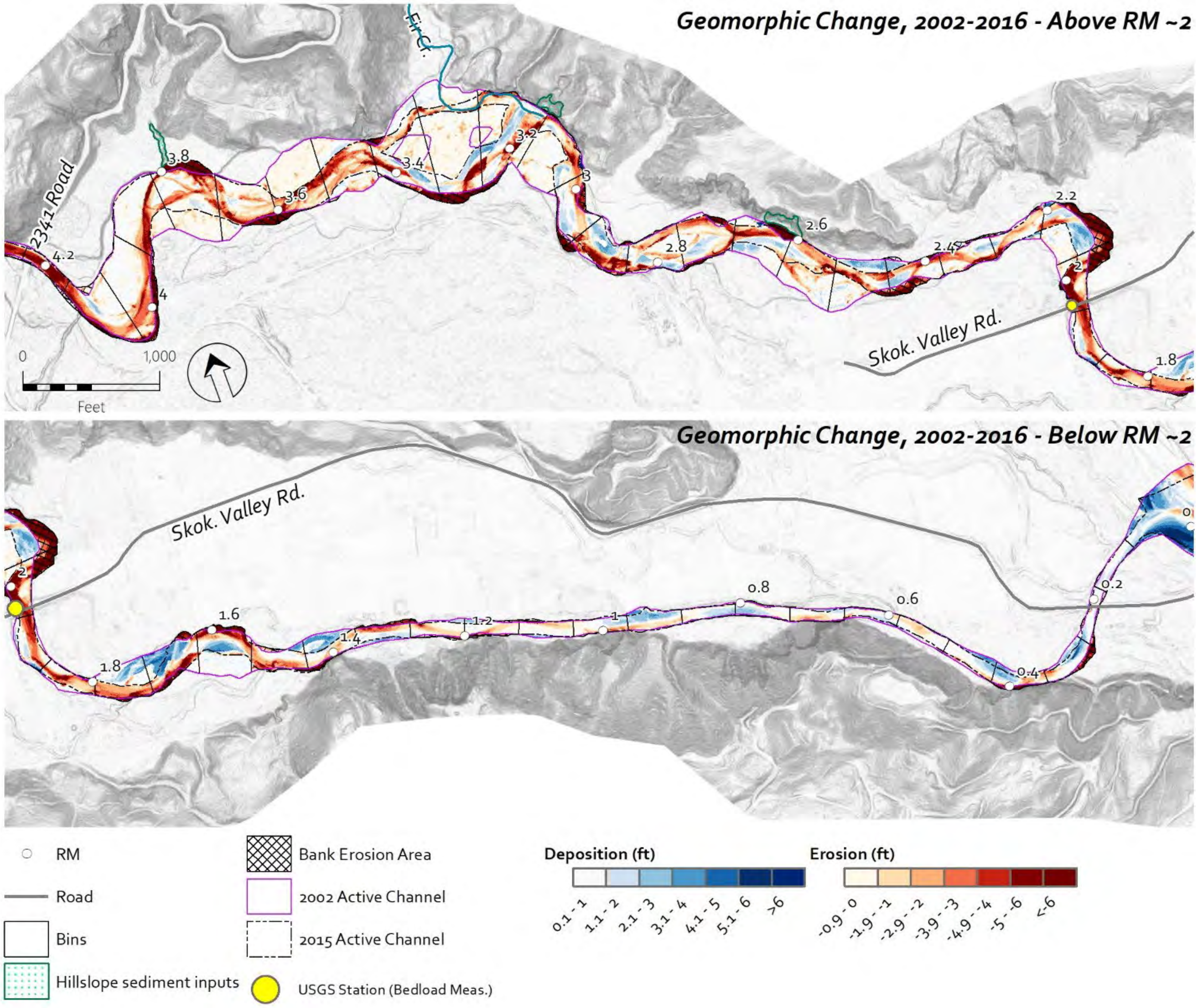

Figure 22 Maps of geomorphic change from 2002-2016, derived from LiDAR differencing. Note, the results shown do not reflect the corrections applied for inundated area during the 2002 LiDAR flight, and so the maps show more erosion than probably occurred in reality. These corrections for inundated area were accounted for in analysis steps subsequent to mapping.

Table 4 Summary of volume changes (CY) by reach from 2002-2016.

	Upstream of USGS Gage	Erosion Reach	Depositional Reach	Full Reach
	RM 4.2-2	RM 4.2-1.5	RM 1.5-0	RM 4.2-0
Bed	-85,700	-91,000	26,900	-64,200
Bank Erosion	-85,200	-92,700	-10,600	-103,300
Hillslope Inputs (Discrete)	-20,700	-20,700	0	-20,700
Sum	-191,600	-204,500	16,300	-188,200

The geomorphic change maps in Figure 22 as well as longitudinal plots of binned volume changes in Figure 23 summarize the measurements of change along the reach. These results show net erosion decreasing in intensity in a downstream direction from RM 4.2-1.5, and net deposition below RM 1.5.

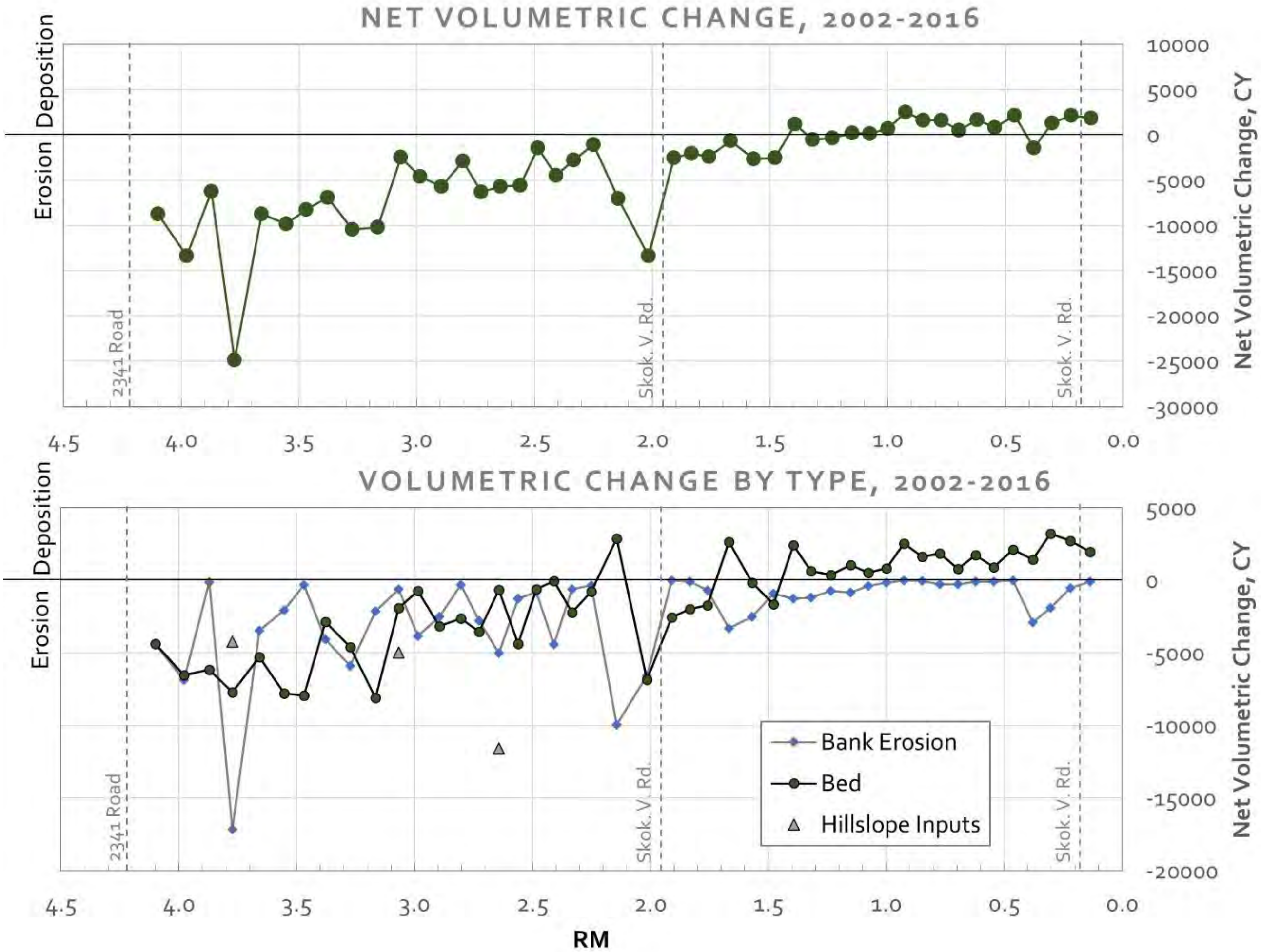

Figure 23 Volumetric erosion and deposition measured from 2002-2016 along the project reach. Top: Net volume change as calculated in 400-foot bins mapped along the combined active channel areas in 2002 and 2016. Bottom: Volumetric changes by type (bed, bank erosion, hillslope inputs). Only non-zero hillslope volumes are shown for clarity.

Erosion in the upper ~2.5 miles is mostly sourced from bank and bed erosion, which each represent about 45% of the total erosion (Table 4). A vast majority of this eroded material is alluvium (either stored below the bed or on adjacent river terraces) that had been deposited by the creek sometime in the past. Therefore, this erosion represents alluvium (i.e., sediment transported by Vance Creek at some point in its history) coming out of storage.

Discrete hillslope inputs represented the remaining 10% of the total measured erosion, sourced at three distinct inputs from the northern valley wall. Two of these were significant landslides at RM 3.1 and 2.6, the lower of which is coincident with obvious lateral erosion at the valley wall toe. This same input at RM 2.6 is adjacent to the large landslide noted to have occurred in the late 1990s by

Skillings-Connolly, Inc and Simons and Associates (1999). The upstream-most hillslope input came from a small tributary incising rapidly into river terrace at RM 3.8. Therefore, a significant proportion of the hillslope inputs are associated with Vance Creek eroding at the valley margin, which is consistent with the general associations made in Section 7 about the coincidence of toe erosion and landslide scars in the broader valley.

In the lower 1.5 miles of stream, net deposition resulted from stream bed aggradation, smaller volumes of bank erosion relative to upstream (due in part to diminished stream sinuosity), and a lack of obvious hillslope inputs (Table 4). The pattern of deposition here is roughly coincident with the zone of reduced sediment transport capacity and patterns of aggradation described in sections above.

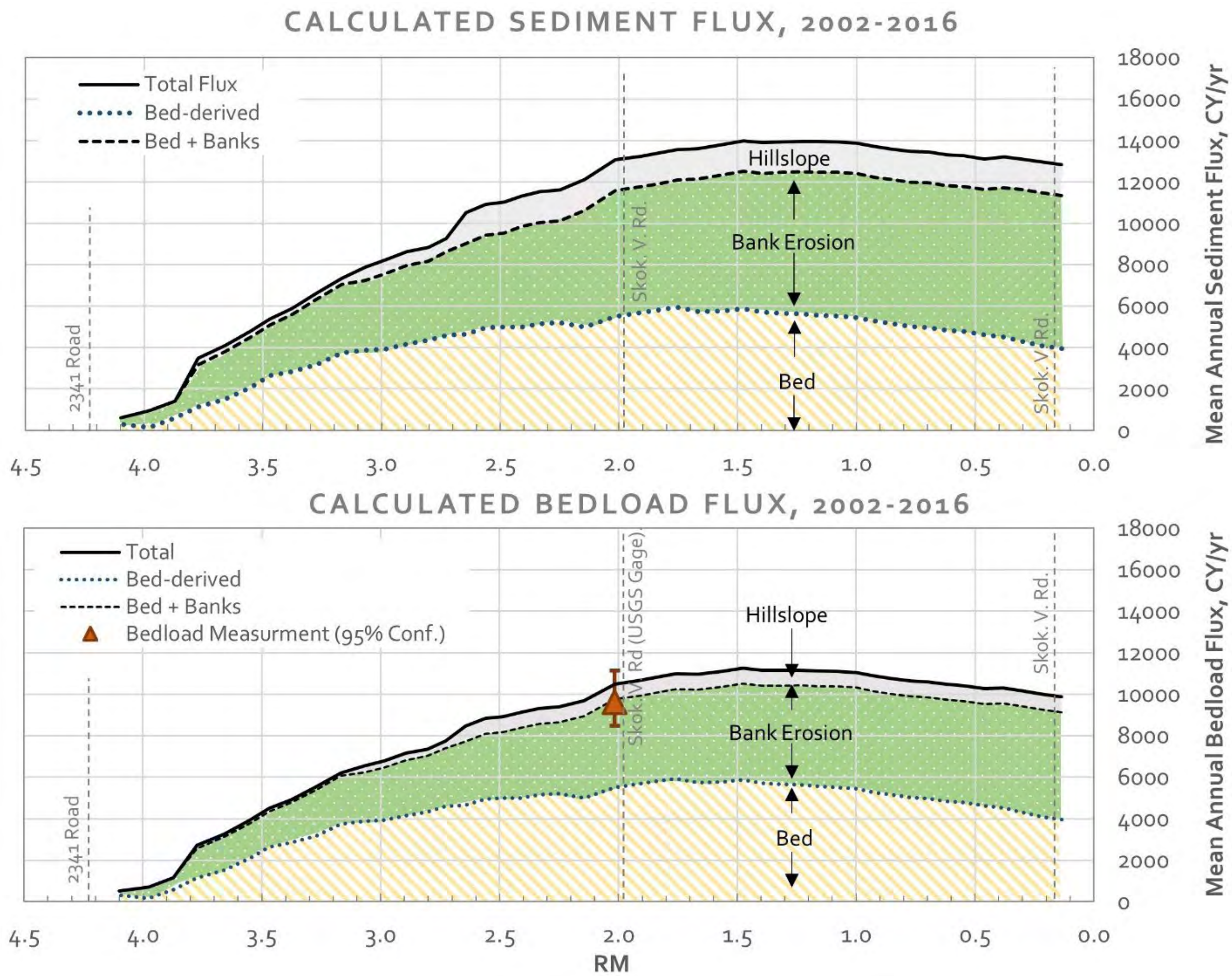

Figure 24 **Calculated sediment fluxes based on longitudinal summation of volumetric changes measured in the project reach from 2002-2016. Fluxes shown in the top plot incorporate the full volume change in beds, banks, and hillslopes. The bottom plot incorporates assumptions about suspended v. bedload in the varying sources of sediment to derive calculated bedload fluxes. The annual bedload flux calculated with the bedload rating is shown for comparison.**

Based on measured volumetric changes, the rates of sediment transport along the reach were also calculated using the longitudinal summation process. Calculated annual sediment loads (Figure 24) increase along Vance Creek from RM 4.2-1.5, reflecting the dominance of erosion in this reach. In the lower 1.5 miles, calculated annual sediment transport rates decreased modestly with net deposition on the bed.

Assuming the suspended load component of eroded material (30% of eroded banks and 50% of hillslope inputs) is flushed rapidly out of Vance Creek, we can then calculate annual *bedload* transport rates, which can then be compared with estimates derived from USGS measurements (Figure 24). At the USGS gage location itself, these morphologic flux calculations (based on accumulated geomorphic change) produce an estimated mean annual flux of 11,100 cubic yards/year for the 2002-2016 period. Of that volume, an estimated 55% was derived from bed erosion, 38% was sourced from bank erosion, and 7% was supplied via hillslope inputs.

The annual bedload flux estimate derived from geomorphic change also falls within the 95% confidence range of mean annual fluxes predicted using the USGS rating curve and Monte Carlo approach for the same period (Figure 24, bottom). This relative agreement in the two estimates implies that local erosion within the lower valley accounted for most or all the bedload passing the USGS gage. Stated inversely, it also suggests that sediment delivery from the upper watershed was minimal during the same period.

Error Considerations

Potential errors in the sediment budget merit consideration prior to further interpretation. For the morphologic sediment budget, the three sediment sources enumerated likely have varying degrees of error in volumetric measurements. Bank erosion and hillslope measurements are considered to be relatively high-confidence measurements because they were measured over smaller areas with more vertical change and therefore are less subject to LiDAR or data-processing artifacts. In contrast, bed change measurements likely had the greatest associated error because of the typically smaller depths of change over broader areas. These areas also required more post processing efforts for inundated area and terrain representation (as described in Section 6). That stated, the LiDAR-based elevation changes on the bed are also reasonably consistent with more direct means of measurement (i.e., surveyed thalweg change and bridge inspection records), adding a degree of confidence to the data.

The estimates of annual flux derived from USGS measurements also have potential errors to consider. In many respects these errors relate to the short time over which measurements were made (2019-2020) and the potential for a changing rating curve through time that may reduce validity for the 2002-2016 period. While the Monte Carlo analysis evaluated the effect of data scatter around the developed bedload rating curve, it did not address potential variation in the rating curve itself. Despite some of these limitations, we are encouraged by the agreement between these estimates and other published estimates of bedload yield in the broader Skokomish River watershed.

Summary Points of the Sediment Budget

The morphologic sediment budget suggests that erosion within the project reach itself (particularly the upper half) is the overwhelmingly dominant contributor of sediment flux over the period (2002-2016) studied. This represents a significant finding because it also implies that sediment delivery from the upper watershed was limited over the same period. The relative contributions of bed, bank, and hillslope sources to bedload passing the USGS gage are estimated to be 55%, 38%, and 7%. The minimal flux from the upper watershed combined with local erosion of alluvial sources implies episodic delivery to and erosion of material from the lower valley (i.e. the project reach). As evidenced by the mixed sources of eroded alluvial material (i.e. multiple century old alluvial terraces in addition to the streambed material of unknown age), this episodic sediment transfer process must happen on varying timescales.

The sediment budget also indicates that the deposition measured in the lower 1.5 miles of the creek represented a fairly small proportion (10%) of the volume transported to the lower reach.

11. Interpretation and Synthesis

Overview of Reach-Scale Fluvial Processes

The geomorphic assessment paints a clear picture that lower Vance Creek is a true "response" reach in almost every sense of the definition laid out by Montgomery and Buffington (1997). Response reaches are generally those with low capacity to transport the sediment that is delivered from upstream, which makes them particularly responsive to watershed disturbances such as changes in sediment supply and/or hydrology. This condition is particularly true for response reaches that lie directly downstream higher gradient "transport" reaches that efficiently transport sediment through to lower gradient reaches below.

The study reach fits that exact landscape positioning, with relatively steep (~3%) and confined canyon reaches upstream that rapidly transition to low gradient, unconfined reaches in the project reach. This transition occurs not only at the canyon mouth, but also along the project reach where slope declines from 0.8% near RM 4 to 0.1% at the mouth, and sediment transport capacity reduces by about 70% over that same reach. The morphologic implications of this transition are recorded by the wide active channels (presumably sediment-rich) found in the uppermost reach which decline moving downstream (Figure 9). Additionally, recent aggradation during the 20th and 21st century (discussed further below) in the South Fork Skokomish River appears to have reduced sediment transport capacity in Vance Creek through time. Overlaying on these longitudinal reductions in sediment transport capacity are significant gains in sediment flux (resulting from bed and bank erosion in the upper reach) along the reach. In combination, the reductions in transport capacity and the increasing sediment lead to deposition in the lowermost reach (particularly below RM 1).

Planform patterns also vary along the reach. Existing planform patterns found in the reach include a meandering pattern above RM 3.5, incipient island braided (anabranching) pattern from RM 3.5-2, and a nearly straight pattern in the lower 2 miles. From field observations in the segment from RM 3.5-2, incipient vegetated islands appear to be forming almost exclusively around woody debris. As has been shown by several studies (e.g., Beechie et al., 2006), stream planform is a fundamental indicator of overall instream and floodplain habitat quality (particularly island braided patterns) that can also be degraded significantly through riparian logging and instream wood removal. Although we have little detail on the nature of these actions and their direct impact, it is clear the riparian zone was logged (probably just prior to 1900 when the valley was first settled) and wood removed for flood conveyance. Comparison with regionally derived predictors for channel patterns indicates that the upper half of the reach is most likely to support an island braided (i.e. anabranching) pattern, whereas the lower 2 miles are more likely to support single-thread (meandering or straight) patterns.

Stream Evolution relative to Watershed (Natural and Anthropogenic) Disturbances (~RM 1.5-4)

Due to its position just below the canyon mouth, the creek segment from RM 1.5-4 is most likely to respond to watershed-scale disturbances. In general, the assessment of bed elevation changes revealed that the upper 2.5 miles of the project reach has experienced net degradation of ~0.2 ft/decade over at least the last several centuries. This long-term estimate of lowering is derived from a prominent fluvial terrace surface (covering much of the upper valley bottom) with radiocarbon ages of about 500 years. The relatively long-term degradational state probably was set up by a past climatic period when large volumes of alluvial material were deposited in the valley (forming the broad terrace). Subsequent climatic changes must have led to more favorable transport conditions (some combination of less sediment production or greater stream flows) that allowed the creek to incise and establish an equilibrium profile. That period of transport appears to have persisted for several centuries leading to present day.

Expectedly estimates and measurements made over finer timescales in the 20th and early 21st century reveal some more variation in bed change. We estimate a period of relative balance from ~1940-1980 (as estimated through relict floodplain landforms), and generally faster rates of ~0.5-1.5 ft/decade in the last ~40 years (as estimated with various terrain datasets). In general, the confidence level in these rates of change are greater for the most recent period of relatively rapid incision (when multiple measurement- and landform-based sources converge on similar rates). Confidence levels are relatively lower for the 1940-1980 estimate of balanced change, which is based on relative rates measured at two landforms in separate segments of the river.

Potential logging-related sediment pulses and downstream aggradation have potential to inform watershed-scale restoration in Vance Creek and the Skokomish River watershed more broadly. Therefore, the assembled history of bed changes overlain with the history of logging is of interest. From the estimates above, the bed history in RM 1.5-4 is one of predominantly degradation, with the only possible deviation being a period of balance from 1940-1980. This period of apparent bed stability (i.e. cessation of degradation) coincides with the early half of the intense logging period (1950s-early 1990s) in the upper watershed (Figure 4) which may initially suggest that a logging derived sediment pulse caused the creek to temporarily fill in with sediment. However, several factors challenge this interpretation, including: (1) our low relative confidence in the 1940-1980 stability estimate, (2) the expected lag times in transport of sediment from the upper watershed to the lower watershed (i.e. an aggradation signal is more likely to occur late rather than early in the logging period), and, (3) the DNR-estimated volumes of sediment delivered from landslides during the logging period (Table 1) are relatively small (<2,000 cy/yr) compared to the estimated bedload flux (~9,500 cy/yr) passing through the valley.

Although the bed changes provide little to no evidence of a major logging-derived sediment pulse, mapping by BOR (2011) does indicate channel simplification in the RM 1.5-4 segment in the middle part of the 20th century. They found that vegetated island area (a common indicator of planform complexity and multiple channel threads) from RM 2-3.5 declined from the 1930s to a nadir of zero in the mid-1960s. Since that point, island area has steadily climbed to present day, suggesting some recovery in the degree of channel complexity. Based on our field observations, existing vegetated islands in this segment consistently nucleate around large wood pieces and appear to be continuing that trend of growth. The exact cause for historical channel simplification and then possible recovery is at least suggestive of some anthropogenic disturbance, probably relating to wood removal or riparian logging around the early or part of the 20th century.

Gravel Budget and Related Dynamics

Bedload yields as determined through USGS measurements and rating curves are broadly in line with yields in the broader Skokomish River watershed. Average bedload flux was estimated at 14,400 tons/year, which equates to 700 ton/year/mi^2 of contributing area. For comparison, Collins et al. (2019) found watershed yields in the mainstem Skokomish of about 590 ton/yr/mi^2. This suggests that the contributions to the Skokomish River system may be modestly higher but are also not excessively large relative to the broader Skokomish watershed.

The findings of the morphologic sediment budget shed light on varying legacy sources of sediment to Vance Creek and implications for future trajectories in sediment delivery to Vance Creek the broader Skokomish River watershed. The apparently diminished sediment delivery from the upper watershed in the 2002-2016 period is at least suggestive of pulsed delivery of sediment to the project reach.

The predominance of alluvial and glacial sources introduced via vertical erosion of the bed and lateral erosion of terraces and valley walls indicates the varying legacy sediment sources contributing to the project reach. The older Holocene and Pleistocene legacy sources of sediment introduced to the creek through lateral terrace and valley wall erosion represented a significant portion (45%) of bedload passing the USGS gage from 2002-2016. Erosion of the more than 500-year-old fluvial terraces represents a clear legacy of Holocene sediment dynamics in the valley. And toe erosion and landsliding from valley walls formed of glacial material introduces an even older legacy source of sediment from continental glaciation. Given the sheer volume of this material remaining and the likelihood that the creek will continue to erode these legacy deposits, it is reasonable to assume these sources will persist for the foreseeable future (well beyond the timescale of our management actions).

Aggradation and Confluence Dynamics (RM 0-1.5)

Several sources of information indicate that the lowermost 1 to 1.5 miles of creek are depositional and aggrading. Floodplain convexity and channel superelevation indicate that a degree of aggradation in this reach has been active for some relatively long period spanning many decades or centuries. More recently, repeat surveys, bridge inspections, and LiDAR datasets indicate that aggradation in this reach generally increases in a downstream direction, with the fastest rates of 1.5-4 ft/decade occurring at and just below the Skokomish Valley Road Bridge. Several natural and man-made factors appear to contribute to this aggradation.

Natural factors include the low slopes and floodplain character. The highly concave stream profile in the project results in this lowermost segment of creek having far reduced stream power and transport capacity/competence relative to upstream reaches (~70% of those at the upper end of the project reach at RM 4). Additionally, floodplain topography in the lower mile appears to make the creek naturally more prone to flooding (thus removing sediment transport capacity within the channel). This natural tendency for flooding and deposition is at least in part supported by early stream improvement efforts (levee building and dredging) being focused in this lower creek segment (as reported by BOR [2011]).

Multiple compounding and related factors induced by creek manipulation and confluence changes have led to further tendency for deposition in this creek segment. Several of these factors stemmed from channel realignment in the late 1950s (probably in 1959 when the Skokomish Valley Road bridge was constructed), which changed the creek to a cross-valley alignment and probably reduced its slope directly. It also left open the historic creek channel (which flows down-valley to the right and is now occupied by Swift Creek) as an off-take of flood flows, effectively reducing flow and sediment transport capacity in the stream channel. Additionally, the Skokomish Valley Road bridge at RM 0.2 was (or, as a result of subsequent deposition, became) a probable hydraulic constriction with potential backwater effects extending upstream.

In at least the past few decades, a dominant factor in this deposition within the lowermost Vance Creek is probably aggradation of the South Fork Skokomish River at the confluence. Collin's et al. (2019) document aggradation rates of up to 2.5 feet per decade at the confluence since the mid-1990s, which effectively reduces gradients in Vance Creek. This resulting aggradation in Vance Creek has increased downstream toward the confluence (in turn, reductions in gradient have become more severe in a downstream direction). Through time, we expect deposition to migrate upstream as gradients reduce progressively in an upstream direction until Vance Creek has a new equilibrium slope established).

From a practical standpoint, this aggradation near the mouth--which is likely to continue for the foreseeable future--poses several challenges. Sediment deposition is likely to increase hydraulic interaction with the Skokomish Valley Road bridge and more generally exacerbate flooding in this reach. A key flood pathway of concern is the historic Vance Creek channel (i.e., the one currently occupied by Swift Creek) because it would direct flooding down the broader Skokomish valley and along its low margins. Exacerbated flooding down the historic Vance Creek alignment is also likely to increase avulsion potential along this historic alignment, a potential identified by previous studies (e.g. Skillings-Connolly, Inc and Simons and Associates, 1999).

12. Key Conclusions and Implications for Stream Restoration

Several key conclusions emerge which have direct relevance to restoration and management planning in the watershed:

- Due to a significant downstream transition in slope, stream power, and general geomorphic character, natural sediment transport and stream processes vary significantly along the reach and represent important context for restoration actions. Although much of this transition is gradual, a transition from erosion to deposition occurs at about RM 1-1.5.
- Estimates of bedload yield (flux per unit watershed area) based on USGS measurements indicate those in Vance Creek are similar to those found in the broader Skokomish River watershed. Average bedload flux was estimated at 14,400 tons/year, which equates to 700 ton/year/mi^2 of contributing watershed area.
- The morphologic sediment budget of the project reach revealed that legacy Holocene fluvial and Pleistocene glacial deposits eroded within the lower 4 miles of Vance Creek represent significant sources of sediment. These sources enter the creek via lateral erosion of Holocene terraces and toe erosion of Pleistocene glacial deposits which induces significant landsliding (as was documented by this study as well as Skillings-Connolly, Inc. and Simons and Associates [1999]). Given the volume of these legacy sediment deposits remaining in the

lower valley (particularly from RM 1.5-4), they are expected to persist as sediment sources for the foreseeable future.

- The assessment did not reveal a clear signal of sedimentation derived from logging in the Vance Creek watershed. The upper segments of the project reach, which are considered most likely to "feel" such a pulse of aggradation, were found to be largely degradational for the past several centuries. However, channel simplification around the middle 20th century, as revealed by mapping of vegetation island areas through time (by BOR [2011]), points to likely anthropogenic disturbance that aligns with period of intense logging in the middle 20th century (riparian logging or instream wood removal appear to be possible culprits for the noted channel simplification).
- Based on comparison to channel pattern domains established by Beechie et al. (2006), the upper and lower halves of the reach are likely to support island braided (anabranching) and single threaded (meandering or straight) patterns, respectively. The channel segment from RM 2-3.5 has several incipient vegetated islands formed around woody debris that have grown in area since 1965, suggesting that recovery from past channel simplification has begun to some extent. This also points to the likely responsiveness to additional wood placement and restoration in this channel segment and further upstream toward the upper end of the project reach.
- The lowermost mile of creek suffers from sediment deposition that has potential impacts for flooding, bridge longevity, and avulsion through the historic (pre-1959) Vance Creek channel. Although natural stream power limitations are at play, other contributors to this deposition include a historic creek/confluence realignment and, more recently/importantly, rapid deposition in the South Fork Skokomish River. Measurements of bed change in Vance Creek since 2002 indicate aggradation rates on the order of multiple (1.5-4) feet per decade, which coincides roughly with measured rates in the South Fork Skokomish River.

  Given the implications of sediment deposition for increased flooding, increased hydraulic interaction with the Skokomish Valley Road Bridge (and that bridge's age), and potential increases in avulsion potential along the historic Vance Creek channel (now Swift Creek), this lowermost creek segment represents an important target for further consideration and broader management actions. Monitoring of deposition rates should also be conducted via topographic survey of repeat cross-sections or similar.
- From a geomorphic and physical process perspective, effective habitat restoration strategies vary longitudinally along the reach:
  - The lowermost two miles of creek are relatively simplified (straight channel, limited instream complexity), but are also supported by groundwater-dominated (cool) streamflow in the summer (see separate W2r memo for this project). Habitat restoration strategies in this segment should build instream complexity to enhance or restore physical habitat conditions in this potential thermal refuge. These efforts need to be considered relative to sediment deposition and flooding in the lowermost creek, and potential broader strategies to address these issues. There may be opportunities to realign the Vance Creek confluence through its historic alignment to promote sediment flushing, although such an effort would require significant

coordination with restoration project efforts currently underway along the South Fork Skokomish River.

- The upper two miles of the project reach are more dynamic in nature and have potential to further develop an island-braided planform. But, this segment also experiences surface water loss and drying in the summer, which manifests during the lowest flow conditions as a completely dry channel from ~RM 2.6-3.9 and a series of isolated (longitudinally disconnected) groundwater-fed pools from ~RM 1.8-2.6. Restoration or enhancement of large wood in this reach would likely support the recovery toward an inland braided planform, and should support further scour pool development and expanded groundwater-fed habitat.

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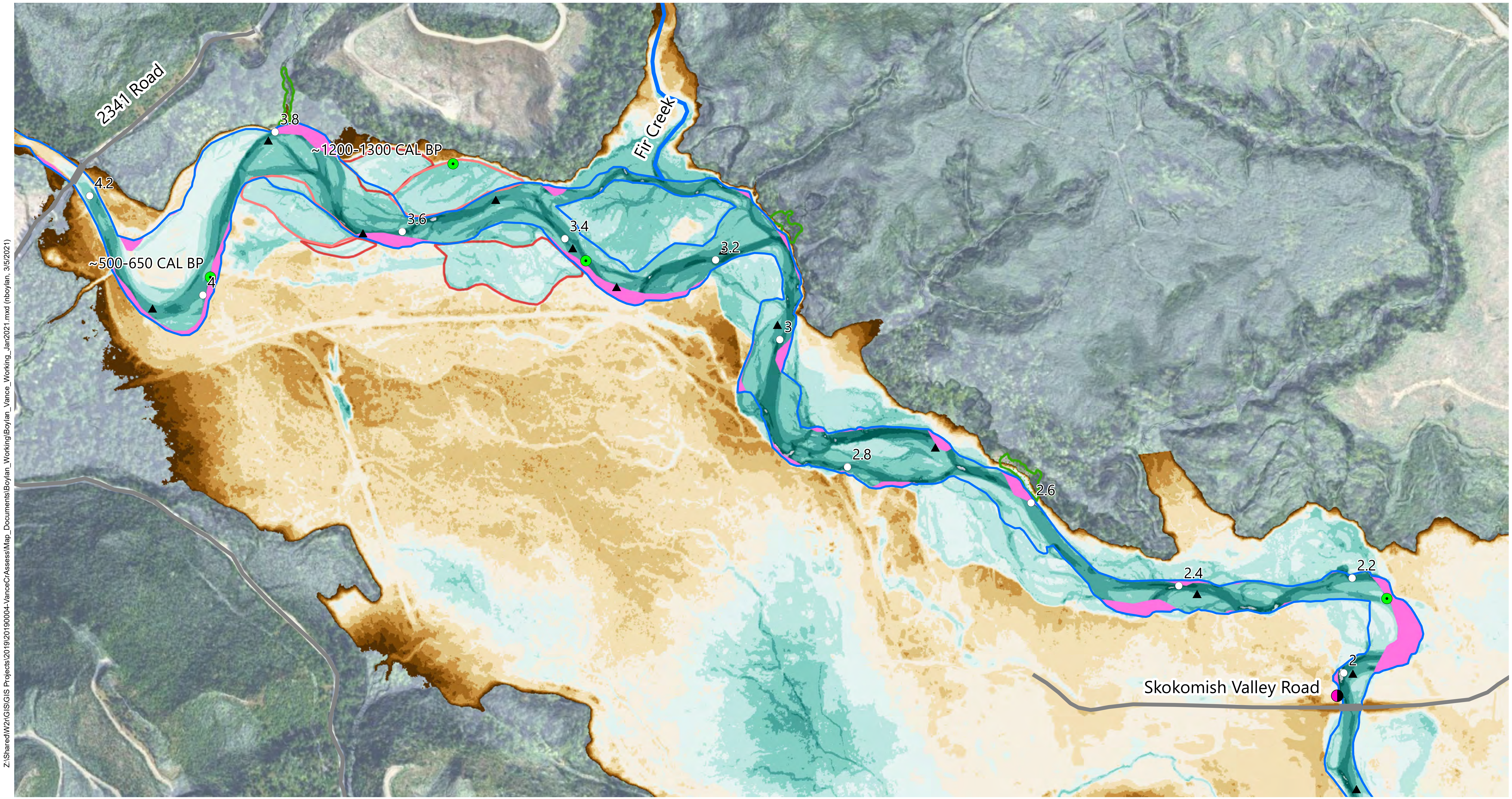

SOURCE: MCD LiDAR (2016), ESRI Aerial

Mason Conservation District

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Relative Elevation (ft)

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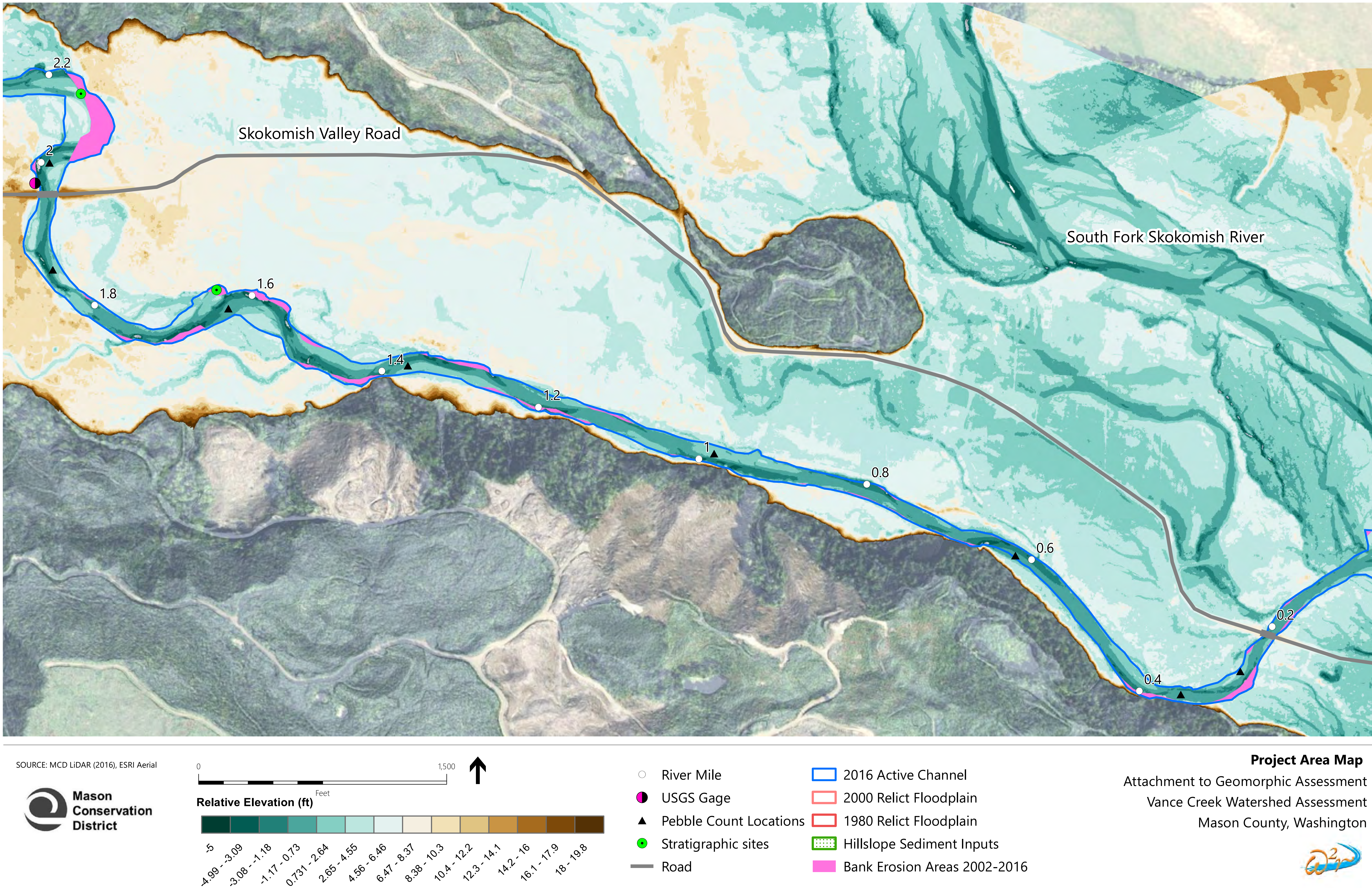
- River Mile
- USGS Gage
- Pebble Count Locations
- Stratigraphic sites
- Road
- 2016 Active Channel
- 2000 Relict Floodplain
- 1980 Relict Floodplain
- Hillslope Sediment Inputs
- Bank Erosion Areas 2002-2016

Project Area Map

Attachment to Geomorphic Assessment

Vance Creek Watershed Assessment

Mason County, Washington


2.2
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Skokomish Valley Road
South Fork Skokomish River
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SOURCE: MCD LiDAR (2016), ESRI Aerial
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4.56 - 6.46
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14.2 - 16
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River Mile
USGS Gage
Pebble Count Locations
Stratigraphic sites
Road
2016 Active Channel
2000 Relict Floodplain
1980 Relict Floodplain
Hillslope Sediment Inputs
Bank Erosion Areas 2002-2016
Project Area Map
Attachment to Geomorphic Assessment
Vance Creek Watershed Assessment
Mason County, Washington

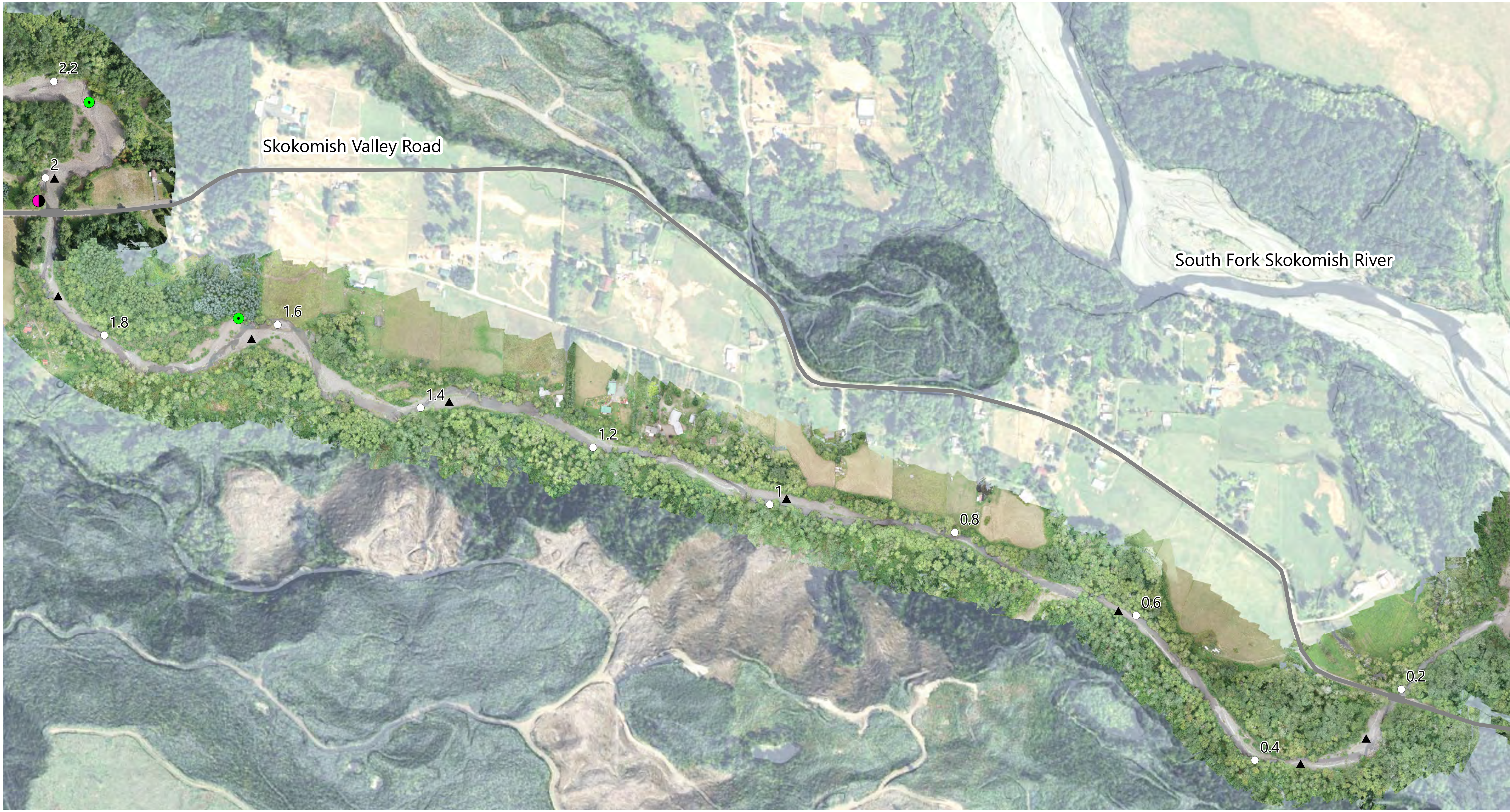
SOURCE: MCD LiDAR (2016), ESRI Aerial
Drone imagery from August 7, 2019

Mason Conservation District

0 1,500
Feet

River Mile
USGS Gage
Pebble Count Locations
Stratigraphic sites
Road
2000 Relict Floodplain
1980 Relict Floodplain
Hillslope Sediment Inputs

Project Area Map
Attachment to Geomorphic Assessment
Vance Creek Watershed Assessment
Mason County, Washington



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SOURCE: MCD LiDAR (2016), ESRI Aerial
Drone imagery from August 7, 2019

0 — 1,500
Feet

Mason Conservation District

- River Mile
- USGS Gage
- Pebble Count Locations
- Stratigraphic sites
- Road
- 2000 Relict Floodplain
- 1980 Relict Floodplain
- Hillslope Sediment Inputs

Project Area Map

Attachment to Geomorphic Assessment
Vance Creek Watershed Assessment
Mason County, Washington

APPENDIX C. STREAM DEWATERING ASSESSMENT

Technical Memorandum

Date:	March 5, 2021
To:	Evan Bauder (MCD), Jon Ambrose (ESA)
From:	Nick Legg, LG
Project:	Vance Creek Watershed and Restoration Study
Subject:	Evaluation of Stream Dewatering

1. Introduction

Vance Creek, a major tributary of the South Fork Skokomish River in Mason County (Washington), is considered a high-priority stream for salmonid species. During summer months, however, fish passage has been limited by chronic dewatering that causes the creek to go fully dry in a stretch near river mile (RM) 3. To date, only the extent and approximate seasonal timing of this drying has been known (US Bureau of Reclamation [BOR], 2011). Because the dry reach coincides with a wide and apparently sediment-rich reach of Vance Creek, one suggested hypothesis is that the creek dewaters because of high sediment loads induced by historic logging in the upper watershed. The present evaluation seeks to better understand the processes of dewatering and groundwater interaction so that restoration opportunities can be more fully understood.

This effort comes as part of a broader watershed assessment of Vance Creek, focusing in large part on the lower 4 miles of stream. The creek dewatering discussed here is most relevant in the approximate upper half of that reach, between a crossing of the Skokomish Valley Road at river mile (RM) 2 and forest road 2341 at RM 4.3, although it has implications for lower portions of Vance Creek as well.

This assessment was completed as part of a broader project led by Mason Conservation District (MCD). Wolf Water Resources (W2r) partnered with Environmental Science Associates (ESA) to lead the on-going technical aspects of the project. MCD supported this technical effort with significant field data acquisition and analysis. In addition, the US Geological Survey (USGS) collected streamflow and sediment data and provided general input. We thank all for their contributions and support with this effort.

2. Watershed Setting

Vance Creek drains the southeastern Olympic Mountains, flowing generally east to join the South Fork Skokomish River and ultimately into Hood Canal. The area of primary interest lies just below a major transition point in the watershed where the creek flows from steep and confined canyons of the Olympic Mountains into a broader low-gradient valley shaped by continental glaciation and subsequent valley sculpting (Logan 2003). The project reach lies entirely in this postglacial landscape, where Vance Creek has apparently carved its valley into thick (multiple hundreds of feet) glacial sediments deposited since the retreat of continental glaciers ~16-17 thousand years ago (Porter and

Swanson, 1998). The present-day valley bottom through the reach ranges from 0.3-0.5 miles wide. The active stream channel and floodplain occupy a small portion of this broader postglacial valley.

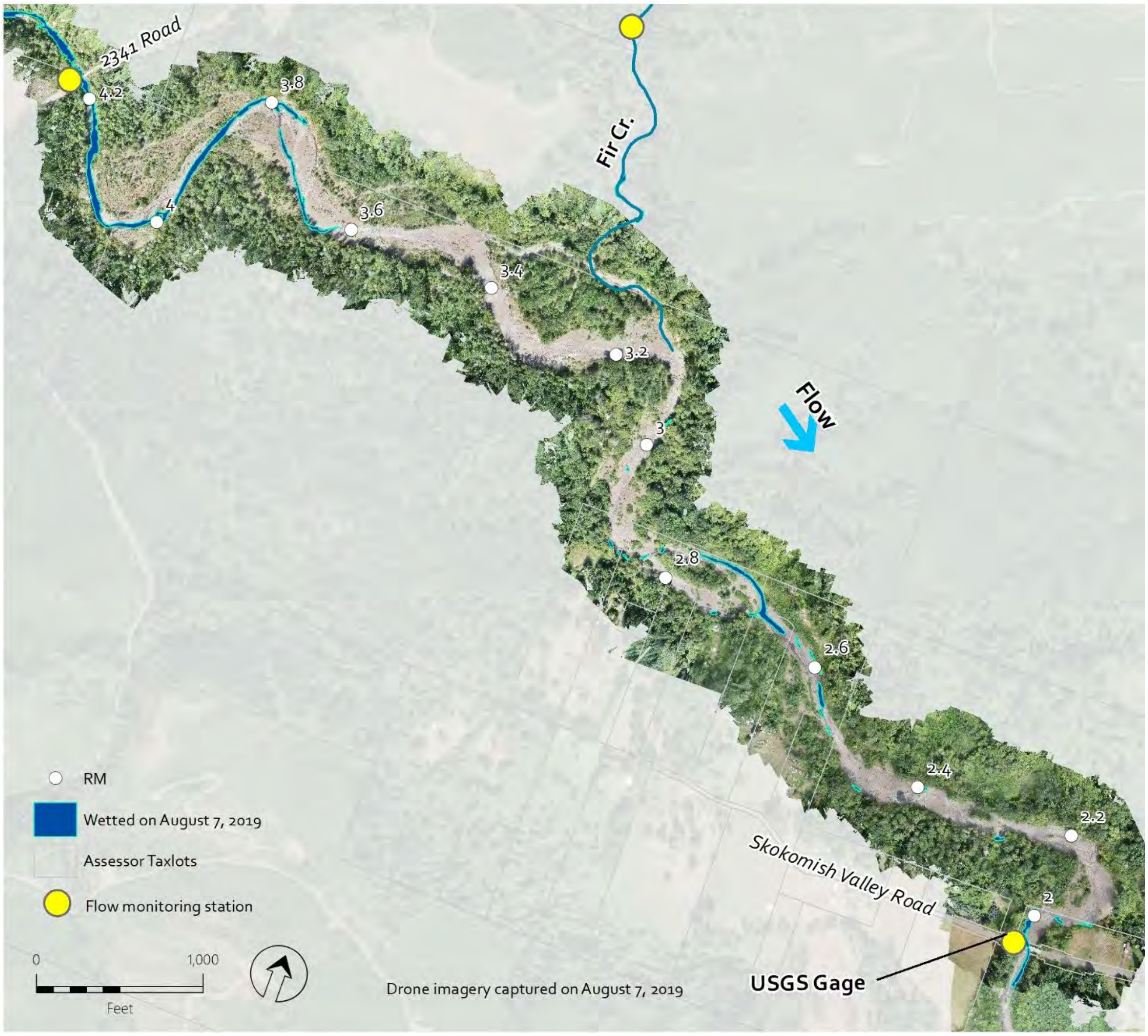

Figure 1 Aerial imagery overview map of the dewatering impacted reach. Aerial images were captured via drone-based photography on August 7, 2019.

Watershed contributions to the reach include Vance Creek itself, as well as the relatively small Fir Creek entering from the north. Vance Creek's contributing area upstream of RM 4.2 is 15.7 square miles (mi^2), with average annual precipitation of 136 inches. With a maximum elevation of about 3000 feet, the watershed is largely rain-dominated in its seasonal flow patterns. Fir Creek, which enters at RM 3.1, has a watershed area of 3 mi^2 (Figure 1). A stream gage operated by the US Geological Survey (USGS) from 2018-2020 and located at the Skokomish Valley Road at RM 1.8 measured the combined hydrologic contribution of these streams (Figure 2). The near-zero discharges visible during September 2020 are a function of the USGS gage being in the zone of creek dewatering.

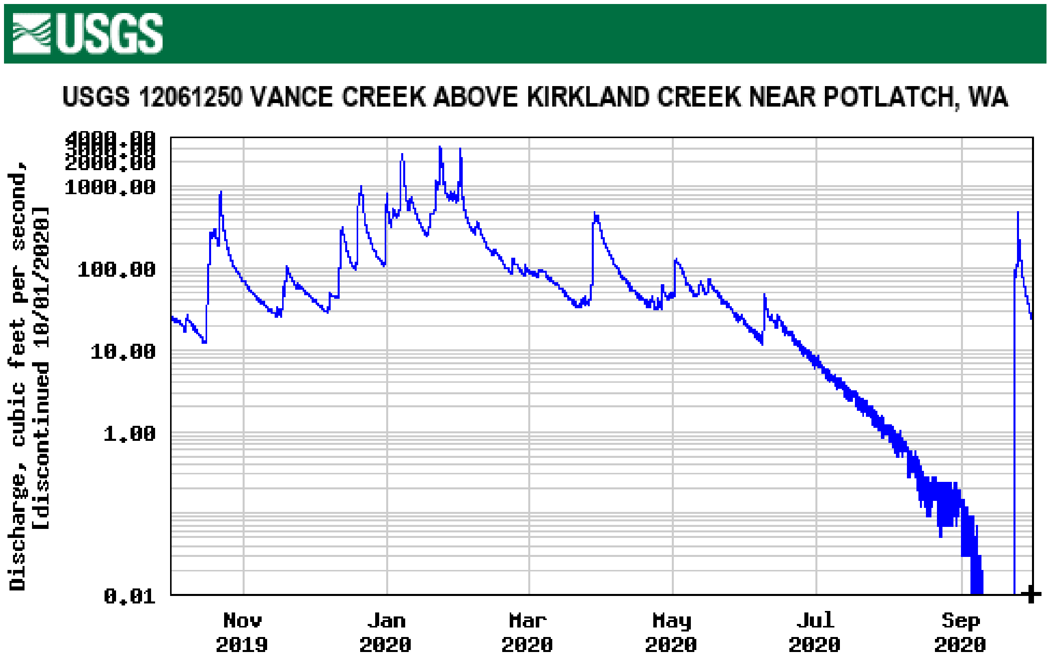

Figure 2 Water year 2020 flows at the USGS gage on Vance Creek.

3. History of Vance Creek Dewatering

During their assessment in 2011, BOR mapped out the extent of dry stream reaches using historical aerial imagery (Table 1). These mapping results show that a dry reach of Vance Creek has been a common feature and consistently located since the earliest imagery available.

Table 1   Summary of dry reaches in Vance Creek as mapped using historical imagery (table source: BOR, 2011)

Year	Extent of Dry Reach (RM)	Photo Timing (if known)
1938	2.8-3.1	-
1946	2.9-3.4	June
1956	2.6-3.3	-
1977	2.3-3.9	-
1985	2.6-3.1	August 15
1995	None	-
2000	2.6-3.4	-
2009	2.7-3.6	-

4. Data Sources and Methods

This study involved detailed flow measurements and monitoring to better understand the local water budget of Vance Creek in terms of longitudinal pattern, timing, and volume of streamflow losses and gains. Global Geophysics also conducted a geophysical (electromagnetic) survey of groundwater levels during summer conditions (August 17 and 18, 2020). The geophysical results inform this evaluation, although the detailed methods are described in a separate report by ESA.

Multiple stream gage records and other flow-data sources were used in this study:

- Longitudinal flow measurements ("seepage runs") made by MCD along the creek on May 30, 2019 and March 4, 2020. With several measurements made along the creek on each day, these measurements were used to track gains and losses from the stream channel.
- USGS stream gage 12061250, active from September 28, 2018 to October 1, 2020 (Figure 1).
- Stream gage records from the summer of 2019, recorded by MCD at the 2341 road (upstream end of project reach) and in Fir Creek. These gages used local gage datums and stage-discharge relationships.

Seepage runs were timed to understand streamflow losses in varying seasons and hydrologic conditions. The May 30, 2019 effort captured declining flows in the early summer. The March 4, 2020 seepage run was intentionally timed in the winter to assess rates of groundwater loss after several months of wet weather, when groundwater levels were more likely to be elevated. Longitudinal losses during summer low flow conditions were assessed using field observations and drone-based aerial imagery captured on August 7, 2019 (Figure 1).

Streamflow monitoring upstream and within the dewatered reach informed the rates and temporal patterns of loss throughout the 2019 summer season. This flow monitoring approach employed gages established at the at the Vance Creek canyon mouth (2341 bridge) and in Fir Creek to capture summer surface water inputs to the dewatered reach (although other small spring inputs were also observed downstream of these gages, it is estimated the two gages capture over 95% of the surface water entering this reach during the summer). The USGS gage is located within the lower end of the dewatered reach and therefore is well placed to inform rates of loss. Specifically, the difference between sum of incoming flows and recorded flows at the USGS gage provide a direct estimate of the net streamflow loss through time.

5. Field Observations

While traversing the project reach of Vance Creek on August 7, 2019 (see Figure 1), observed streamflow conditions fell into four broadly distinct zones along the creek:

- RM 4.2-3.6: Flow was continuous but observably declining in the downstream direction. Measured stream temperatures averaged 68ºF and ranged from 64-70 ºF.
- RM 3.6-3.0: Creek was dry, even in the deepest of scour pools.
- RM 3.0-1.9: Flow was disconnected at the surface with flow isolated in pools (Figure 3). In all but the upstream-most wetted pools (which were notably stagnant and warm), flow was clear and cool with incoming groundwater seepage on the upstream side. Temperatures in the groundwater-fed pools averaged 57 ºF and ranged from 52-64 ºF.
- Below RM 1.9: Just below the Skokomish Valley Road bridge, flow became continuous at the surface, and apparently gained gradually in discharge in a downstream direction toward the mouth of the creek. Temperatures were similarly cool to those measured zone of isolated groundwater pools just upstream.

Figure 3 Isolated groundwater-fed pool, with no surface-water flow at either its upstream or downstream ends.

6. Monitoring and Geophysical Results

Groundwater Table Profile from Geophysics

The geophysical survey reveals the groundwater table relative to streambed during the dry summer months, providing key context for longitudinal patterns of streamflow and observed dewatering. As shown in Figure 4, the zone of declining stream flow corresponds to the greatest separation between the stream and groundwater table. Below RM 3.3, the degree of separation declines but also is sufficient to cause the channel segment from RM 2.9-3.2 to become fully dry in the summer. Moving farther downstream, the groundwater table lies just below the broader active channel but intersects pools and low points in the streambed, which leads to the discontinuous nature of surface flow observed in the field and mapped on Figure 1.

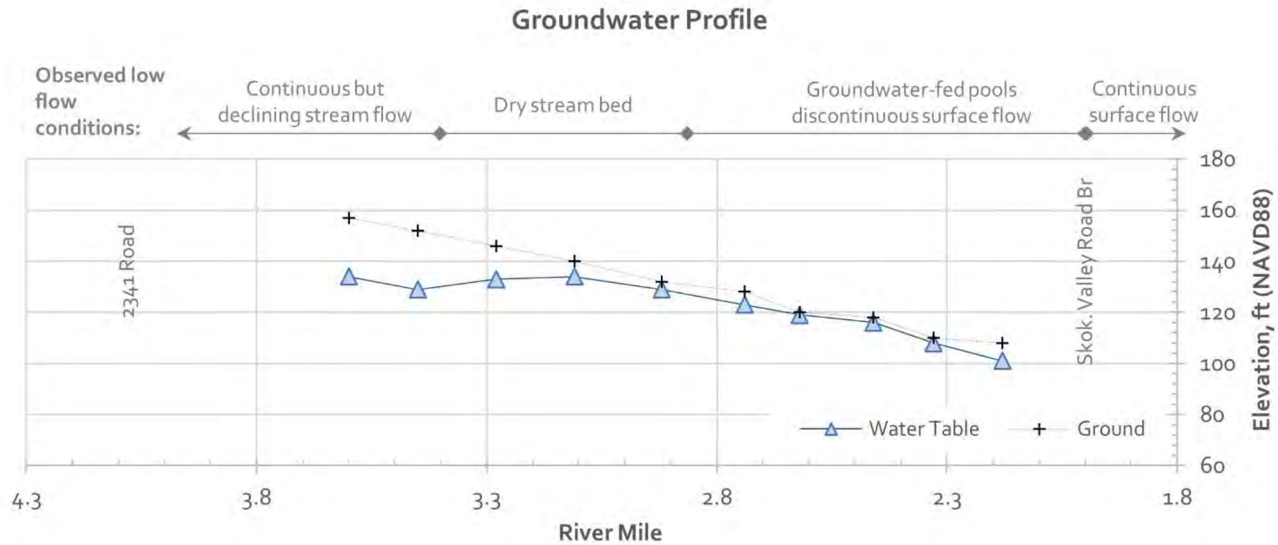

Figure 4 Groundwater profile relative to stream bed elevations as measured on August 17 and 18, 2020, using geophysical (seismic refraction) methods (Global Geophysics conducted the survey).

Seepage Runs

Given the limitations of only a single geophysical profile, the seepage run measurements have improved the inferred changes in water table and surface losses through varying hydrologic conditions (Figure 5).

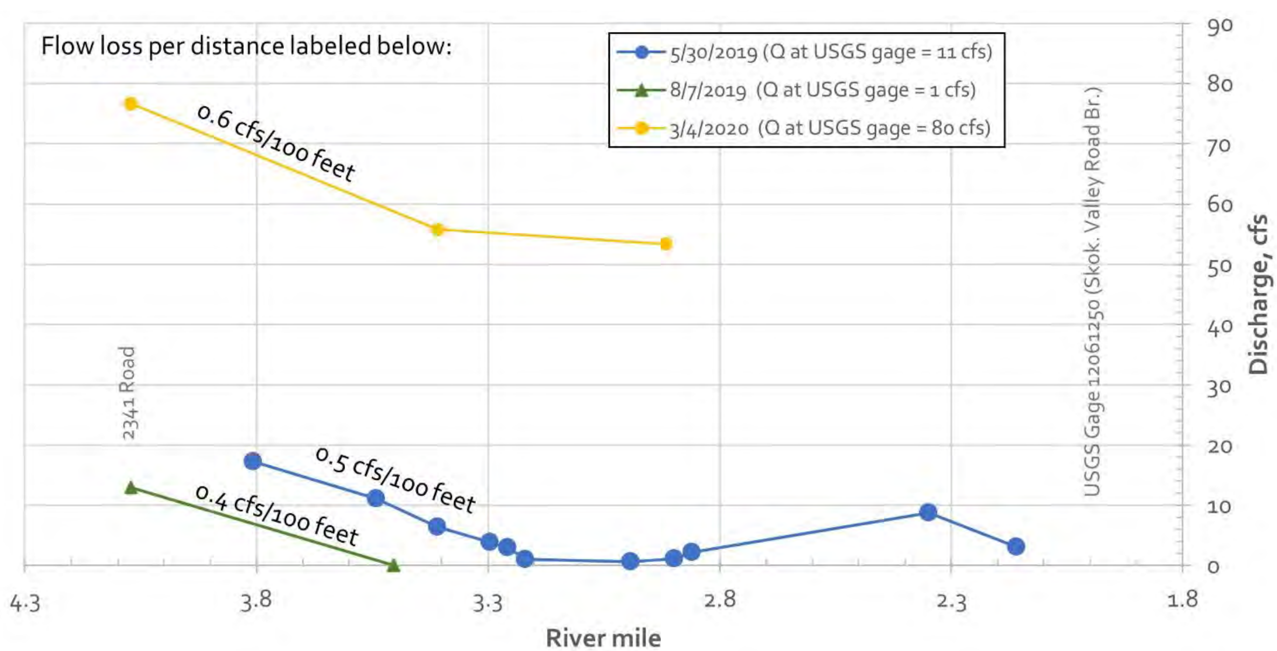

Figure 5 Measured streamflows along the dewatering/dewatered reach of Vance Creek from about RM 2-4. For each measurement date, rates of streamflow loss per channel distance (shown in cfs per 100 feet of channel) are labeled in the most notable zone of loss.

As recorded with the seepage run corresponding to the lowest flow conditions (August 7, 2019), the full stream flow (11 cfs) measured at the upstream end of the reach was lost within about 3000 feet of channel (equating to 0.4 cfs lost per 100 feet of channel). Below the fully dewatered reach, groundwater pools began to appear downstream of RM 2.9 with discontinuous surface flow extending downstream to just below the Skokomish Valley Road Bridge (with an isolated pool at the USGS gage location itself).

The seepage run on May 30, 2019 captures late spring conditions when the streamflow recorded at the 2341 road and USGS gages were respectively ~20 cfs and 11 cfs. At these conditions, dewatering in the uppermost reach occurred at a similar longitudinal rate to that of August 7 (0.5 cfs lost per 100 feet of channel). But, with greater streamflow emerging from the canyon, the fully dewatered segment was also shorter. Downstream of the dry streambed segment, flow become continuous upstream of the USGS gage, where roughly 11 cfs of water had returned. With the zone of connected surface flow extending upstream of the gage, we can infer that the water table was higher on May 30 than August 7, but not to the degree that limited dewatering in the uppermost reach (RM 4.3-3.3).

The seepage run on March 4 captures a short (week-long) dry period within the wet winter season, when streamflows at the 2341 road and USGS gage were both roughly 80 cfs. The longitudinal measurements record loss in the uppermost reach of a rate (0.6 cfs lost per 100 feet of channel) marginally greater than the other two seepage runs, pointing to the persistence of the groundwater separation zone from RM 4.3-3.3. However, at these winter conditions, the total surface flow was too great for the creek to be fully dewatered over the length of channel with separated groundwater. On the basis of similar flows at the 2341 road and USGS gages, the flow volume lost to the subsurface had apparently returned to the stream over a shorter distance than in summer months, pointing to some seasonal fluctuation in the groundwater table (but not enough to reduce dewatering in the RM 4.3-3.3 reach).

Flow Monitoring

Flow monitoring shows that over 20 cfs of streamflow consistently dewatered throughout the summer (Figure 6). Additionally, small summer rain events (delivering up to 50 cfs to the valley) did not result in corresponding discharge increases at the USGS gage, indicating that most or all the summer flow recorded at the USGS had been routed through the shallow groundwater. This condition was only disrupted with the first autumn rain, when the combined flow of Vance and Fir Creeks exceeded 120 cfs.

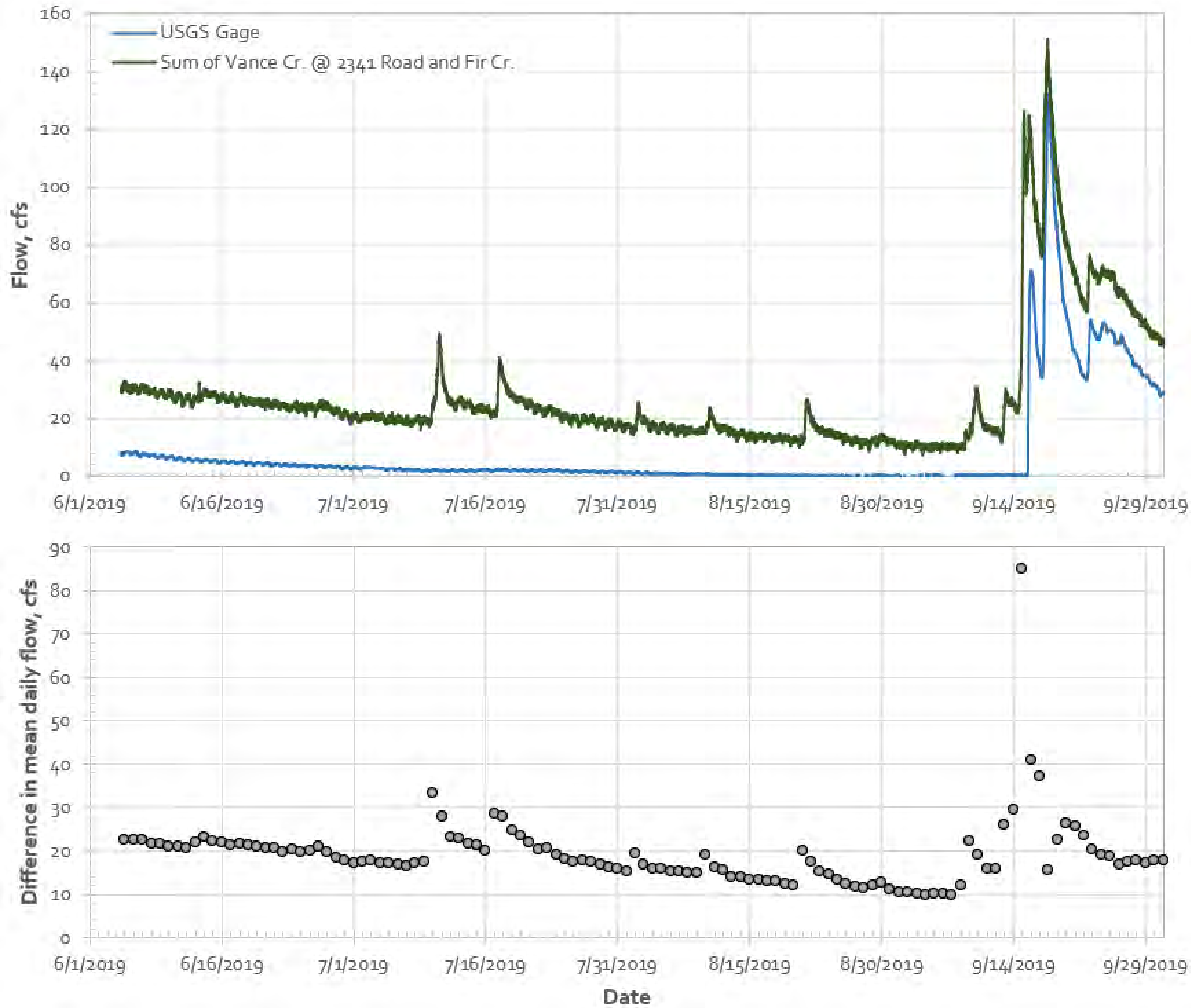

Figure 6 Comparison of gaged flows in the project reach during the summer of 2019. Top: 15-minute data of the combined surface water inputs (Vance and Fir Creeks) above the dewatered reach and the USGS gaged flow located at the lower end of the dewatered reach. Bottom: Difference of daily average flows of two values shown above, reflecting the approximate flow lost to groundwater between the gaging points.

7. Conclusions and Implications for Restoration

The following are conclusions emerged from this investigation:

- Four broad zones of groundwater exchange occur along lower Vance Creek:
    A. Pronounced streamflow-loss zone from RM 4.2-3.6, where groundwater separation is the most significant and persistent throughout the year, but where incoming flows are sufficient to maintain perennial surface flow despite seepage;
    B. Seasonally dry zone from RM 3.6-2.9, where groundwater separation appears to be present for a significant portion of the year at sufficient magnitude to dewater the channel during the drier months;
    C. Seasonally disconnected zone with groundwater-fed pools from RM 2.9-1.8, where groundwater separation varies seasonally but still intersects scour pools, even during summer months; and
    D. Perennially wetted channel that gains in discharge downstream with groundwater inputs (downstream of RM 1.8).
- The dry segment of Vance Creek has been documented at roughly RM 3 since the earliest (1938) aerial photographs available (BOR, 2011), indicating this process has been persistent for nearly a century or longer.
- Geophysical methods revealed groundwater separation from the streambed to be as much as 20 feet in the uppermost portion of the project reach (from ~RM 3.4 and probably upstream to the canyon mouth at RM 4.2) during the summer months. Whereas groundwater tables are inferred to rise and fall seasonally, this upper zone of separation and streamflow loss persists throughout the year. During the winter, however, surface flows are sufficiently large that the losses are not sufficient to fully dewater Vance Creek.
- During the summer, between 10 and 40 cfs of streamflow fully infiltrate before reemerging in the lower 2 miles of creek. Therefore, a vast majority of the summer streamflow in lower Vance Creek (below RM 2) is groundwater-dominated and, as a result, remains cool throughout the summer.

Taken together, the degree of groundwater separation and the persistence of creek drying for nearly a century suggest that the tendency for creek dewatering is in large part due to natural aquifer and geomorphology/physical conditions (probably resulting from the glacial history and subsequent valley evolution).

However, watershed degradation and historic logging following land settlement may have exacerbated sediment loads and dewatering with particular impacts in more marginal stream reaches such as from RM 1.9-2.8 where the summer water table is just below the stream bed. In this reach, reduced wood loading and associated scour pools would logically have diminished the extent and duration of wetted habitat during summer low flows. A separate memo on the geomorphology and sediment budget of Vance Creek addresses sediment loads and potential logging impacts (W2r, 2021).

Additionally, cool summer stream temperatures in the lower three miles of the creek are one clear benefit of dewatering that should not be overlooked. Restoration of physical habitat complexity in this temperature refuge zone has potential to create high-quality habitat, especially in the context of a warming climate.

8. References

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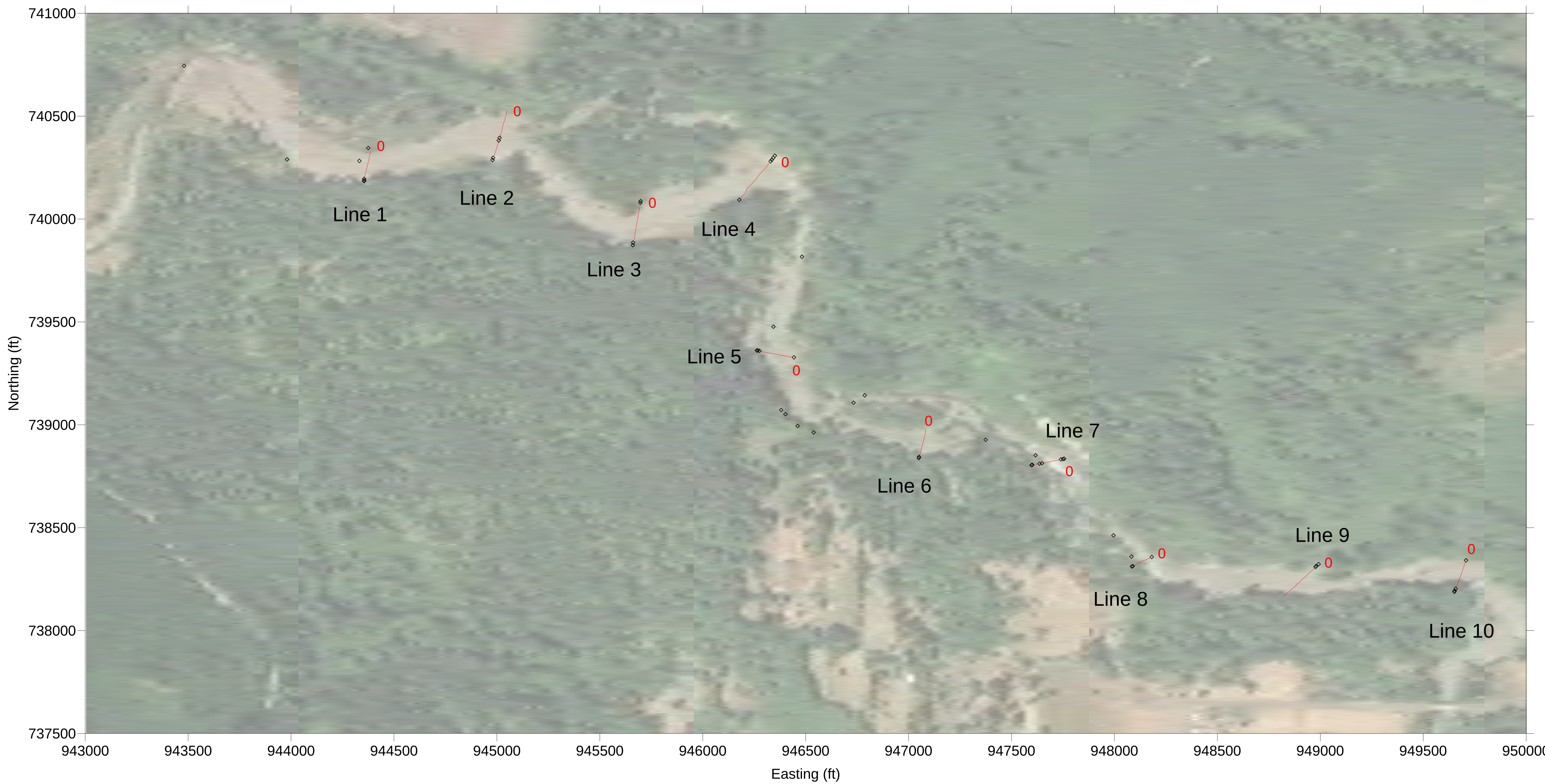
Logan, R.L., 2003. Geologic map of the Shelton 1: 100,000 quadrangle, Washington. Washington Department of Natural Resources, Division of Geology and Earth Resources.

Porter, S.C., and Swanson, T.W., 1998. Radiocarbon age constraints on rates of advance and retreat of the Puget lobe of the Cordilleran ice sheet during the last glaciation. *Quaternary Research*, *50*(3), pp. 205-213.

USGS StreamStats for Washington (https://streamstats.usgs.gov/ss/).

APPENDIX D. GEOPHYSICAL SURVEY



N

Refraction Line

GPS Measurement
(Not on Refraction Line)

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TITLE	**Site Plan**

Global Geophysics
P.O. Box 2229
Redmond, WA 98073-2229
Tel: 425-890-4321

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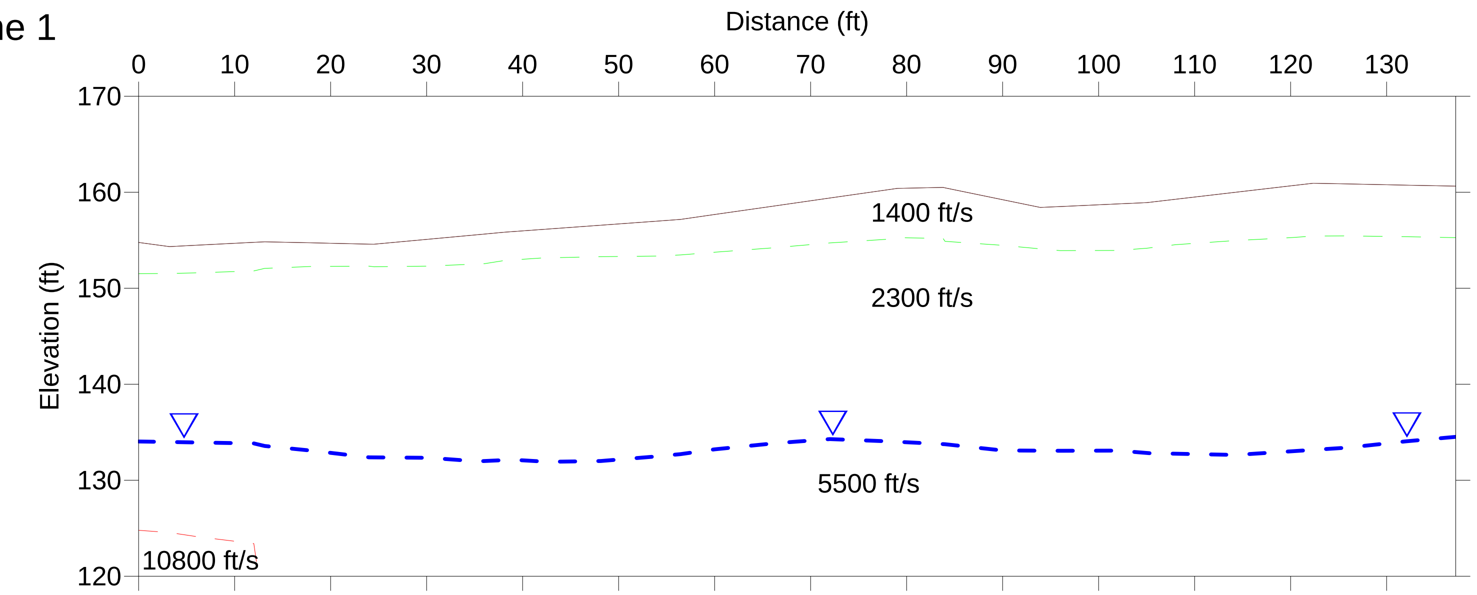

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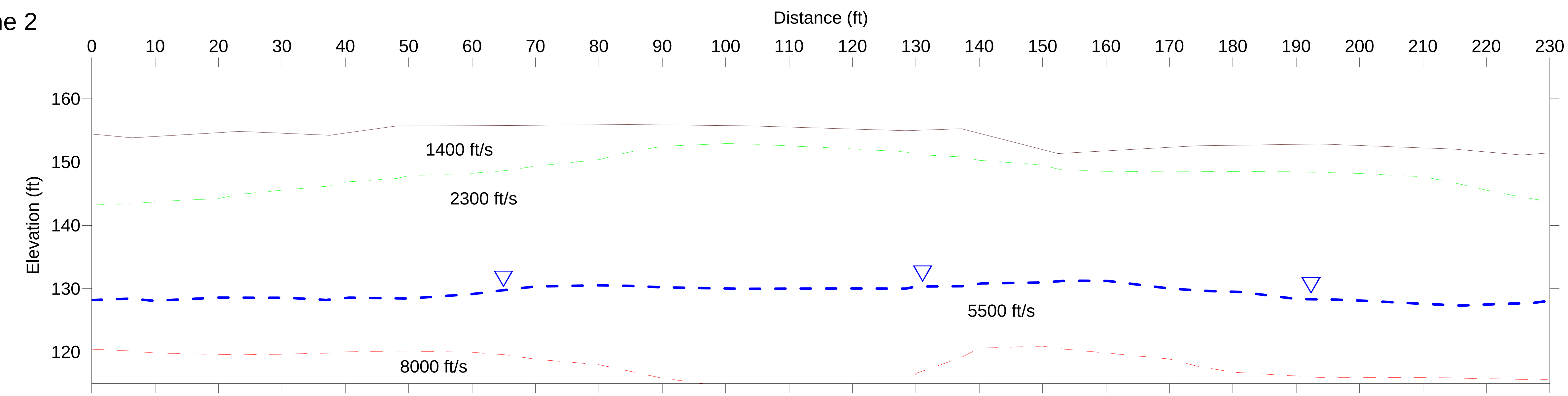

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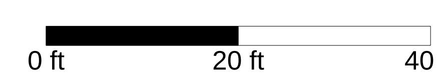
- Water table
- Bedrock



PROJECT
Seismic Refraction Survey at Vance Creek, Shelton, WA

TITLE
Interpreted Seismic Profiles

Global Geophysics
P.O. Box 2229
Redmond, WA 98073-2229
Tel: 425-890-4321

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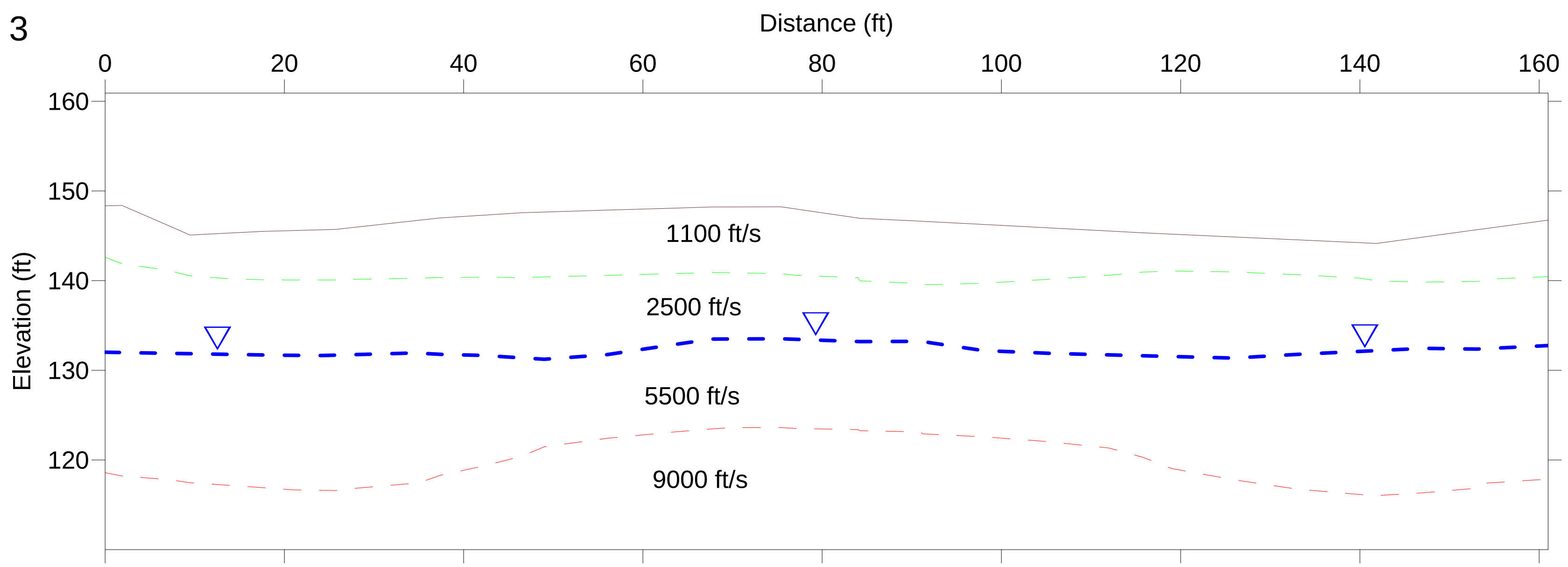

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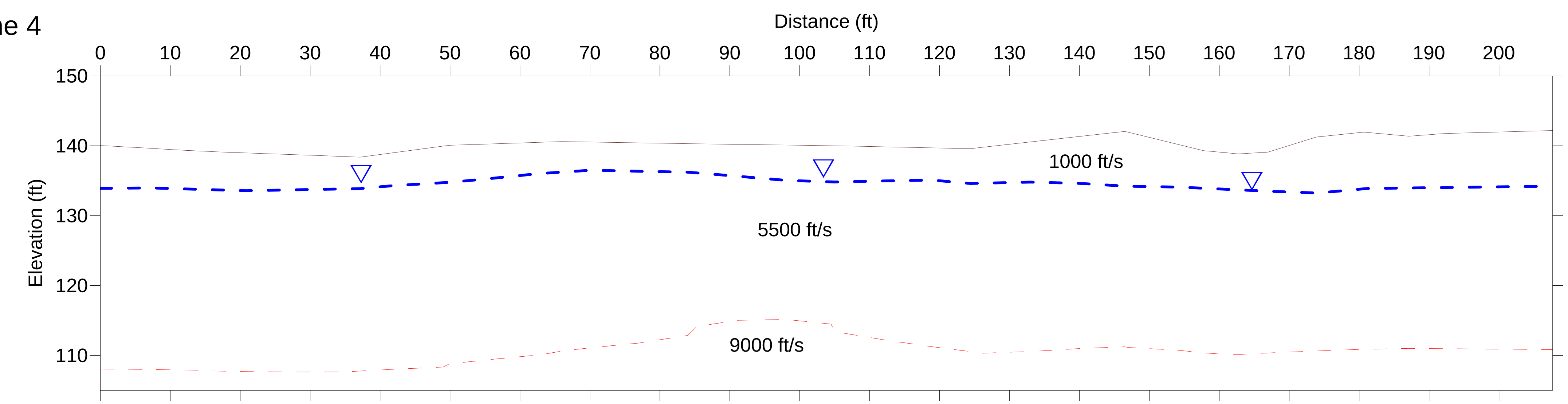

Legend:

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- Water table
- Bedrock

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PROJECT Seismic Refraction Survey at Vance Creek, Shelton, WA			
TITLE Interpreted Seismic Profiles			
Global Geophysics P.O. Box 2229 Redmond, WA 98073-2229 Tel: 425-890-4321	Project #: 110-0818.000 DESIGN -- CADD AK CHECK JL REVIEW --	FILE No. SCALE AS SHOWN REV.	FIGURE 3

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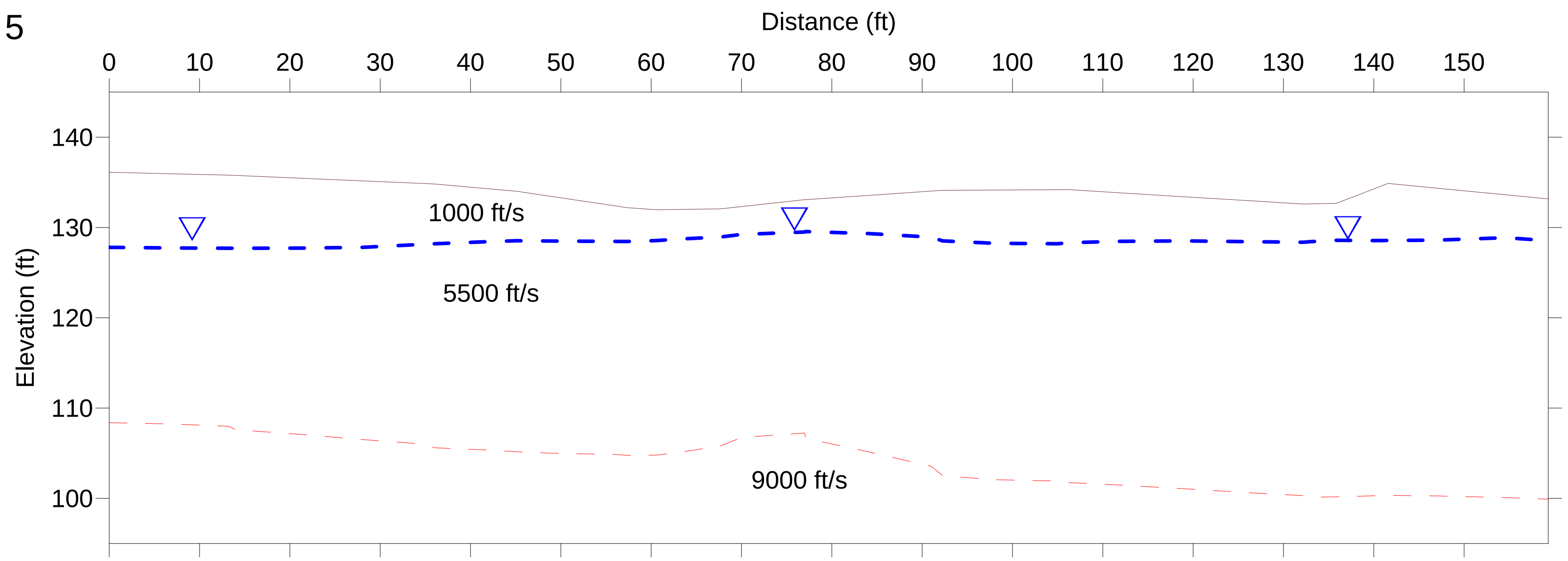

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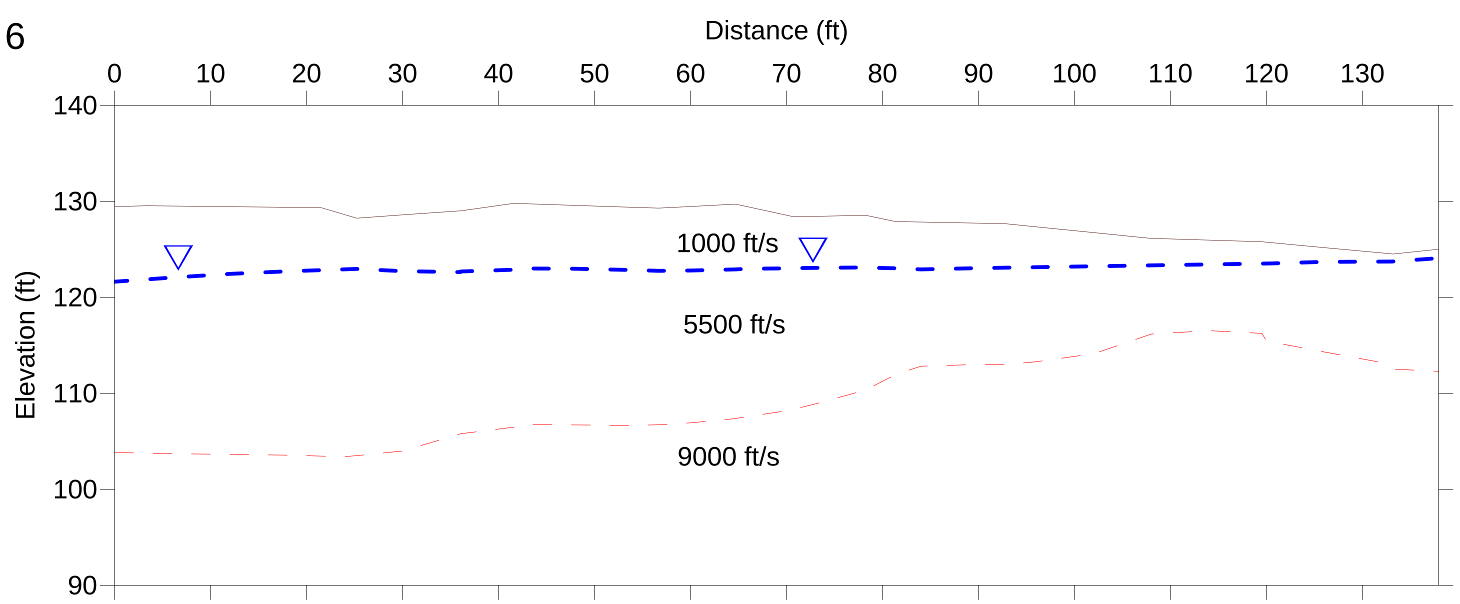

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Ground surface

Interface of loose and compacted soil

Water table

Bedrock

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PROJECT

Seismic Refraction Survey at Vance Creek, Shelton, WA

TITLE

Interpreted Seismic Profiles

Global Geophysics
P.O. Box 2229
Redmond, WA 98073-2229
Tel: 425-890-4321

Project #: 110-0818.000		FILE No.
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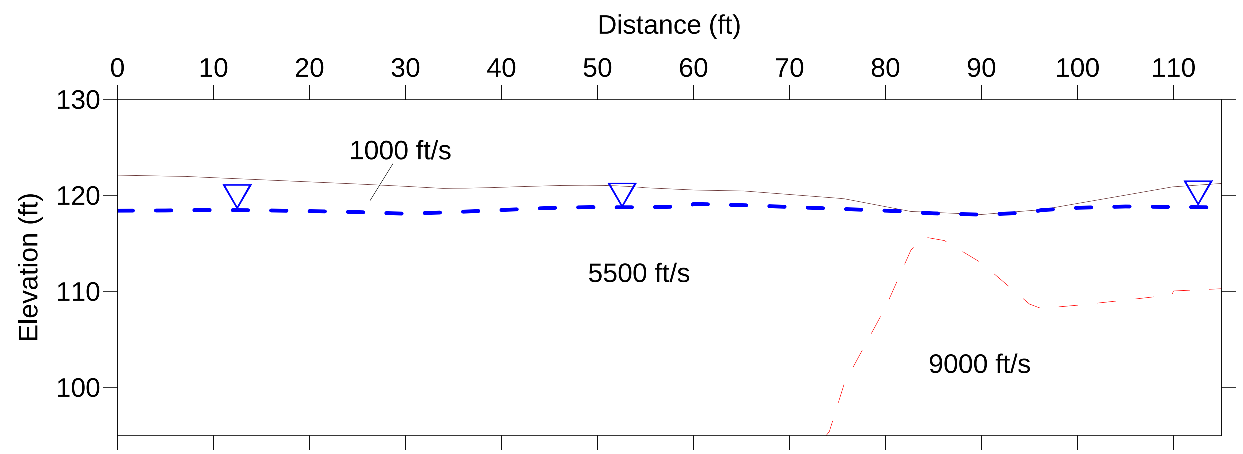

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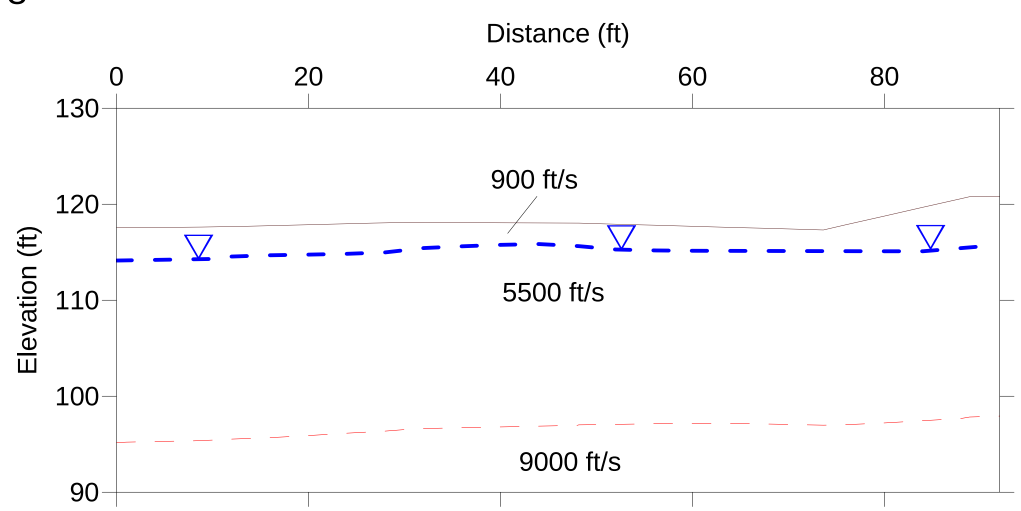


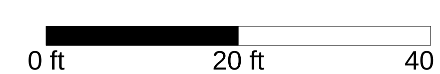
Legend:

Ground surface

Interface of loose and compacted soil

Water table

Bedrock



PROJECT

Seismic Refraction Survey at Vance Creek, Shelton, WA

TITLE

Interpreted Seismic Profiles

Global Geophysics
P.O. Box 2229
Redmond, WA 98073-2229
Tel: 425-890-4321

Project #: 110-0818.000		FILE No.	
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FIGURE 5

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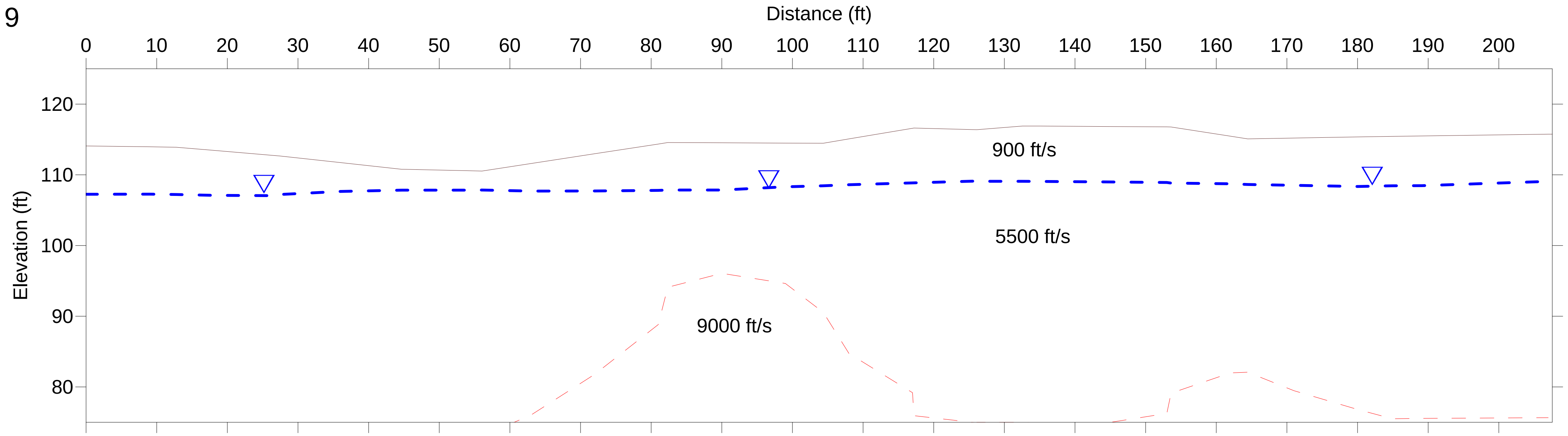

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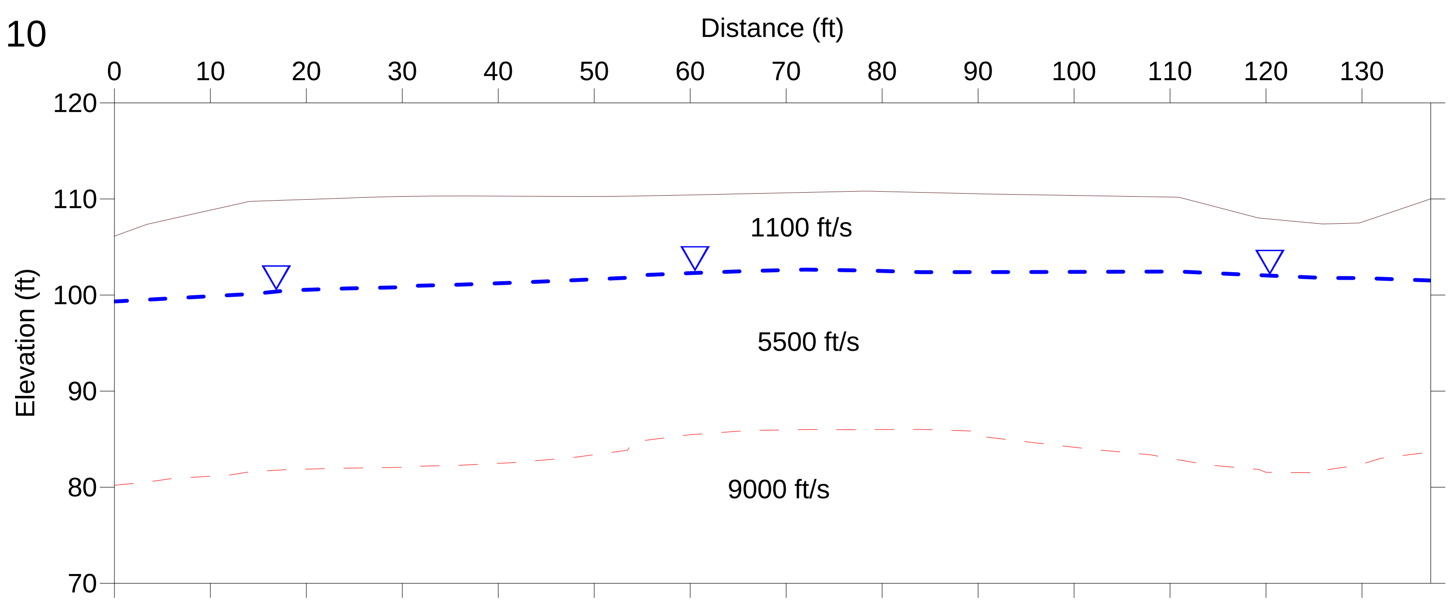

Legend:

Ground surface

Interface of loose and compacted soil

Water table

Bedrock

0 ft 20 ft 40 ft

PROJECT **Seismic Refraction Survey at Vance Creek, Shelton, WA**			
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Global Geophysics P.O. Box 2229 Redmond, WA 98073-2229 Tel: 425-890-4321	Project #: 110-0818.000		FILE No.
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	CADD	AK	**FIGURE 6**
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	REVIEW	--	

APPENDIX E. PHOTO LOG

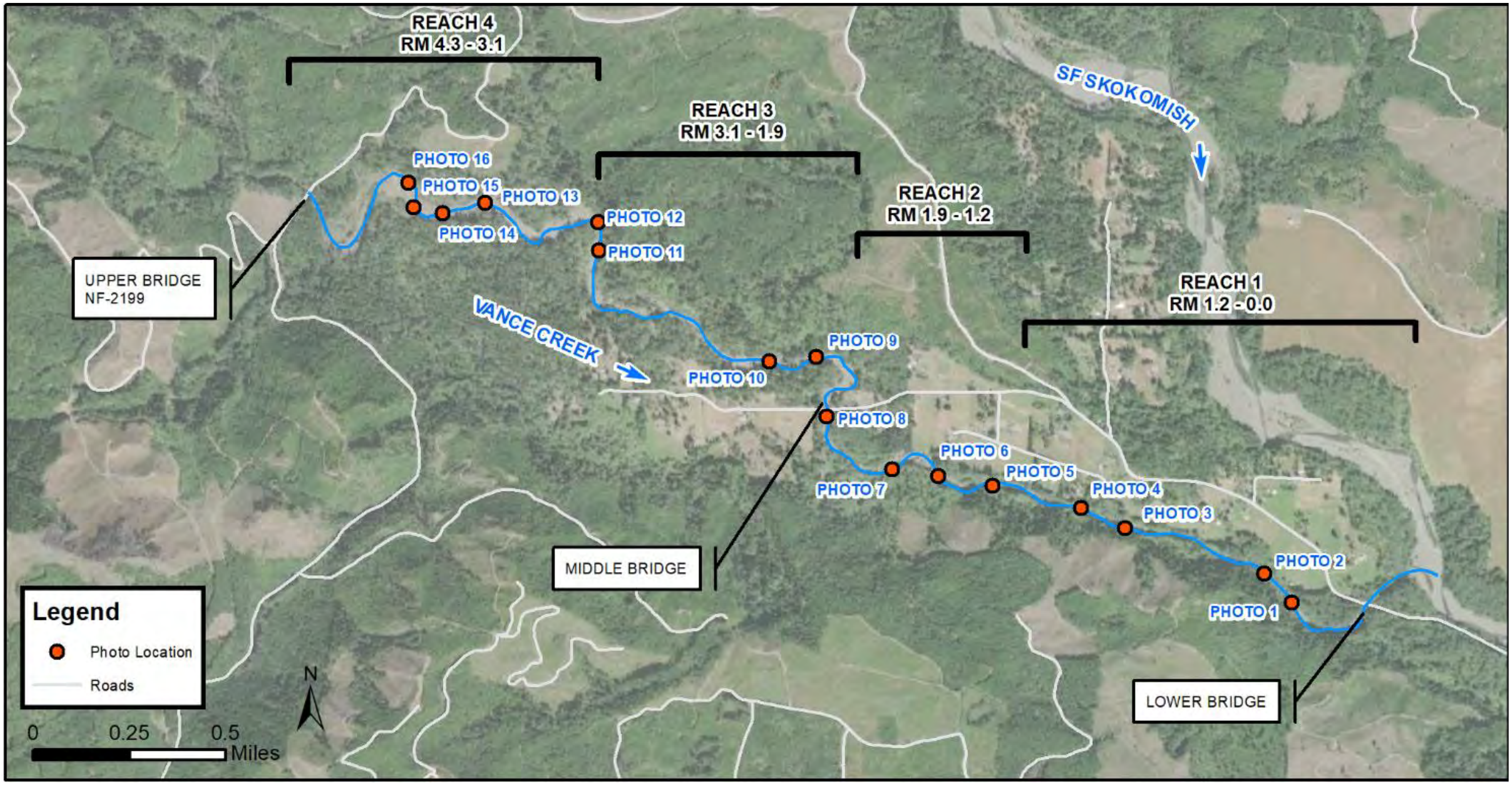

Figure E1. Photo Locations within Vance Creek Study Area

PHOTO 1 – REACH 1
Looking Downstream within Simplified Channel Reach Valley Wall

PHOTO 2 – REACH 1
Looking Upstream at Vegetated Rip Rap Lined Bank

PHOTO 3 – REACH 1
Looking Downstream within Simplified Reach Across Gravel Bar

PHOTO 4 – REACH 1
Looking Downstream Across Gravel Bar with Large Wood Debris

PHOTO 5 – REACH 2
Looking Downstream at Cobble Bar and Eroded Valley Wall

PHOTO 6 – REACH 2
Looking Downstream at Large Woody Debris at Kirkland Creek Confluence

PHOTO 7 – REACH 2
Looking Downstream Across Gravel Bar

PHOTO 8– REACH 2
Looking Downstream within Simplified Reach Across Gravel Bar

PHOTO 9 – REACH 3
Looking Downstream at Cobble Bar

PHOTO 10 – REACH 3
Looking Downstream at Low Gradient Vance Creek

PHOTO 11 – REACH 3
Looking Across Gravel Bar at Vegetated Bank

PHOTO 12– REACH 2
Looking Upstream at Braided Channel Planform

PHOTO 13 – REACH 4
Looking Downstream at Cobble Bar and Anabranched Channel Form

PHOTO 14 – REACH 4
Looking Upstream at Low Gradient Vance Creek

PHOTO 15 – REACH 4
Looking Upstream at Steep Eroded Bank

PHOTO 16– REACH 4
Looking Downstream at Point Bars and Vegetated Banks