CLEAR CREEK & CLEARWATER CREEK GEOMORPHIC & HYDRAULIC ASSESMENT MEMO

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Clear Creek & Clearwater Creek Geomorphic & Hydraulic Assessment Memo

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1. Introduction

1.1 Background

The eruption of Mt St Helens on May 18, 1980 greatly altered the landscape surrounding the volcano. The environmental effects were extensive: forests were leveled, rivers reshaped, wildlife communities lost, and human infrastructure destroyed. Though the landscape is recovering from catastrophic disturbance, many of the effects are still apparent today.

Located just east of the volcano, the headwaters of Clear Creek and Clearwater Creek were substantially impacted by the eruption. Upper Clearwater Creek is located on the eastern edge of the blowdown zone, where trees were leveled by the force of the blast. On highly sheltered slopes, a few stands remained as standing dead forest following the eruption. Located just beyond the perimeter of the blast zone, Clear Creek was subjected to large deposits of ash as the ash cloud traveled northeast from the eruption.

As a result, these streams experienced sudden changes to geomorphic processes such as sediment input and transport and large wood recruitment. These processes were further disrupted in the years following the eruption by clearcuts and salvage logging operations within the eruption disturbance zone which slowed the rate of forest regeneration (Titus, 2007). Floodplain logging also proved detrimental. Without old growth trees lining the streambanks, the streams were deprived of the large woody debris needed to generate sinuosity, form pools, for substrate sorting processes, and habitat formation for native salmonid populations (Collins et al., 2012).

With the approval of the Aquatic Conservation Committee, Gifford Pinchot National Forest implemented a Large Woody Debris (LWD) reintroduction project in 2014 on Clearwater Creek. Sixty-four LWD structures, intended to provide a variety of functions and habitat types, were added to the stream (Groskopf & Sleasman, 2014). Despite these efforts, the Forest Service has determined that further restoration is needed to properly restore natural stream function.

1.2 Purpose

The Clear and Clearwater Creek Geomorphology and Hydraulics Assessment contained herein was undertaken to support the development of habitat improvement projects in tributaries of the Muddy River. This project has been funded by the Aquatic Conservation Committee for the Lewis River Hydropower licenses through the Aquatics Fund. This report details the geomorphic assessment, which consisted of desktop analyses of available spatial datasets, field assessment, and a preliminary hydraulic assessment.

The overall goal of this project is to assess the geomorphic conditions pertinent to the development of cost-effective restoration opportunities that have the general aim of improving habitat complexity and diversity for spawning and rearing life stages of focal species (spring Chinook and Coho salmon). Preliminary criteria identified for the identification and evaluation of restoration opportunities include:

- Conducive to a self-sustaining, process-based approach;
- Focused on response reaches accessible by excavator;
- Response reaches not accessible by excavator are to be evaluated for helicopter wood placement; and,

- Ability to improve habitat diversity and complexity for spawning and rearing life stages.

To achieve these overall goals, this report documents the existing geomorphic conditions and will inform the development of alternatives and the Alternatives Analysis phase of the project.

2. Project Area Overview

Clear Creek and Clearwater Creek are tributaries of the Muddy River, which drains the eastern flanks of Mt St Helens, in the Cascades ecoregion (EPA, 2016) of southwestern Washington State. The Muddy River flows to the south, where it confluences with the Lewis River near the upstream end of Swift Reservoir (Figure 1). As perennial tributaries, these streams support high relative abundances of spring Chinook salmon redds compared to other local tributaries, as documented in the 2021 Lewis River Aquatics Coordination Committee's Draft Annual Report. Accordingly, the project areas extend from the confluences with the Muddy River to the upstream extent of anadromous fish habitat on both streams. The Clear and Clearwater watersheds are generally north-south in orientation, with steep, headwater and colluvial tributaries entering from the east and west.

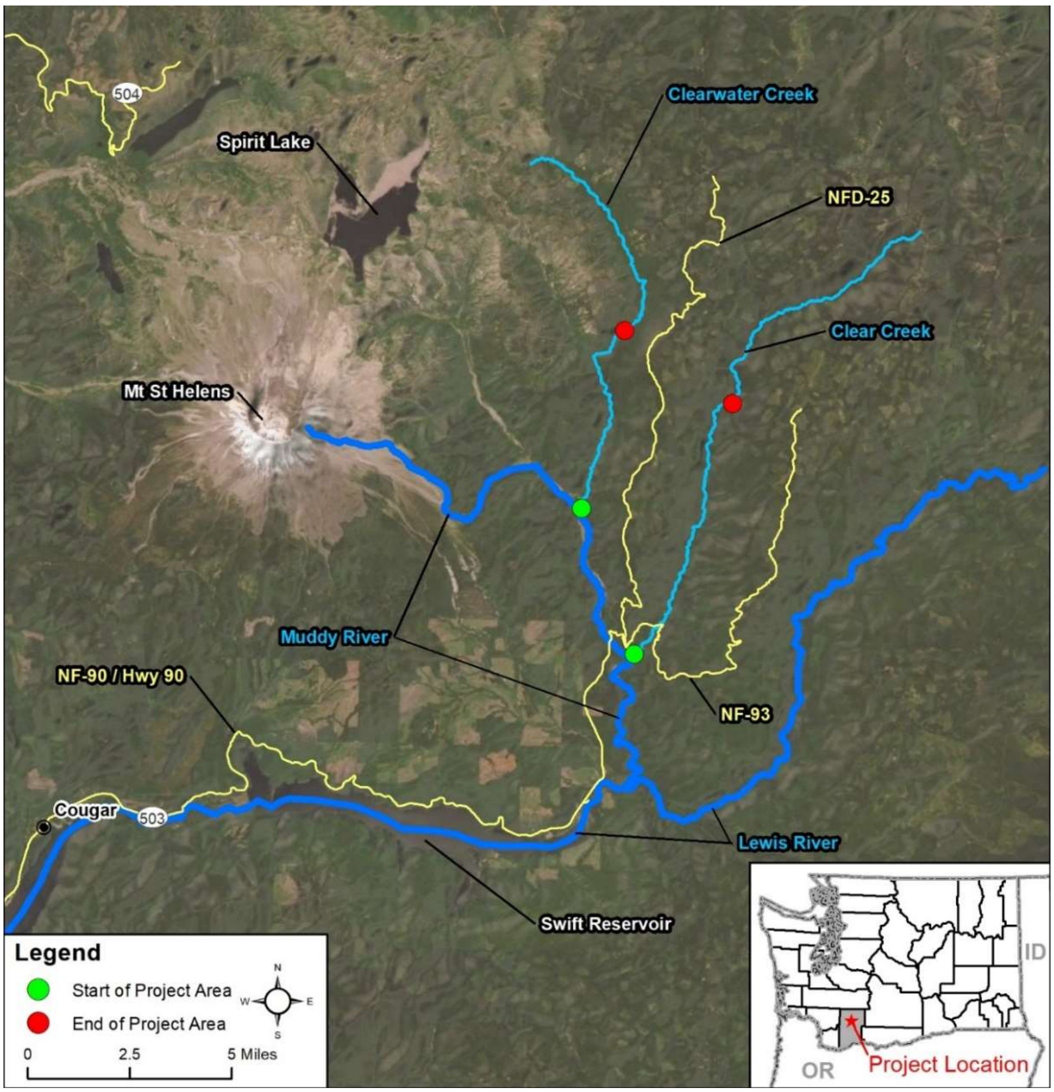

Figure 1. Overview Map of Project Area

A gaging station has been in place, intermittently, on the Muddy River since 1927. The annual hydrographs shown on the envelope graph for the Muddy River (USGS 14216500) in Figure 2 shows runoff patterns typical of rainfall-dominated watersheds of the western Cascades– elevated winter flows, with low flow periods occurring during the late summer and fall. Flows remain elevated through the spring, bolstered by snowmelt from higher elevation, alpine and sub-alpine zones in the Muddy and Clearwater watersheds.

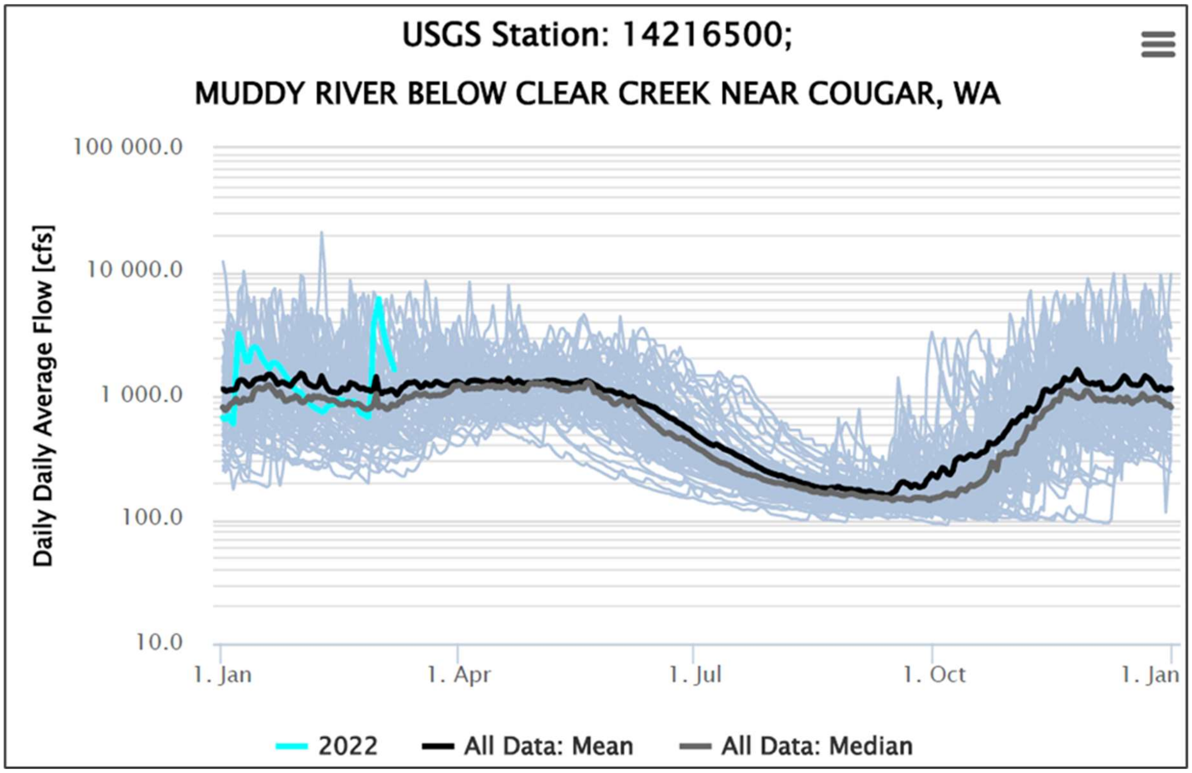

Figure 2. Envelope graph for the available data for USGS 14216500. The graph shows the variability captured by annual hydrographs (gray lines) overlain by mean, median, and calendar year 2022 mean daily flows.

Logistically, the project areas are remote and offer limited cell service, fuel, and access opportunities for project crews. Though numerous logging roads exist throughout the area, few are maintained. NF-93 was the only maintained road accessing Clear Creek at the time of survey and there were no roads providing access to Clearwater Creek.

2.1 Watershed Characteristics

Disturbance regimes for Clear and Clearwater can be defined by volcanic activity, debris flow, channel avulsion, flooding events of 1996 in the lower reaches, and logging. While volcanic activity may be most impactful in the Clearwater watershed, debris flow and logging may be the most impactful in the Clear watershed. These disturbance regimes are detailed below.

2.1.1 Clear Creek

Bordering the Clearwater Creek watershed to the east, the Clear Creek watershed encompasses a total of 47 square miles. Just outside of the Mt St Helens blast zone, Clear Creek was spared from widespread forest loss and present-day conditions show canopy cover over 73.8 percent of the watershed (USGS, 2022). Clearcut logging—rather than eruption forces—have been the primary cause of reductions in canopy cover in the Clear Creek watershed. The December 30th, 1984 aerial image on Google Earth shows patches of clearcut logging, mostly located near the ridgetops and upper hillslopes (Figure 3). Slope failures, associated with the clearcut patches, are visible in the upper watershed. It appears that large portions of the riparian forest were left intact, and a number of old-growth-sized trees were observed standing in the floodplain and stabilizing accumulations of large wood in the channel (Photo 1). Downstream of FS-93, portions of the riparian forest are dominated by successional alder stands where sediments were deposited on the floodplain during previous flooding events.

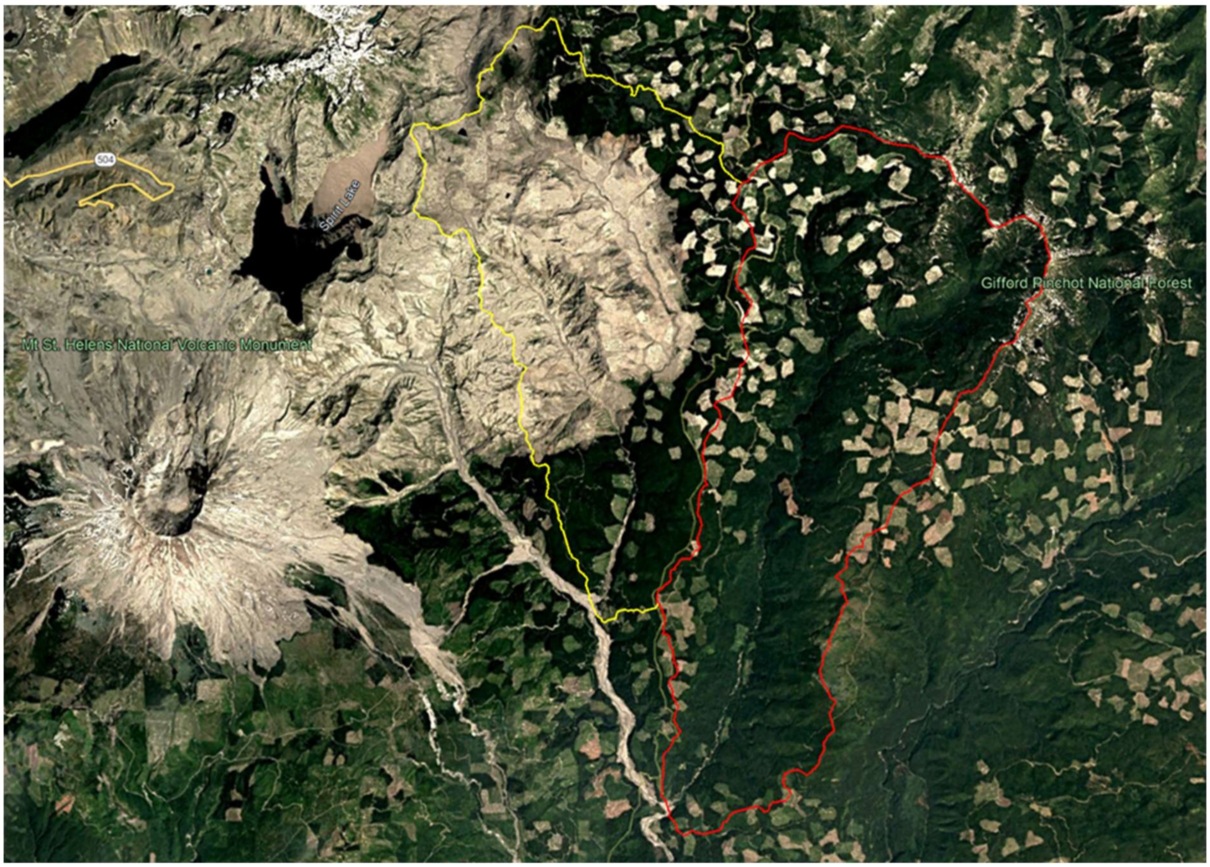

Figure 3. Historic aerial imagery of clearcut logging. Clear Creek watershed is outlined in red and Clearwater Creek watershed is outlined in yellow (Source: Google Earth, 12/30/1984)

Photo 1. Old-growth-sized tree standing in the floodplain (left) and stabilizing a large wood accumulation in Clear Creek (right).

2.1.2 Clearwater Creek

With a total drainage area of 39.5 square miles, the Clearwater Creek watershed is located directly west of the Clear Creek watershed. During the eruption of Mt St Helens, the portions of the watershed above the Bean Creek confluence were subjected to channelized blast forces and searing heat (Figure 4), resulting in blown down forest and standing dead forest. This reduction of forested area remains to present day, with just 42.3 percent of the total watershed covered by canopy (USGS, 2022).

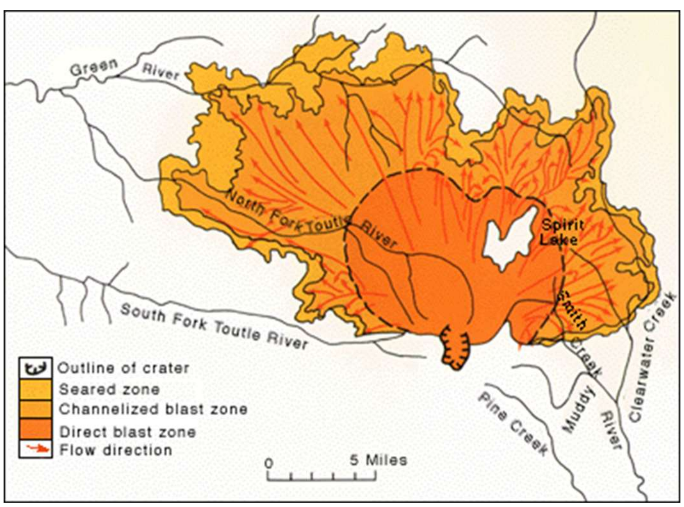

Figure 4. Mt St Helens 1980 Eruption Blast Zones[1]

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[1] Watson, J. 1997. Lateral "Blast". https://pubs.usgs.gov/gip/msh/lateral.html

Lisle (1995) conducted monitoring in the upper reaches of Clearwater Creek (above the confluence with Bean Creek) and noted that a substantial amount of wood and sediment (ash, sand, pumice, and gravel) was washed into the channel in the first 1-2 years following the eruption and quickly transported to the lower reaches. Mass wasting on the hillslopes delivered coarse material to the stream. Figure 5 shows post-eruption channel conditions on Clearwater Creek, though specific information regarding the date and specific location were not included in the article.

Figure 5. Channel conditions in upper Clearwater Creek following the eruption of Mt St Helens (Lisle, 1995).

In addition to eruption disturbances, the forests surrounding Clearwater Creek have been subjected to salvage logging and clearcut logging in the years since the eruption. Despite the accompanying revegetation efforts by timber companies in the early 1980s, areas of salvage logging have recovered at a slower rate than areas of natural regeneration (Titus, 2007). Floodplain logging of old growth forest has further altered the wood recruitment cycle of the stream by reducing availability of LWD needed to produce stable wood accumulations that drive complex geomorphic processes and habitat formation. Today, these clearcuts exist as successional stands of alder where the species has recolonized large floodplain sediment deposits from previous flood events. With a disrupted wood recruitment cycle and reduction of riparian shade, the Clearwater Creek fishery may also be at increased risk of rising water temperatures in response to climate change (Poole et al., 2001).

A stream restoration project, implemented by the U.S. Forest Service (USFS) in 2014, was completed on the lower 1.7 miles of Clearwater Creek. This project consisted primarily of bank-buried and bank-attached wood structures[2]. The present-day effects of these restoration efforts are detailed throughout the Geomorphic Assessment and Discussion portions of this report.

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[2] The details of the implementation are described in *USFS. 2014. Clearwater Creek In-stream Habitat Restoration Project Closeout Report. USFS Region 6, Gifford Pinchot National Forest, Mount St. Helens National Volcanic Monument.*

3. Methods

3.1 Geomorphic Assessment

The geomorphic assessment consisted of both desktop analysis and field observation components performed by DJ&A P.C. (DJ&A) and Inter-Fluve. The desktop portion utilized light detection and ranging (LiDAR) data and LiDAR-derivative datasets (e.g., slope maps and relative elevation models) to facilitate interpretations of geomorphic process and measurements of various channel characteristics, primarily bed slope, and confinement ratio (defined as the ratio of channel width to valley width). The 2019 QL2 data, sourced from the Washington Department of Natural Resources (DNR) website by DJ&A in May of 2022, is accurate to 1 ft and features 2 data points per square meter. The digital elevation model (DEM) derived from this data are also accurate to 1 ft, with a resolution of 1 meter.

Prior to fieldwork, relative elevation models (REMs) were developed for both streams. These high-resolution REMs (shown in Figure 6) illustrate topographic relief relative to a reference surface elevation without displaying above ground features such as trees and surface water. REMs were developed for the Clear and Clearwater valleys, displaying the height of 3.28 ft (1 meter) cells above or below reference surfaces created from an estimated channel centerline along each channel alignment. The Clear and Clearwater REMs were created using elevation data from the previously described LiDAR datasets and the kernel-density approach described in Olson et al., 2014. Search radii of 1,000 ft and 750 ft were used to develop the reference elevation surfaces for the Clear and Clearwater valleys, respectively. The Clear Creek and Clearwater Creek REMs were used throughout the geomorphic assessment for navigation, identification of relict channels and opportunities for floodplain reconnection, and will be used throughout the alternative-development process.

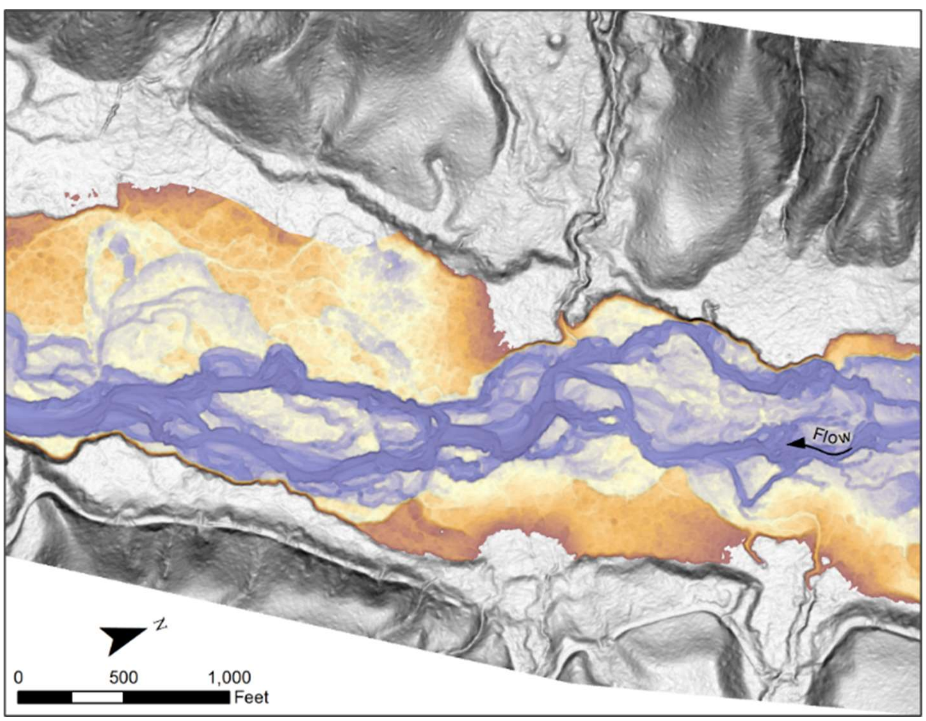

Figure 6. Section of REM from Clear Creek highlighting the anastomosing channel pattern. Shades of yellow and orange show higher relative elevations while shades of blue show lower relative elevations.

DJ&A and Inter-Fluve conducted in-field geomorphic and project identification surveys of Clear Creek and Clearwater Creek in May of 2022. The goal of these surveys was to document existing stream geomorphic character and provide preliminary data needed for development and analysis of restoration design alternatives.

Due to limited road access and high flows, DJ&A personnel surveyed a subset of the total project area including the lower 1.5 miles of Clearwater Creek, lower 1.3 miles of Clear Creek (mouth to FS-93 bridge), and 1.5 miles of upper Clear Creek. Based out of nearby Hood River, Oregon, Inter-Fluve personnel were able to access and survey more comprehensive segments of the streams during periods of wadable streamflow. These surveys captured the lower 3 miles of Clearwater Creek and lower 6 miles of Clear Creek. Upstream progress of Inter-Fluve personnel on Clearwater Creek was halted by unsafe wading conditions in a bedrock canyon, while upstream progress in Clear Creek was halted by a transition to a high-gradient channel form which was determined to be unsuitable for stream restoration activities. Table 1 below summarizes the extent of the surveys completed by DJ&A and Inter-Fluve.

Table 1 Surveyed Stream Segments

DJ&A	**Begin**	**End**
Clearwater Creek	46.168427, -122.031808	46.186809, -122.023697
Clear Creek (Lower)	46.114785, -122.004350	46.127713, -121.990048
Clear Creek (Upper)	46.166981, -121.968825	46.191037, -121.967327
Inter-Fluve		
Clearwater Creek	46.16775, -122.0324	46.20817, -121.0177
Clear Creek	46.114785, -122.004350	46.18544, -121.9662

DJ&A field personnel walked each stream until encountering a prominent morphologic feature such as a log jam, key rock piece, grade control structure, or toe wood installation. The feature location, dimensions, and stability were then recorded along with notes regarding pool formation, substrate sorting, or other associated effects as applicable. Where possible, field personnel measured features directly using pocket tapes and range finders but relied upon visual estimation for features that were out of reach. In addition to discrete features, bankfull and floodplain width measurements were recorded frequently using a laser range finder. Finally, photos were taken of surveyed features and stream reaches from various angles. Given the extent of the project area and need for efficient data collection, measurements were taken at the discretion of field personnel rather than at regular intervals, with the goal of clearly characterizing trends and changes in stream geomorphic character. Table 2 below summarizes the measurements taken by field personnel.

Table 2 Field Measurements

Feature	**Measurement(s) and/or Classification**
Key Pieces—Rock and Woody Debris	Intermediate axis (Rock), Length and Diameter (Wood), Stability Class
Log Jams	Key Piece Length and Diameter, Stability Class

Feature	Measurement(s) and/or Classification
Toe Wood Installations	# of Pieces, Avg Exposed Length and Diameter, Stability Class
Grade Control	Type and Stability Class
Stream Channel	Bankfull Width and Basic Rosgen Classifications
Floodplains	Floodplain Width and General Observations

Trimble GPS-enabled waterproof field tablets featuring channel alignment maps and 100 ft stationing were used for navigation and data collection, and a geotag-capable camera was used for survey photos. All data was recorded as georeferenced point features and mapped onto the stream alignment map. Upon completion of the surveys, field collected data was exported to a spreadsheet summarizing all measurements and field notes. This data was then used to create AutoCAD maps of each stream, providing a user-friendly representation of existing conditions data that will serve as the basis for future design alternatives. Additionally, geotagged photos were exported as a geospatial .KMZ file to provide a visual “tour” of the surveyed stream reaches.

Inter-Fluve collected data on the existing log jams, key piece sizes, and associated channel response and also focused on identifying opportunities for LWD introduction, including orientations, rough estimates of wood quantity, and whether the locations were better suited to machine or helicopter placement. Using a GPS-enabled field tablet, potential sites and source trees were mapped as georeferenced points on a map featuring channel alignment and 100 ft stationing.

Finally, each stream was divided into reaches based on zones of uniform geomorphic characteristics along each valley (Figure 7). The locations of the breaks between reaches were initially assigned in GIS based on long-valley changes in channel planform and/or valley confinement. For example, the upper-most portions of Clear and Clearwater creeks are single-thread channels confined in narrow valleys with little-to-no floodplain formation or other valley bottom landforms. These transition downstream to wider valleys with more complex channel planforms and valley bottom morphologies. Reach divisions and descriptions were subsequently refined and updated from field observations, which noted the impacts of infrastructure, land use, and other human impacts on the geomorphology of the Clear and Clearwater valleys. Field observations identified the downstream-most reach break on Clearwater Creek, located where the channel planform shifts from predominantly anastomosing to single-thread as a result of bank stabilization efforts along this section of Clearwater Creek.

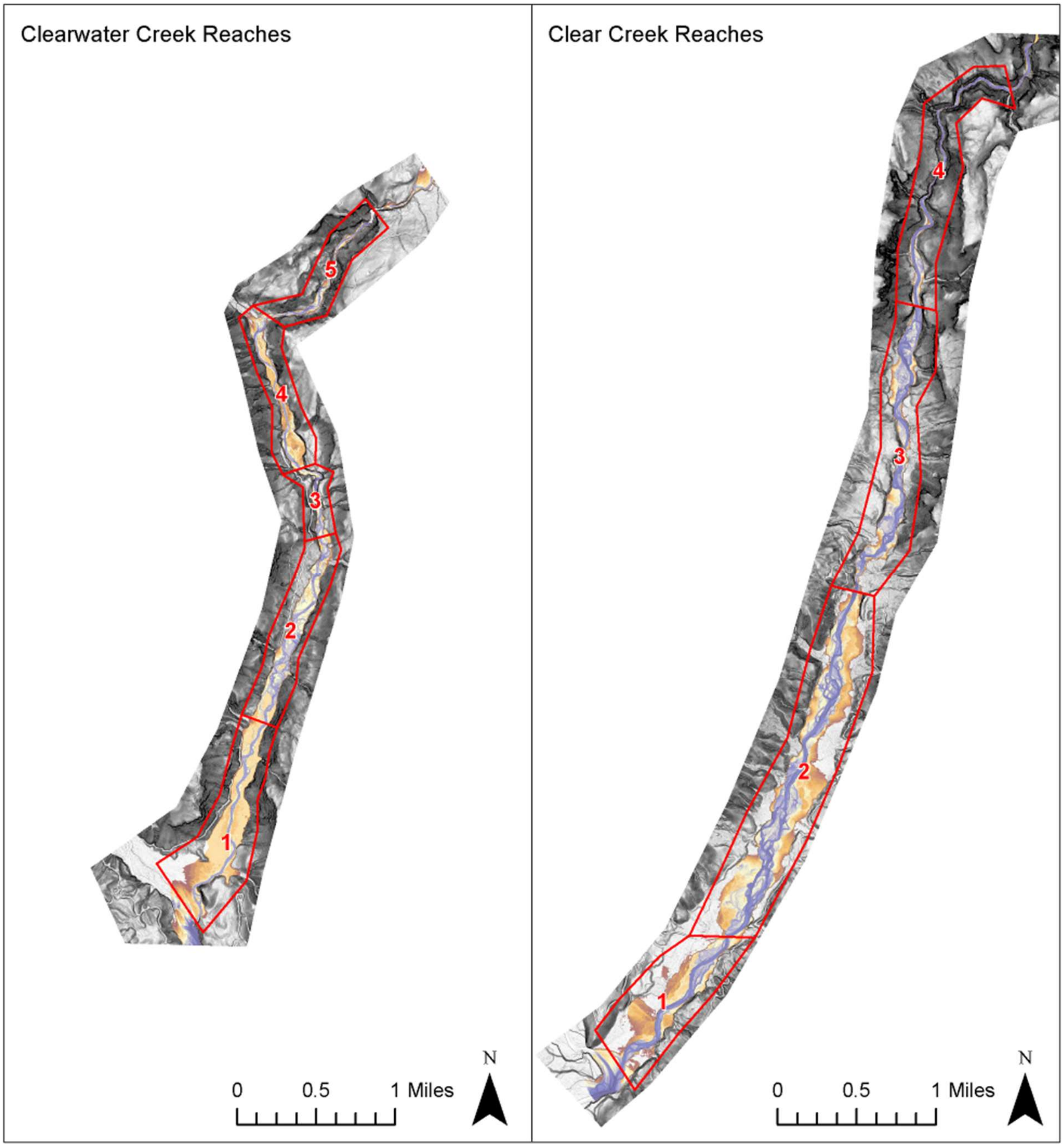

Figure 7. Reach Boundaries in Clearwater Creek (left) and Clear Creek (right)

3.2 Hydraulics Assessment

Flood routing analyses were completed to evaluate potential flood impacts resulting from low-flow, 2-yr,10-yr, and 100-yr flood events. A 1-dimensional computer simulation was performed for Clearwater Creek and Clear Creek using HEC-RAS Version 6.1.0 rainfall-runoff computer software. The software was developed by the U.S. Army Corps of Engineers (USACE, 2021). The flows for the scenarios described above were calculated using StreamStats (USGS, 2021). StreamStats data was pulled at all locations showing tributaries and the larger tributaries were included in the HEC-RAS models.

Additionally, research for historical stream gage data was performed. Both reaches have stream gages; however, both were only active for approximately nine years in the 1980's and there were no gages on nearby, comparable streams with enough data to run analysis for comparison. Manning's n-values were assigned using National Land Cover Database data (NRCS, 2016). Additional assessment of each hydraulic model will be performed as part of the Alternatives Analysis task which follows this Geomorphic and Hydraulic Assessment task.

4. Assessment Results and Discussion

4.1 Clear Creek

Reach metrics for Clear Creek are provided below in Table 3. These metrics provide numeric and categorical data for the geomorphologic characteristics and processes discussed in the following sections.

Table 3 Clear Creek Reach Metrics

Reach	Length	Single or Multi-Thread	Average Bankfull Width (ft) a	Confinement Ratio	Average Bankfull Depth (ft) a	Entrenchment Ratio	Bankfull Width-Depth Ratio	Sinuosity b	Average Gradient b	Rosgen Class
1	9,936	Single	263	0.70	5.50	1.4	47.8	1.15	0.43%	F
2	13,400	Varies	289	0.65	5.54	1.5	52.2	1.09	0.90%	D, B
3	11,664	Single	241	0.68	5.54	1.5	43.5	1.20	1.12%	B
4	10,500	Single	109	0.78	5.75	1.3	19.0	1.33	2.26%	F

a Measurements taken from HEC-RAS for surface width of 2-year flow
b Measurements taken from AutoCAD

4.1.1 Hydraulic Assessment

Modeled mid-channel velocities in Clear Creek generally decrease as the stream transitions from confined, high-gradient geomorphic character in the upper reaches to unconfined, low-gradient character in the lower reaches. In upper Clear Creek (Reach 4) fluctuations in these modeled velocities appear relatively uniformly spaced, illustrating the effect of consistent step-pool morphology associated with boulder and bedrock-controlled channels.

Hydraulic simulations for portions of Clear Creek featuring single-thread channels due to high valley confinement display less overall variability in mid-channel velocity, with fewer occurrences of velocities over 2 ft/s and below 0.3 ft/s. This increased flow uniformity is seen throughout Reach 1, and the confined portions of Reaches 2 and 3.

Based upon this preliminary review of the hydraulic models, heterogeneous hydraulic conditions which produce habitat complexity are most associated with the portions of Clear Creek that feature low valley confinement, floodplain connectivity, multithread channels, and recruitment of LWD. Further interpretation of the hydraulic models, however, will be necessary while developing and analyzing alternatives.

4.1.2 Geomorphic Assessment and Discussion

4.1.2.1 Reach 1

Reach 1 on Clear Creek extends downstream from the bridge on NF-93 to the confluence with the Muddy River. The reach is relatively unconfined, though bounded on the north side by an elevated river terrace (Photo 2). Channel slope is around half of a percent with an average bankfull width of approximately 260 feet. Unlike upstream reaches the channel is predominantly single thread, which may be related to the restoration project that was implemented at some point in the past (Photo 3). Much of the immediate overbank is covered by alder (likely deposited during the 1996 flood), which provides little erosion resistance to Clear Creek flows and thus is not large enough to influence channel geomorphology (Photo 4). The lack of large (key piece) trees has limited habitat development through Reach 1.

Photo 2. Large conifers, recruited from the terrace visible in the background, are forcing pool scour and the formation of bedforms in Clear Creek.

Photo 3. Remaining portion of a bank buried wood structure scouring a pool in Clear Creek.

Photo 4. Alders, perhaps associated with the 1996 floods, line a portion of Clear Creek through Reach 1. The alders are not large enough to create roughness and influence the local geomorphology.

4.1.2.2 Reach 2

Reach 2 has an anastomosed channel pattern that periodically transitions to single thread in the locations most heavily constricted by tributary fans. The average channel gradient is 0.009 ft/ft (slightly steeper than Reach 1), and though relatively unconfined, the valley width is heavily encroached upon by tributary fans and debris flow. Old growth trees are present throughout the floodplain and act as key pieces in the channel, with valley jams (i.e., wood accumulations that span much of the valley bottom) driving anastomosis through avulsion around the hardpoints created by the wood accumulations (e.g., Photo 5, Photo 6). Key pieces vary in length but were estimated to be greater than 3 feet in diameter (i.e., diameter at breast height, DBH). Racked material contained pieces with stems in the 16-24 inch size class (with various lengths). Simplified sections of channel (e.g., Photo 7, Photo 8) coincide with tributary fans and flood deposits covered in alder. In these locations, the river has been unable to recruit large trees (e.g., Photo 9) into the channel. At the upstream end of the reach, a large landslide has pinched the valley, creating a steep cascade (Photo 10).

Photo 5. Clear Creek working through wood accumulations that have persisted through time. The wood accumulation has influenced the formation of deep pools and multiple channels across the valley bottom.

Photo 6. Valley-spanning wood accumulations with forest recolonization on the downstream side (hydraulic shadow) of the accumulations.

Photo 7. The channel upstream of a channel-spanning jam is aggraded (note the sediment buildup on the far side of the river in the inundated alder stems) and the available wood (young alder) is not sufficient size to influence the local geomorphology.

Photo 8. Wide and shallow section of channel lacking wood of sufficient size to self-stabilize in the channel.

Photo 9. In situ key pieces provide opportunities onto which to rack additional material.

Photo 10. Rapids at the top of Reach 3 associated with a large debris fan.

4.1.2.3 Reach 3

Reach 3 is similar to Reach 2, with a slightly narrower valley. Reach slope increases to 0.011 ft/ft and the channel pattern consists of a confined single-thread channel with pockets of multi-thread (i.e., response), largely driven by wood deposition. The upstream end of the reach is marked by a transition to a predominantly transport channel (Photo 11). Through Reach 3, channel pattern and complexity is driven by wood deposition, the recruitment of old growth trees, and the formation of valley jams. Considerable habitat complexity is created by avulsion around and through the valley jams (e.g., Photo 12, Photo 13). The vegetated islands seen in the aerial and in the REM are locations where the forest is recolonizing old wood accumulations (e.g., Photo 14).

Photo 11. Looking upstream from the top end of Reach 3 at the transition from transport to response.

Photo 12. Racked wood forcing avulsion and side channel creation near the top of Reach 3.

Photo 13. Two side channels converge (background) to form deep, covered rearing and holding pools (foreground).

Photo 14. Racked wood on the upstream face of a valley-wide jam supporting forest succession and an avulsion-induced anastomosing channel planform.

4.1.2.4 Reach 4

Reach 4 was not assessed in the field, but contains a highly confined, transport channel with little wood visible in the aerial photographs (Figure 8). Reach slope is estimated at 0.023 ft/ft and controlled by bedrock and boulders. The reach is predominantly transport with only small, lateral accumulations of alluvium visible.

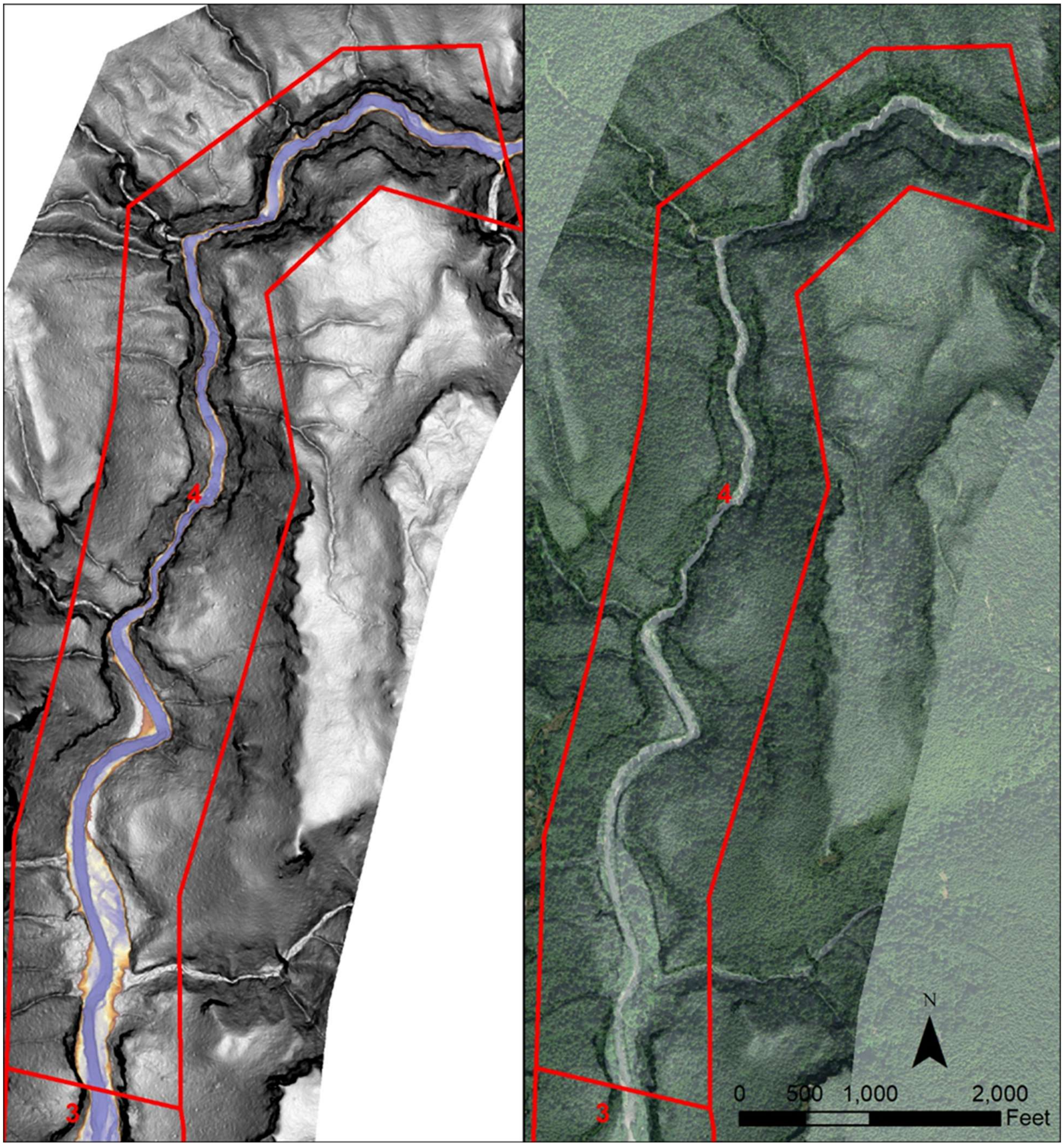

Figure 8. REM and aerial imagery for Reach 4 of Clear Creek

4.1.2.5 Clear Creek Synthesis of Field and Desktop Observations

The geomorphic characteristics of Clear Creek appear to be primarily controlled by valley confinement and the recruitment of old growth trees. In locations where confinement is reduced, considerable habitat complexity is present as a result of the recruitment of key pieces and the formation of large, valley jams. Collins et al., (2012) described conceptual models of floodplain landform and forest development in western Washington, including an anastomosing channel pattern driven by avulsion (Figure 9). Hardpoints created by persistent wood jams protect patches of forest by resisting lateral erosion and causing the channel to avulse around. This conceptual model was observed throughout, and fits well with the observed stream response in unconfined portions of Clear Creek. Fitting with field observations and with the conceptual model, increasing the number of stable hard points in the unconfined sections of Clear Creek will drive increases in habitat complexity and the large wood cycle.

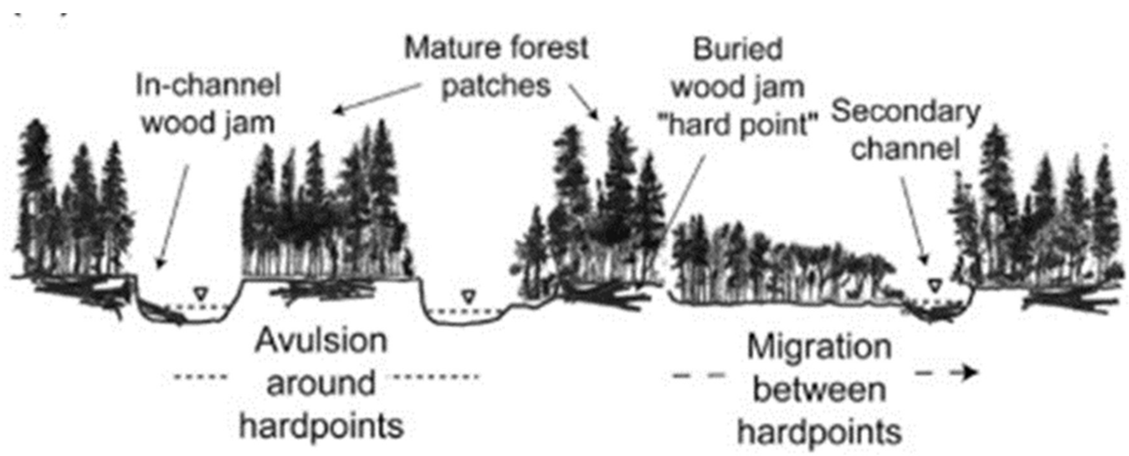

Figure 9. Conceptualization of an anastomosing channel pattern and forest succession driven by avulsion around hardpoints (Collins et al., 2012).

4.2 Clearwater Creek

Reach metrics for Clearwater Creek are provided below in Table 4. These metrics provide numeric and categorical data for the geomorphologic characteristics and processes discussed in the following sections.

Table 4 Clearwater Creek Reach Metrics

Reach	Length	Single or Multi-Thread	Average Bankfull Width (ft) [a]	Confinement Ratio	Average Bankfull Depth (ft) [a]	Entrenchment Ratio	Bankfull Width-Depth Ratio	Sinuosity [b]	Average Gradient [b]	Rosgen Class
1	7,700	Single	513	0.82	8.63	1.2	59.4	1.1	0.25%	F
2	7,037	Varies	288	0.70	5.35	1.4	53.8	1.1	0.85%	F, D
3	2,933	Single	132	0.68	5.52	1.5	23.9	1.2	1.53%	B
4	6,043	Single	110	0.55	5.59	1.8	19.7	1.2	2.28%	B
5	5,729	Single	86	0.75	4.61	1.3	18.7	1.2	4.63%	B

[a] Measurements taken from HEC-RAS for surface width of 2-year flow
[b] Measurements taken from AutoCAD

4.2.1 Hydraulic Assessment

Modeled mid-channel velocities in Clearwater Creek generally decrease from upstream to downstream, as the stream transitions from confined, high-gradient geomorphic character to unconfined, low-gradient character in the lower reaches. This is illustrated by the gradual decrease in minimum mid-channel velocities modeled in the low flow scenario.

The most heterogenous velocities modeled were associated with Reach 2, where multithread channels and most of the LWD recruitment and jam formation were observed. In contrast, Reach 1, consisting of the lowermost 1.5 miles of Clearwater Creek, consists of lower velocities and more uniform flow conditions than other portions of the stream. In this reach, only two occurrences of mid-channel flows exceeding 2 ft/s were identified in the model. However, this assessment did not account for flow conditions along the stream banks where previous restoration efforts have resulted in multiple toe wood installations. During the development and analysis of alternatives, further interpretation of the hydraulic model will be necessary, especially around existing wood installations where the effects of previous restoration efforts can be analyzed.

4.2.2 Geomorphic Assessment and Discussion

4.2.2.1 Reach 1

Reach 1 in Clearwater Creek has a relatively low gradient (0.0025 ft/ft) channel that is controlled by bedrock at the downstream end near the confluence with the Muddy River (Photo 15). The creek is single thread throughout the reach and appears to be working its way down through mudflow and flood deposits that have buried the past floodplain. The riparian vegetation is dominated by alder and the channel bed is heavily embedded in fine sediments (Photo 16). Ash and welded tuff were observed throughout. A 2014 restoration project lined the river right side with wood structures that were observed in various states of function (e.g., Photo 17). Complexity is limited to built structures that are still functioning, limited in situ jams (e.g., Photo 18), and sections where the active channel is working through standing dead trees that were buried by post-eruption sediments (e.g., Photo 19).

Photo 15. Confluence of Muddy River and Clearwater Creek with bridge and falls visible in the center of the photo.

Photo 16. Riparian vegetation is dominated by single age class alder, perhaps associated with the 1996 floods. The channel bed through Reach 1 is highly embedded (foreground).

Photo 17. Wood structures and rootwads installed as part of the 2014 restoration project.

Photo 18. Apex log jam with substantial quantity of racked logs and debris.

Photo 19. Clearwater Creek flowing through buried, former floodplain forest (note tree stumps sticking up in bed of channel).

4.2.2.2 Reach 2

Reach 2 sees the channel transition back to anastomosis, driven by the presence of many large valley jams (e.g., Photo 20). Overall reach slope increases to 0.0085 ft/ft with the dominant control being the valley jams. Throughout much of the reach, active channels are working into buried, past floodplain and standing snags are prevalent. Habitats throughout the reach are complex and varied. Wood accumulations contain a mix of large pieces, a substantial amount of debris, and smaller racked material. Similar to observations from Clear Creek, key pieces vary in length and are at least 3 feet DBH; racking logs vary, and do contain larger pieces in the 16-24 inch size class (DBH).

Photo 20. Very large, valley-spanning log jam near the upper end of Reach 2 (top right). The jam contains a mixture of key pieces and substantial racked logs and debris (bottom). The channel is heavily aggraded on the upstream face of the jam (top).

4.2.2.3 Reach 3

Reach 3 is a relatively short, bedrock-controlled and confined canyon reach (Photo 21). It is a high energy transport reach, with a slope of 0.015 ft/ft and very limited floodplain development.

Photo 21. Short, bedrock-controlled canyon reach of Clearwater Creek.

4.2.2.4 Reaches 4 and 5

Reaches 4 and 5 were not assessed in the field, but a number of observations were made from other sources (Figure 10). Reach 4 is located in the blast zone, primarily single thread, and appears to be working through mudflow deposits from the Mt St Helens eruption and, likely, flood debris and deposits from flood events in 1996. Reach slope is 0.023 ft/ft with planform complexity limited to the Bean Creek fan. The portion of the reach affected by the blast remains unvegetated except for a riparian strip along the bank. These lateral deposits are likely high and hydrologically disconnected at all but the highest flows. Reach 5 is a highly confined transport reach, though some pockets of alluvium can be seen in the REM. Reach slope is relatively high (0.046 ft/ft), and the reach ends at Paradise Falls, a 125-foot tall waterfall and passage barrier to anadromous fish.

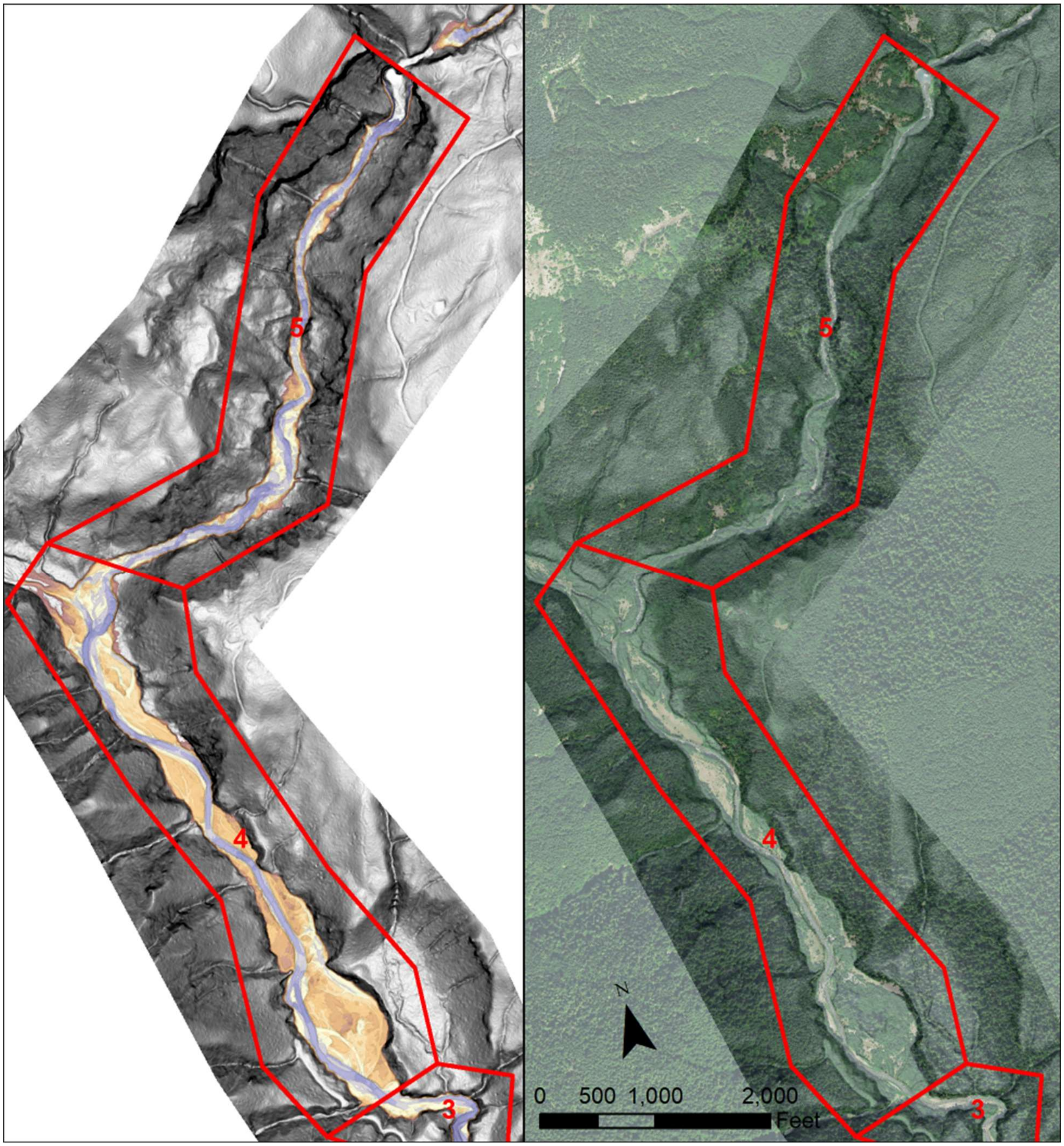

Figure 10. Reaches 4 and 5 of Clearwater Creek were directly impacted by the Mt St Helens eruption. Mudflow buried the valley through Reach 4. Reach 5 is heavily confined by bedrock.

4.2.2.5 Clearwater Creek Synthesis of Field and Desktop Observations

Clearwater Creek has been substantially disturbed by the Mt St Helens eruption and potentially the 1996 floods. Through much of the observed length, the creek appears to be working through sediments that have buried its past channel and floodplain. The channel bed appears to be highly embedded by fine sediments though cleaner patches of gravel were observed in close proximity to deposited wood. Reach 2 is similar to Clear Creek, exhibiting an anastomosed channel pattern driven by avulsion around wood jams and rafts. In that sense, Reach 2 is further evolved than the adjacent reaches and may present more immediate opportunities for habitat uplift.

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