Photo source: Wilson (12 Sep. 2022)

MF Nooksack Channel Monitoring & Adaptive Management
Year 2 Monitoring

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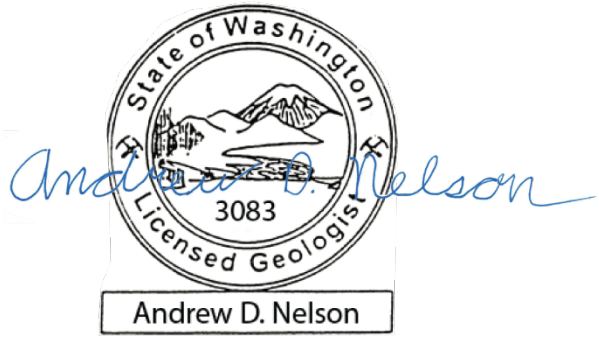

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- Annie Dufficy — Project Geomorphologist
- Jaron Brown — Project Hydraulic Engineer
- Amiana McEwen — Project Hydraulic Engineer
- Barry Chilibeck — Senior Review & Fish Passage Assessment

NHC partnered with Wilson Engineering on the as-built survey and Kleinschmidt R2 for Fish Passage Assessment:

- Tom Brewster — Survey Lead
- Paul DeVries — Fish Passage Assessment

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1 INTRODUCTION

The City of Bellingham (City), with partner organization American Rivers, removed the City's water diversion dam on the Middle Fork Nooksack River in summer 2020 and restored the river through the previous dam site to a natural historical channel configuration, as part of the Middle Fork Nooksack Fish Passage Project. This was intended to provide passage and restore fish access to approximately 16 miles of pristine spawning and rearing habitat in the upper Middle Fork Nooksack River for three Endangered Species Act (ESA) listed fish species: spring Chinook salmon (*Oncorhynchus tshawytscha*), Steelhead (*O. mykiss*), and Bull Trout (*Salvelinus confluentus*).

NHC was retained to monitor channel response to the dam removal following the Draft Effectiveness Monitoring and Adaptive Management Plan, or MAMP (City of Bellingham and American Rivers, 2019). The purpose of this Plan is to verify that the project meets the intended project goal of restoring the channel to a natural configuration by monitoring the physical river responses that improve fish passage and habitat connectivity. Four key monitoring metrics, outlined in Table 1.1, are the focus. This report, completed following observations of the river through autumn 2022 and published in spring 2023, presents results of the Year 2 Monitoring completed by NHC, in collaboration with partners Wilson Engineering and Kleinschmidt-R2, to complete this work.

Table 1.1 Key monitoring metrics

Monitoring Technique	Monitoring Metric	Thresholds	Decision Pathway
Photo/Visual Survey	N/A Provides indication of channel changes to inform field work.	N/A	N/A
Digital Elevation Model Development and Analysis	N/A Provides indication of channel changes to inform field work.	N/A	N/A
Channel Longitudinal Profile derived from Digital Elevation Model	Average Water Surface Elevation slope along low flow centerline.	1. >8% average slope over the entire monitoring site length. 2. >12% slope occurring over a 200 ft length within the monitoring site.	1a. <7% Average (Pass) 1b. >7% (Monitor) 2a. >7% in any 200 ft segment (Monitor) 2b. >10% in any 200 ft segment (Evaluate Adaptive Management Action)
Channel Cross Sections derived from Digital Elevation Model	Channel Water Surface Elevation at Minimum Instream Flow.	> 3ft water surface elevation decreases at any channel cross section.	1. <1ft decrease (Pass) 2. >1ft decrease (Monitor/Investigate) 3. >3ft decrease (Evaluate Adaptive Management Action)

Tasks completed in the second-year monitoring effort and preparation of this report included several survey efforts completed with a Terrestrial LiDAR Scanner (TLS) or Unmanned Aerial Vehicle (UAV) and field photo documentation on two separate occasions: winter high flow and autumn low flow. New topographic surfaces were compiled from the survey data to document changes from the as-built condition composite surface of fall 2020.

The focus of this report is to document channel adjustments observed and measured since the One-Year Monitoring Report (December 2021-September 2022), which include channel response to the November 2021 flood. These floods include multiple peaks approaching or exceeding a 10-yr event and one substantial flood on November 15, 2021 approaching a 50-yr event. Figure 1.1 illustrates the timing of these various observations relative to flood pulses and their associated stream power that occurred through September 2022. Photographic and surveyed documentation of the reach at the winter high flow (December 2021) and two-year mark (September 2022) revealed that the channel bed remained mostly stable in this monitoring period. The previous report presented a qualitative analysis of the geomorphic changes to the reach during the 2021 floods, but low-flow biological and topographic survey was needed to provide quantitative metrics for fish passage. This report addresses the previously outlined concerns surrounding regrade extent and magnitude during the floods using updated topographic data, highlights the continued success of the restored main channel, and provides discussion on the benefits to fish passage as a result of these widespread adjustments.

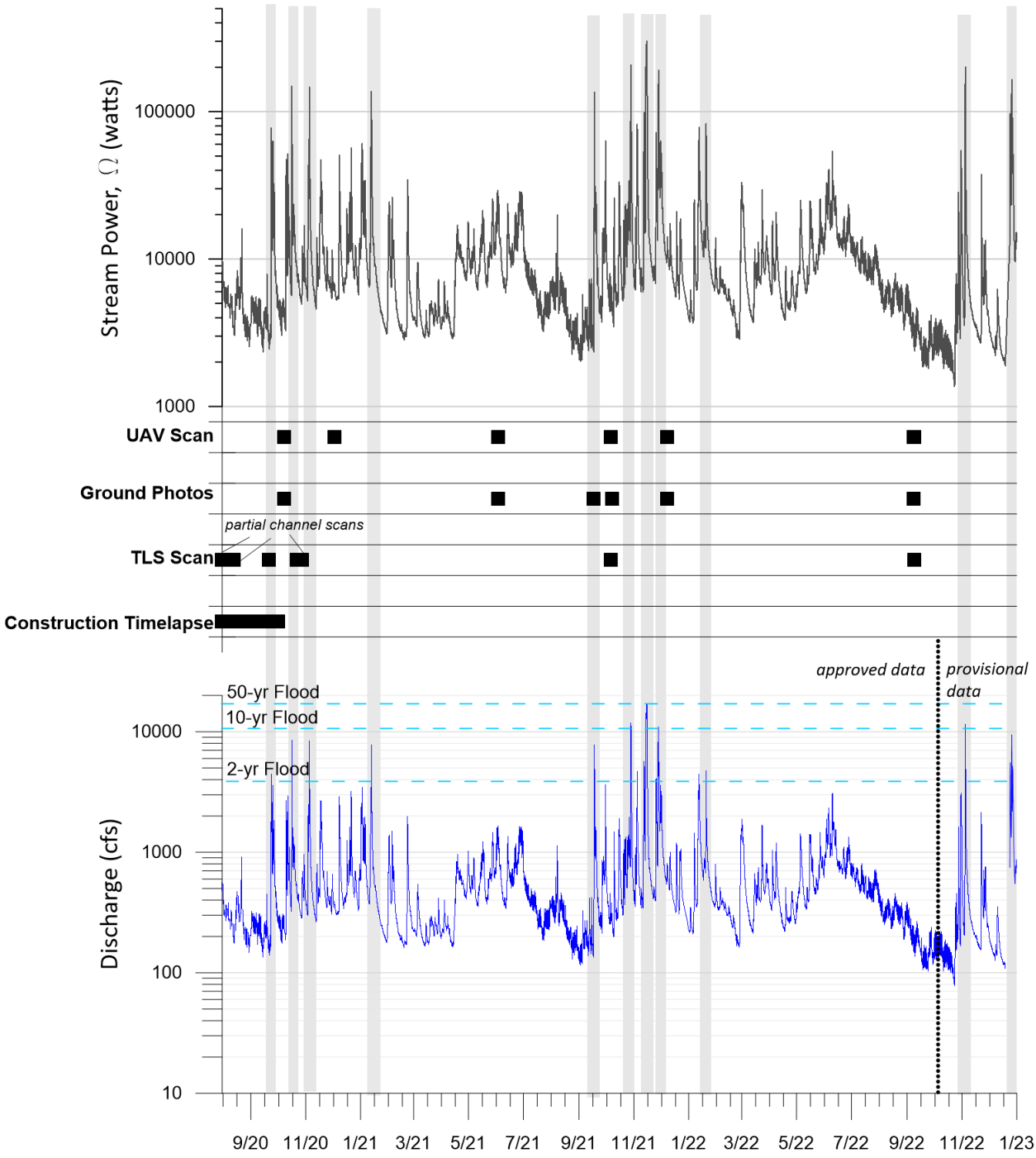

Figure 1.1 Timeline of stream flow, stream power, and observation efforts from August 31, 2019 to January, 2023

This two-year post-construction monitoring report is structured in the same way as previous monitoring reports, with an overall site-scale narrative describing the layout of the monitoring observations, key observations during the winter high-flow and two-year monitoring site visits, as well as a summary of observed changes since monitoring began, specifically from the November 2021 flood. It is supported by an appendix of detailed exhibits showing conditions and changes in conditions at each monitoring site visit.

2 MONTORING METHODS

2.1 Monitoring Site Layout

Photo documentation and cross section extraction locations were defined at approximately 20 ft intervals (allowing some flexibility to choose good and accessible vantage points) along the left bank of the channel, extending from a point defined as station zero, which is located approximately 200 ft downstream of the historic dam crest, to Station 760, which is located approximately 560 ft above the historic dam crest and 55 ft downstream of the new intake, as illustrated in Figure 2.1 (for context, the regraded reach extends from about Station 60 to about Station 400). These are named by the corresponding bank station. In addition, photo documentation points were set at eleven vantage points around the channel; these are given brief descriptive names.

Topographic and profile extraction lines were also laid out on the site to define locations for measuring changes in water surface elevation and profile slope, as also illustrated in Figure 2.1. Topographic cross section extraction lines were laid out crossing the channel at each photo monitoring station. Topographic profile extraction lines were laid out along dominant flow paths that may act as distinct fish passage routes. The measured distances along the bank provide a standardized “stationing” for the whole monitoring area. Because each profile extraction flow path has slightly different lengths than the Bankline, locations along the flow paths are defined by both along-path stations and by standard stationing.

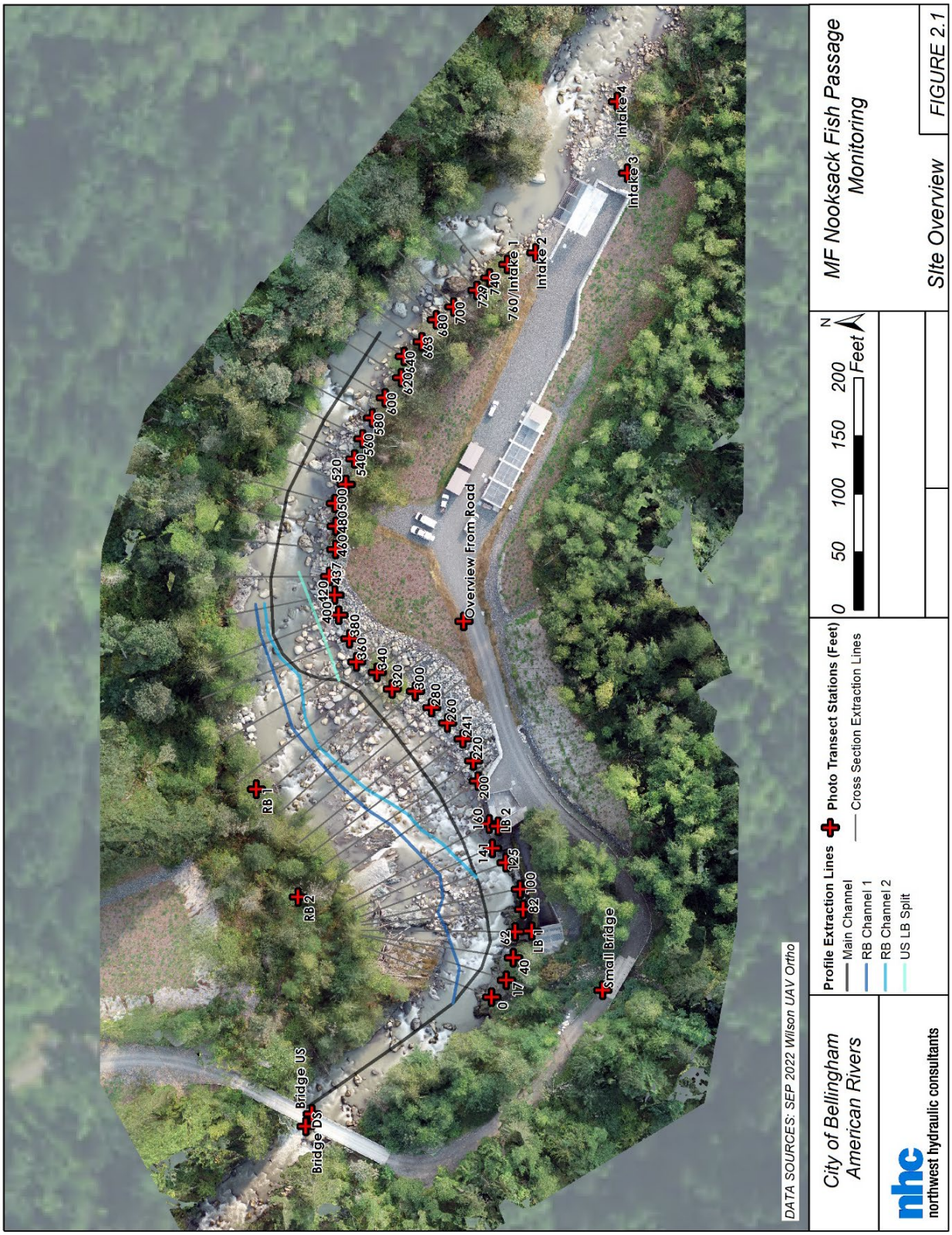

Figure 2.1 Map illustrating monitoring site layout

2.2 Survey & Documentation Techniques

Two topographic survey techniques were used to define the as-built surface and document subsequent channel changes, photogrammetry from UAV imagery, and TLS scanning. Table 2.1 outlines the timing of survey observations, equipment used, and discharge condition at the time of observation, as well as documentation of notable floods (greater than 10-yr event) that occurred during the monitoring period.

Table 2.1 Timing of site visits and observations collected.

Date	Observation Location or Notable Event	Equipment	Approximate Discharge/Flow Condition
Autumn 2020	Whole site	Methods described in NHC (2021)	Observations from 225-650 cfs, high flows up to 8,500 cfs
Winter-Spring 20/21	Moderate flows	NA	4 flow pulses over 2,000 cfs, max flow 7,800 cfs
3 June 2021	Spring high flow observations	Ground-based Photo Documentation, DJI Mavic 2 Pro UAV/UAS System equipped with Hasselblad 20MP Camera	1,200 cfs
17 Sept 2021	Year 1 Photo Documentation	Ground-based Photo Documentation	140-160 cfs
6 Oct 2021	Station 50 to Station 480	Trimble TX-5 Terrestrial 3D Laser Scanner & DJI/Matrice 200 UAV/UAS System equipped with ZenMuse 24MP Camera	275 cfs
8 Oct 2021	Photo documentation points defined in Figure 2.1.	Theodolite App running on iPhone 6s.	225 cfs
15 Nov 2021	> 25 yr RI Flood	NA	17,200 cfs
28 Nov 2021	> 10 yr RI Flood	NA	12,700 cfs
8 Dec 2021	Post-flood photo documentation	Ground-based Photo Documentation, DJI Mavic 2 Pro UAV/UAS System equipped with Hasselblad 20MP Camera	475 cfs
8 Sep 2022	Year 2 Low flow photo documentation	Ground-based Photo Documentation, DJI Mavic 2 Pro UAV/UAS System equipped with Hasselblad 20MP Camera	152 cfs

Date	Observation Location or Notable Event	Equipment	Approximate Discharge/Flow Condition
12 Sep 2022	Year 2 low flow survey	Trimble TX-5 Terrestrial 3D Laser Scanner & DJI/Matrice 200 UAV/UAS System equipped with ZenMuse 24MP Camera	205 cfs

3 AS-BUILT THROUGH DECEMBER 2021

3.1 Summary of Past Geomorphic Change

Prior to the November 2021 floods, only minor channel adjustments were observed in the observation reach. Most of these changes occurred in the right bank pathways (RB 1 and RB 2), where headcutting was first initiated around Transect 200 but had not propagated upstream to the boulders at the Fish bypass pool outlet in October 2022. The restored main channel remained largely unchanged during this time in large part due to the stability of the designed boulder clusters. Significant changes occurred to the channel bed during the November 2021 floods, which exceeded the threshold expected to mobilize individual boulders outside of jammed units. These changes are evident in Figure 3.1, Figure 3.2 and Figure 3.3. Boulder transport had notably altered the right bank pathways, midchannel bar and the facility Fish bypass outlet pool upstream of the main channel and right bank pathway flow split. In particular, as anticipated in NHC (2021), headcutting continued along the right bank flow pathway, resulting in mobilization of boulders forming the hydraulic control for the Fish bypass outlet pool and overall channel lowering. Relatively minor changes had occurred in the restored left bank pathway in comparison, suggesting that the boulder jams effectively held the designed channel in place during the flood. As will be described in Section 5.3 of this report, channel lowering of this main restored channel did in fact take place, especially upstream near the Fish bypass outlet, but most of the clusters remained stable or settled to a more stable position.

Qualitative comparisons of the October 2021 and December 2021 orthomosaics show large scale reorganization of the channel bed in the post-flood photographs. Prior to the large flow event, boulders outside of the restored flow path were not organized in stable morphologies such as boulder clusters or jamming arches, resulting in widespread mobilization during the flood. Boulder transport of some of the largest grains (estimated D_{84} and above) in the November flood appears to have restructured the bed into a more stable jammed state characteristic of an organized step-pool morphology, increasing the overall stability of the bed compared to the less-organized state present along the right bank flow paths before the November 2021 flood (Church and Zimmermann, 2007; Zimmermann et al., 2010). Some of these step features are composed of bedrock near the right bank (Figure 4.1). If the bedrock continues to erode unevenly, slots and chutes may develop, providing alternative fish passage routes through the bedrock-controlled reaches. The discontinuous exposure of bedrock on the channel bed within this reach also provides the opportunity for pools to develop downstream.

Sediment transport during the November 2021 flood also resulted in the exposure of large boulders in the mid channel bar as well as the dewatering and exposure of boulder steps just upstream of the Fish bypass outlet pool. Lowering of the midchannel bar has created wider flow pathways in the right bank channels. Most of the midchannel bar was submerged during the December 2021 site visit, suggesting that these previously distinct channels are connected during even low flows.

A final significant change that occurred during the November 2021 floods was deposition of boulders on the right bank bar at approximately station 125, downstream of the primary regrade area (Figure 3.1). This deposition was likely facilitated by the most downstream boulder jam (Jam 1) and the large boulders placed in the riffle downstream. There was uncertainty in the December 2021 topographic

surface, where overtopping water can cause errors in the SfM processing, but these visual observations were later confirmed in the September 2022 low-flow topographic surface, suggesting that aggradation of 5 feet or more has occurred since As-Built conditions. This deposition appears to have increased the elevation of the hydraulic control at the base of the regrade reach, which would lower the average slope through the regrade area. See Section 5.4 for more information on the magnitude of localized channel lowering and aggradation.

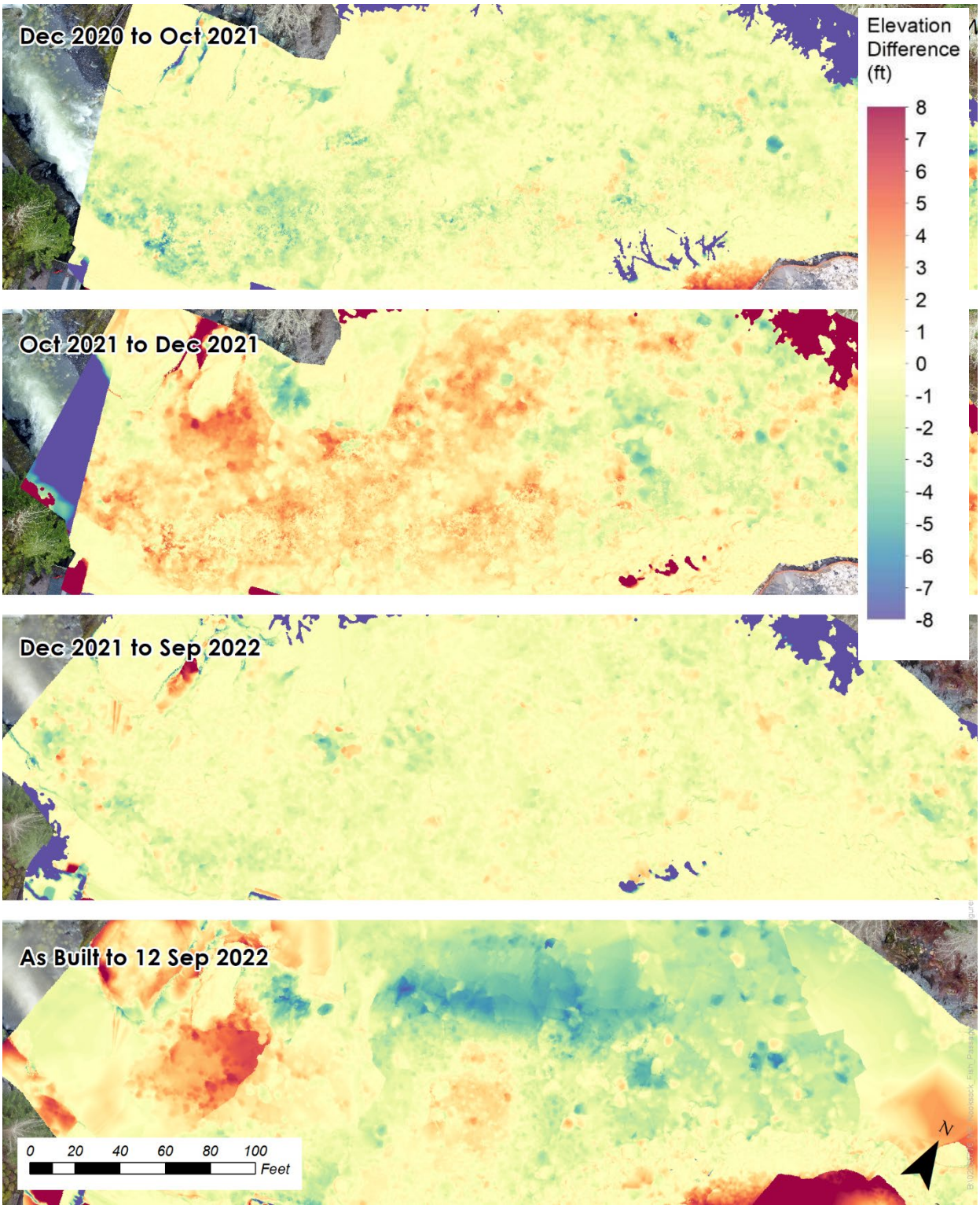

Figure 3.1 DEM surface comparisons showing differences between the design surface and as-built surface (top) and between the as-built surface and subsequent topographic surfaces. Red colors indicate aggradation and blue colors degradation.

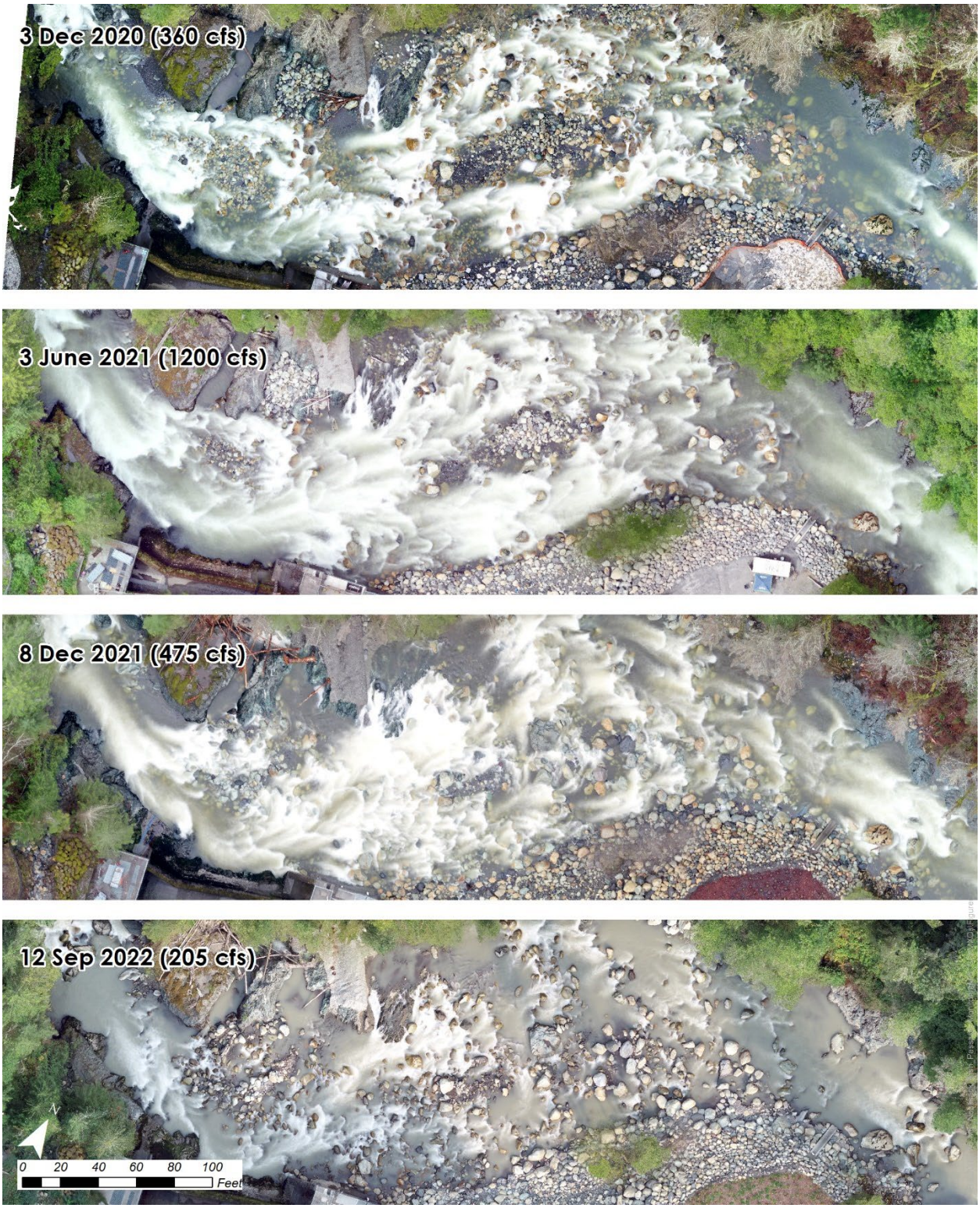

Figure 3.2 Orthomosaic comparisons showing observed channel conditions during monitoring site visits between December 2020 to September 2022.

The November 2021 floods provided an early opportunity to test the stability and adaptability of the designed channel during a large magnitude event (approaching 50-yr recurrence). Figure 3.3 displays channel bed changes within the flow split between station 140 and the fishway at 437 feet. Despite widespread channel lowering, the designed boulder clusters remained mostly stable during the November 2021 flood, preventing the same degree of bed mobility and large-scale reorganization as observed in the right bank channels. Only two of the boulder clusters destabilized from their jammed state during the floods, Jam 5 and Bonus Cluster 2. These clusters (outlined in red in Figure 3.3) are located at the upstream extent of the design channel, suggesting that boulder cluster instability increases upstream with proximity to the pool outlet, between stations 320 and 437. Select boulder movements can be seen in Figure 3.3, where displacements (shown as colored polygons) range from 12 to 25 feet.

Readjustment of the main channel has increased the complexity of the reach. During the flood, mobile small boulders and cobble being transported from upstream locked into place newly configured arched step-pool morphologies in the restored main channel, increasing the total number of pools in the reach. Therefore, the designed jams worked to not only maintain passable slopes, but they also added stable roughness, both on the left bank and along the lowering midchannel bar, from which networks of new jamming features of transported cobbles and boulders could form. This observation supports the findings from the step-pool flume experiments of Zimmerman (2010), which argues that bank roughness has a stronger effect on bed stability than either the flow or sediment supply.

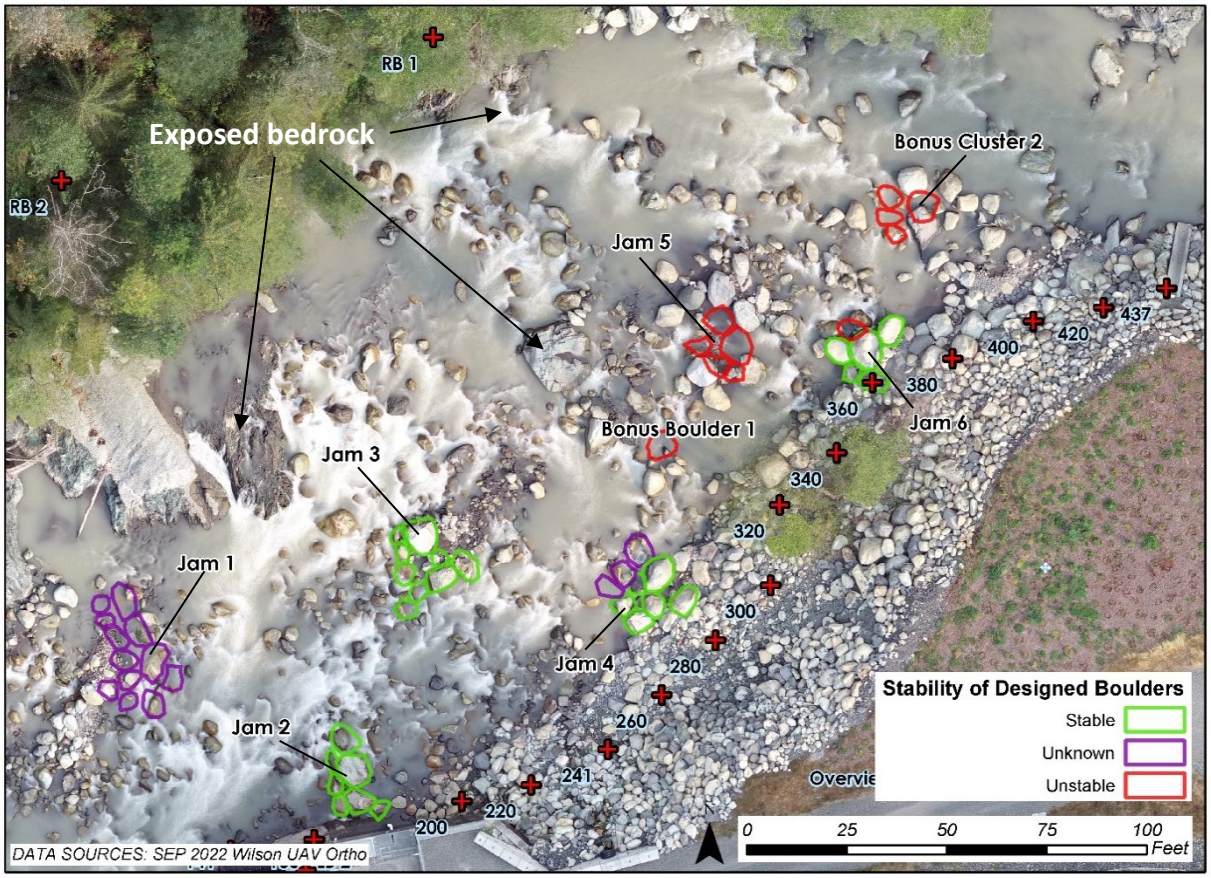

Figure 3.3 September 2022 (205 cfs) orthomosaic documenting relative instability in the restored channel, with engineered boulder cluster jams labeled. Areas of exposed bedrock on the channel bed are also labeled. (Photo: Wilson Engineering)

3.2 High Flow Fish Passage Conditions Observations

High flow observations were conducted during the December 2021 site visit (475 cfs). In an effort not to duplicate work, an additional high flow site visit was not conducted in the spring given the relatively stable hydrograph and absence of large channel-forming flows (10-yr or greater) between December and the spring of 2022. Reorganization of the entire bed into more stable step-pool arches has created numerous pathways for fish. At this discharge, the hydraulic steps between boulder lines are generally backwatered, reducing the height of the steps relative to low flow conditions. Reorganization across the channel, including the mid-channel bar, has also widened the active channel at high flows. The lack of confinement in both the right bank pathways and regraded main channel allows moderately higher flows to expand in width. This, in addition to the overall increase in the number of moderate size step-pool units and pockets diffuses the hydraulic energy and prevents the development of velocity barriers. Margins of both the right and left-bank flow paths, especially across the now-submerged mid-channel boulder-cobble bar, present areas with adequate depth for adult salmon passage (typically > 1ft) and lower velocities than along the thalweg of each flow path.

Figure 3.4 UAV oblique photos showing channel evolution at the flow split between the restored left bank channel and right bank pathways in October 2020 (top), June 2021 (middle), and December 2021 (bottom).

4 SEPTEMBER 2022 LOW FLOW OBSERVATIONS

Low flow observations took place in early September 2022 prior to onset of autumn rains. Following the site visit, there were no major concerns regarding fish passage through the observational pathways. The channel bed structure has remained largely stable and unchanged since the December 2021 observations. The most obvious addition to the channel was fine sedimentation and high turbidity, where recent sediment pulses, likely originating from bank erosion or landslides in the upper watershed, had deposited sand in most of the visible pools in the reach. While this sand may trigger areas of aggradation in the topographic comparisons between December 2021 and September 2022 in Figure 3.1, this aggradation is episodic and expected to wash out of the system in the fall and winter flows. The widespread regrade and channel lowering through the Fish bypass outlet pool was more apparent during low flows (Figure 4.1), where the slide outlet sat perched nearly a foot above the water surface during the visit (152 cfs). It should be noted that the intake facility does not operate a flows below 305 cfs, when the stage is higher. Lowering of the pool has resulted in emergence of a step that had previously been backwatered, as noted in Figure 4.1, but this step is similar to those present along the reach upstream and is not interpreted to adversely affect fish passability.

As mentioned in the high flow observational discussion, the reorganization of small to medium-sized boulders across the channel has resulted in the diversification and unification of flow pathways in the previously separated main channel and right flow paths, and remain connected at low flows of at least 300 cfs. Previously held concerns about the dewatering of the main channel in response to channel regrade in the right flow pathways have been reduced after visual observation and topographic confirmation that the main channel and right flow paths have regraded simultaneously. Therefore, the engineered boulder clusters have worked as designed by adjusting with the lowering channel, maintaining passable slopes in the main channel, and creating stable roughness from which small step arches can build and form new jamming features and pools. The abundance of available pools provides ample resting areas for migrating fish. Flows along the upstream left bank flow split, which continues to feed water into the main channel, will be monitored at future low-flow observation visits to assess its risk for dewatering as this reach further adjusts. Another potential concern from the December 2021 site visit was the unknown bedrock exposure extents along the right bank channel. The degree of exposure is still largely unknown due to fine deposition along the right bank, high turbidity, and lack of safe access to this bank.

Figure 4.1 Oblique aerial view of pool outlet comparison near Transect 400c between October 2020 (left, 225 cfs) and September 2022 (right, 152 cfs).

View looking upstream ***View looking downstream***

Figure 4.2 Repeat UAV imagery showing low-flow channel comparisons between October 2020 (top) and September 2022 (bottom)

5 PERFORMANCE METRICS

Complete photo documentation and topographic cross section and profiles are plotted in Appendix A. This section summarizes qualitative and quantitative performance metrics defined in the MAMP.

5.1 Longitudinal Profile Metric 1: Average Slope Through Regraded Reach

The average slope between station 60, at about the bottom of the regraded reach, and station 400 at the top of the regraded reach is 6.7% in the composite as-built surface, 6.6% in the October 2020 TLS derived DEM, 6.3% in the October 2021 UAV TLS DEM, and 6.2% in the September 2022 UAV TLS DEM. The reduction in the average slope through the reach following the November 2021 flood has occurred due to accumulation of sediment in the bed downstream of the regrade reach and headcutting at the upstream side of the regrade reach (Figure 3.1). All these values are below the 7% maximum slope threshold defined in the 1a MAMP decision pathway and trending toward a lesser average slope (Table 1.1). Therefore, as indicated by this attribute, the regrade is functioning as intended.

5.2 Longitudinal Profile Metric 2: Average Slope Over Any Individual 200 Ft Segment

Slopes for 200 ft segments were extracted along each profile path outlined in Figure 2.1 and are plotted in Figure 5.1. Along the main channel, the September 2022 slopes are consistently below 8%, except for one small reach at the 175-ft stationing that is between 8 and 8.5%. The right bank flow paths (RB 1 and RB 2) have a lower average slope compared to previous monitoring periods, and no longer exceed 9%. The upstream left bank split is less than 200 ft long, but the average slope along that split is 5%. There are no major changes to the channel slope from October 2020 to September 2022 apart from the regrade in the right bank flow paths trending in the direction of shallower overall slopes.

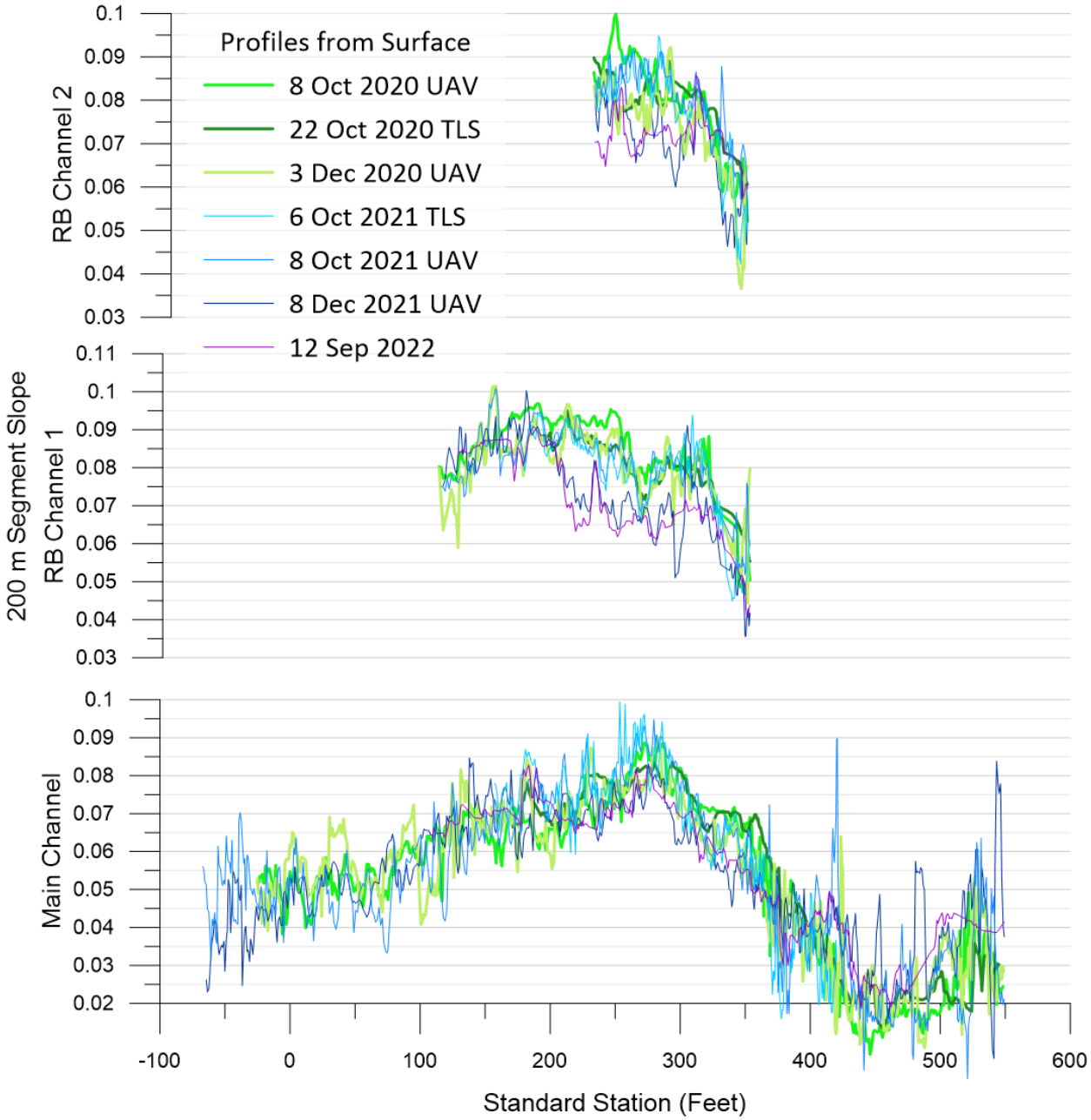

Figure 5.1 Plots showing 200 ft segment average slopes for each monitoring DEM.

Along the main channel, the December 2021 slopes are more consistently below 8%, including the reach between the 200 and 300-ft stationing. The main channel is less steep between the 280-ft stationing and the 420-ft stationing in December 2021 than previously. This reach of the restored channel coincides with boulder displacement observed in Figure 3.3, and therefore reflects channel regrade following bed mobilization and reorganization during the autumn 2021 floods. Just upstream of this reach in the fish bypass return pool the stream is steeper than as built conditions but still within 2 and 5%. The first and second right bank flow paths (RB 1 and RB 2) are both less steep in December 2021 than previously, with

much of the channel upstream of the 200-ft stationing below 8%. Development and regrading of the right bank flow pathways to a lower slope opens a valuable secondary fish passage route through the regraded reach of channel.

All segments are below the action threshold of a 12% slope (Table 1.1) and below the 2b decision pathway threshold of a 10% slope; but several are above the 7% 2b decision pathway indicating continuing monitoring is needed.

5.3 Longitudinal Profile Metric 3: Step-pool adjustments upstream of the fish bypass return pool

Overall, the moderate degradation of the regrade reach is reducing the average slope and presumably increasing fish passability, however the regrade is increasing the slope of the channel upstream as a result. In particular, the regrade has exposed a boulder step at Transect 480 (step 1), immediately upstream of the fish bypass slide. A new step formed at Station 580 during the November 2021 flood events (step 2), likely due to a combination of channel bed reorganization and dropping of the low flow water surface elevation. Two prominent steps upstream have remained mostly unchanged in morphology at Station 729 (step 3) and Station 760 (step 4) (Figure 4.1, Figure 5.2, Figure 5.3). To provide a quantitative assessment in addition to the qualitative observations from photos, head drop and average slopes over 20-ft segments were calculated for the reach using both the September 2022 and October 2020 TLS topographic surfaces. At both steps, local slopes approach 15% in the 2022 surface as compared to the 2020 topographic surface, where slopes remain below 10%. These steep steps are separated by long pools. The average slope of this reach between Station 440 and Station 600 is 7%. The head drops, rounded to the nearest 0.5 feet, were approximately 2.5 feet, 3 feet, 4 feet, and 3 feet across steps 1 through 4, respectively. These drops do not exceed the 5-ft threshold as outlined in the MAMP.

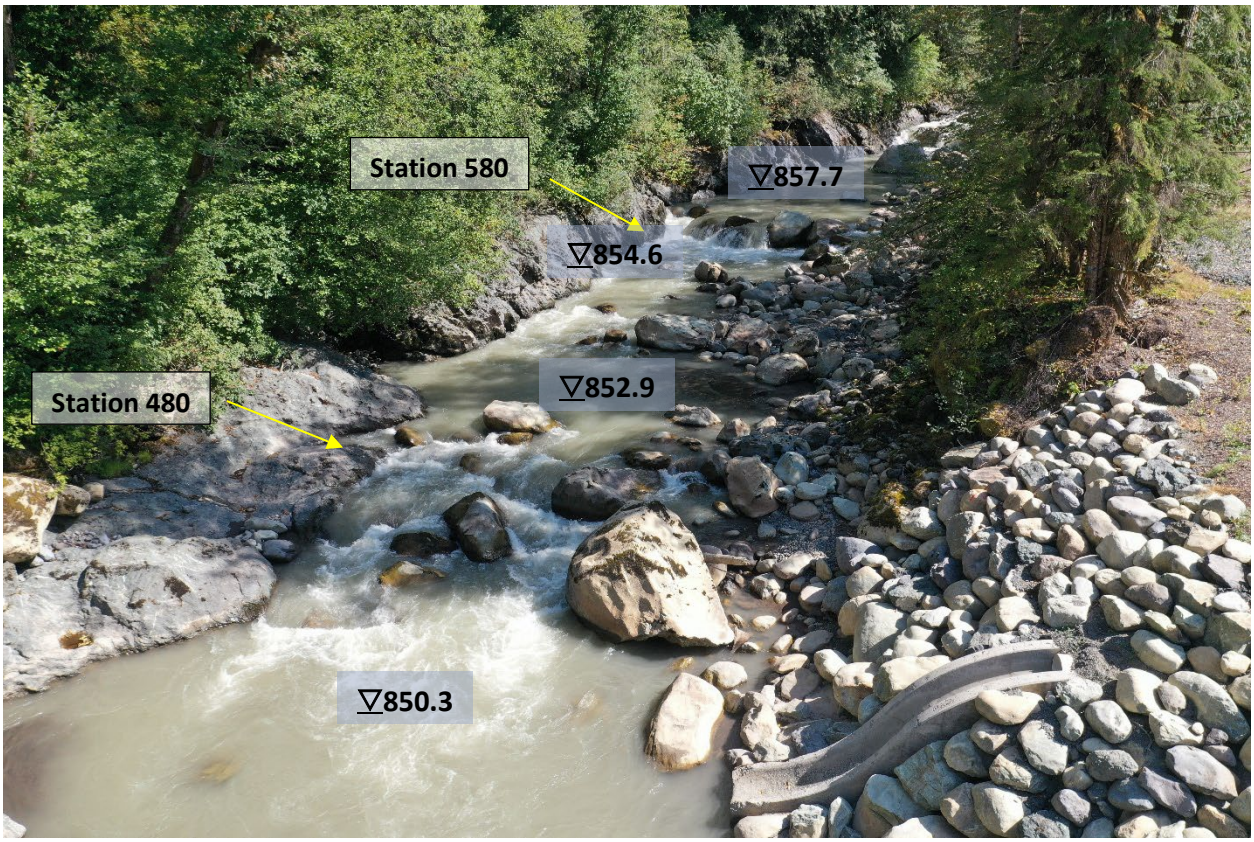

Figure 5.2 View of channel conditions between the fish outlet (Station 437) and Station 580 with water surface elevations extracted from the TLS scan on Sep. 12, 2022 at prominent channel steps (205 cfs).

Figure 5.3 View of channel conditions between Station 663 (downstream photo extent) to the water intake structure upstream with water surface elevations extracted from the TLS scan on Sep. 12, 2022 at prominent channel steps (205 cfs).

5.4 Cross Section Water Surface Elevation Decrease for September 2022

The performance threshold for water surface elevation decrease at any channel cross section is 3 ft, which triggers evaluation of monitoring or adaptive management actions, with a decision pathway of more than a 1 ft decrease in the water surface elevation triggering further monitoring or investigation. Early on in the monitoring work, significant topographic changes were observed in the secondary right bank flow pathway (RB 1) in comparisons between the as-built DEM and subsequent monitoring (Figure 3.1). While this rapid and ongoing regrade of the secondary right bank flow pathway (RB 1) was expected, the water surface changes exceeded the above outlined thresholds. Therefore, separate values for the water surface were tabulated for the constructed main left bank flow pathway (main channel), which is the primary focus of this monitoring effort and subject of the MAMP and secondary right bank flow pathway.

Because the quantitative target for this metric is change in water surface—which varies with discharge in the river—NHC developed a hydraulic model representing the as-built topographic surface and

calibrated this model to images of the channel before the first flood event caused geomorphic change. The model development and calibration procedure are described in Appendix B of NHC (2021).

Lateral variability in the water surface, even along individual flow paths, required interpretation to define a specific water surface elevation. This was done by reviewing cross sections extracted from the digital surface model while also reviewing aerial photos to select representative water surface elevations, with preference given to areas of the cross section close to the main channel and RB Channel 1 flowlines plotted in Figure 2.1.

Prior to the November 2021 floods, most vertical changes occurred in RB1, with changes along the dominant main channel flow pathway ranging from +0.55 to -2.0 feet, with nine of twenty-two cross sections exceeding a 1-ft decrease in water surface elevation. Water surface elevations along the regrading secondary right bank flow pathway had decreased by up to 6.8 ft by October 2021 (time of last TLS scan), as was anticipated in the design. These results are broadly consistent with the water surface changes observed in the October 2020 TLS scan compared to the as-built model, which is to say that channel adjustments between October 2020 and 2021 were modest. In October 2021, headcutting in this developing channel had not yet propagated to the outlet of the fish bypass return pool at about station 400, and so the main channel flow pathway was functioning as intended. Erosion along the right bank flow pathways (RB 1 and RB 2), therefore, did not represent a functional impairment to fish passage or the function of the main channel flow pathway as designed.

Updated water surface changes were computed for the September 2022 TLS surface, providing an initial look at changes that have occurred during and after the floods. The results show widespread channel lowering in both the main channel and secondary right bank flow paths, confirming the visual observation of deposition along the right bank further downstream (in some areas at or above 5 feet of aggradation), as well as localized sand deposition in pools. The results confirm the visual assumption that channel regrade has occurred through the Fish bypass outlet pool by 2 to 3 feet. In the main channel, downcutting greater than 3 ft is most prevalent just downstream of the Fish bypass outlet pool (Transect 320 to 400), and is overall more widespread along the right bank.

While incision along the main channel may incite concern about the pathway's viability, it is important to note several factors. Since October 2021, channel regrade has occurred along both the main channel and right pathways (RB 1 and RB 2) contemporaneously. Due to this simultaneous lowering, the main channel has remained lower in elevation than the right flow paths and therefore is not currently at risk of dewatering. This was confirmed at the low flow site visit, as documented in Section 4. The engineered boulder clusters along the main channel have also remained mostly stable, especially downstream (Figure 4.1). It is assumed that the clusters have readjusted and resettled on the channel bed during the channel lowering, resulting in the preservation of the overall channel grade throughout the reach. This is depicted in Figure 5.1, where despite channel lowering the main channel slopes have stayed relatively consistent.

Table 5.1 Observed water surface elevations in September 2022 (at time of the TLS observation). Modeled water surface for the as-built condition hydraulic model for the corresponding discharge, and interpreted change in water surface elevation. Cells with blue text exceed the 1 ft trigger for further monitoring or investigation and cells with blue text highlighted in orange exceed the 3 ft water surface difference that triggers evaluation of monitoring or adaptive management if occurring on the main channel (MC) flow path.

Cross Section	Water Surface from As-built Model with 205 cfs		Observed Water Surface 12 Sep. 2022 (from TLS Surface)		Water Surface Change from As-built Condition	
	MC flow path	RB flow paths	MC flow path	RB flow paths	MC flow path	RB flow paths
0	827.6	827.5	825.9	825.3	-1.7	-2.2
17	827.7	827.7	826.4	827.1	-1.3	-0.6
40	827.8	827.8	826.8	827.6	-1	-0.2
62	828.2	828	827.5	828.3	-0.7	0.3
82	829.3	829.5	828.5	831.9	-0.8	2.4
100	829.8	829.7	829.5	832.9	-0.3	3.2
125	832.3	829.8	830.6	834.3	-1.7	4.5
141	832.9	833.1	831.6	834.2	-1.3	1.1
160	833.9	834.8	832.8	835.4	-1.1	0.6
200	837.2	835.9	836	835.2	-1.2	-0.7
220	838	845.5	837.6	837.4	-0.4	-8.1
241	839.2	845.7	838.8	839.5	-0.4	-6.2
260	840.3	845.8	839.2	841.9	-1.1	-3.9
280	843.1	845.9	841.2	843.4	-1.9	-2.5
300	844.7	846.3	842.3	843.5	-2.4	-2.8
320	846	848.3	843	845.9	-3	-2.4
340	846.9	849.3	843.9	846.2	-3	-3.1
360	848.9	850.4	845.9	847.1	-3	-3.3
380	851.9	851.9	849.2	848.9	-2.7	-3
400	852.5	852.5	849.3	849.1	-3.2	-3.4
420	852.6	NA	849.8	849.8	-2.8	NA
437	852.7	NA	850.4	NA	-2.3	NA

5.5 Qualitative Evaluation of Fish Passage Conditions

As referenced in earlier reporting (NHC, 2021), typical fish passage design criteria are not readily applicable to natural or restored reaches – similar to the project site – where natural volitional passage is provided by complex in situ channel hydraulics that are controlled by natural geomorphic processes. The wide planform, multiple passage opportunities and potentially variable fish movement behaviours make it difficult to quantitatively characterize passage conditions.

Site photos and videos were examined in detail to visually determine potential fish movement pathways through the regrade reach, via primarily swimming behavior. Possible longitudinal pathways were traced, respecting the swimming capability of the fish species that use the reach.

Although the regraded reach experienced meaningful geomorphic changes since before November 2021, in some cases approaching thresholds in the MAMP triggering consideration of adaptive management actions, there were no hydraulics within the channel that appeared to preclude volitional passage at the flows observed, including upstream. Connectivity for adult passage appeared to be highly likely, and different potential swimmable pathways appeared possible for transit of the regraded reach at different flow levels (Figure 5.4). Lowering of the low flow water surface at the upstream end of the regraded reach led to development of larger head drops at existing steps upstream at around stations 480 and 580, but the increased head drops and velocities at the steps were lower than in the unaffected reach between there and the intake, and multiple routes appear passable via a combination of swimming and small leaps (Figure 5.5).

Degradation continued along the right side of the channel, with greater passability than before along the upstream section. However, the downstream section of RB 1 appears to continue to be highly turbulent and aerated and is less likely to be negotiated by upstream migrants than the left side. As noted as a potential outcome in the previous report, the right bank flow path has degraded further and has exposed more of the underlying bedrock. However, it appears from the channel profiles in the appendix that the regrading rate is slowing down, where the right side may be approaching a more stable grade in the future. As such, this route could be potentially passable at higher flows when flow conditions in the left side of the channel become more turbulent and faster.

While our qualitative interpretation does not identify any major concerns for fish passage through the site, we still recommend confirming fish movement through the site on the basis of biological monitoring. It is understood that the implementation of biological monitoring for this reach of the river is beyond the scope of the MAMP, and responsibility for such activity rests with the WRIA 1 Fishery Co-Managers. NHC and the City are aware of planning efforts for these agencies to implement biological monitoring for this difficult-to-access reach of river in the future.

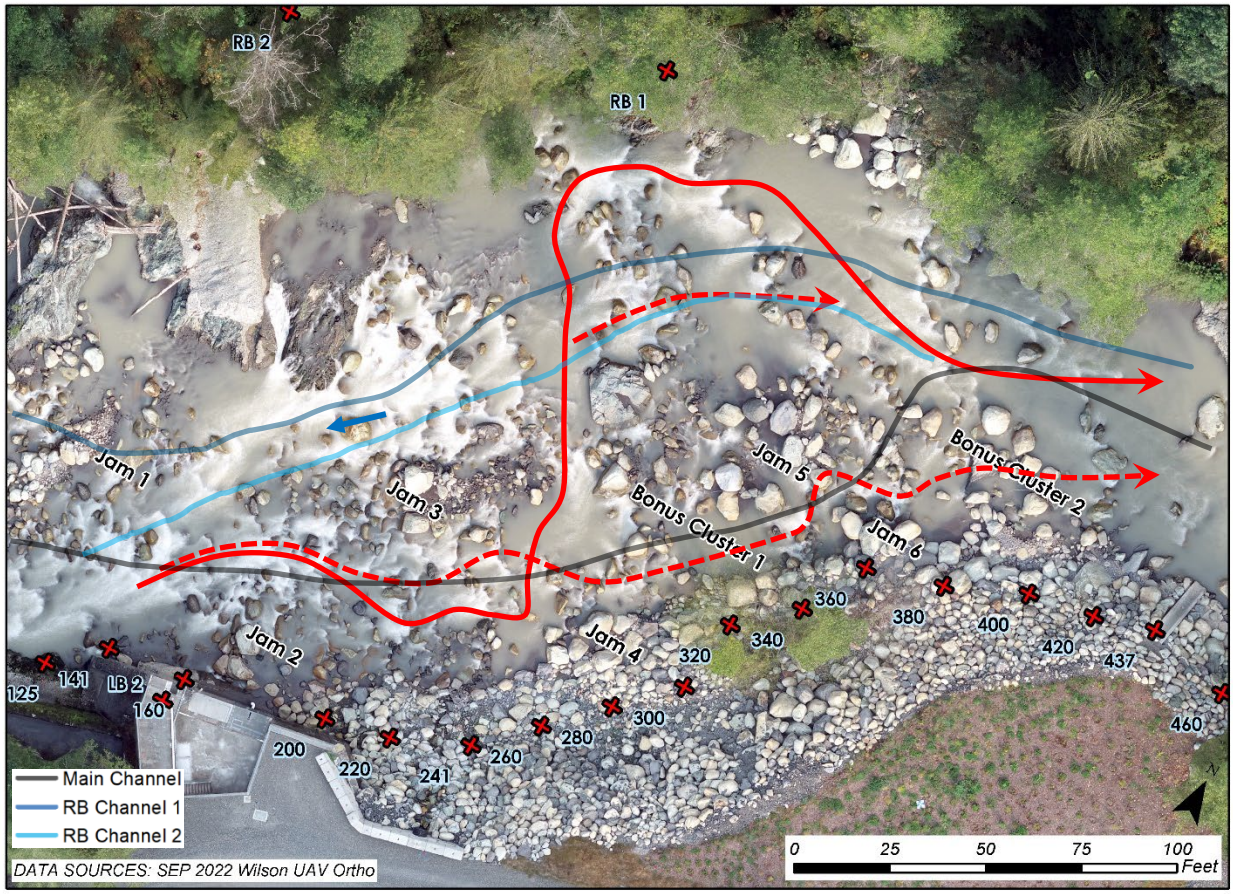

Figure 5.4 Potential upstream passage routes overlaid on September 2022 orthomosaic and relevant monitoring pathways (main channel, RB 1 and RB 2). Solid line = expected primary pathway during lower to mid-flow range; dashed lines = additional routes during mid- and higher flow range. (Photo: Wilson Engineering)

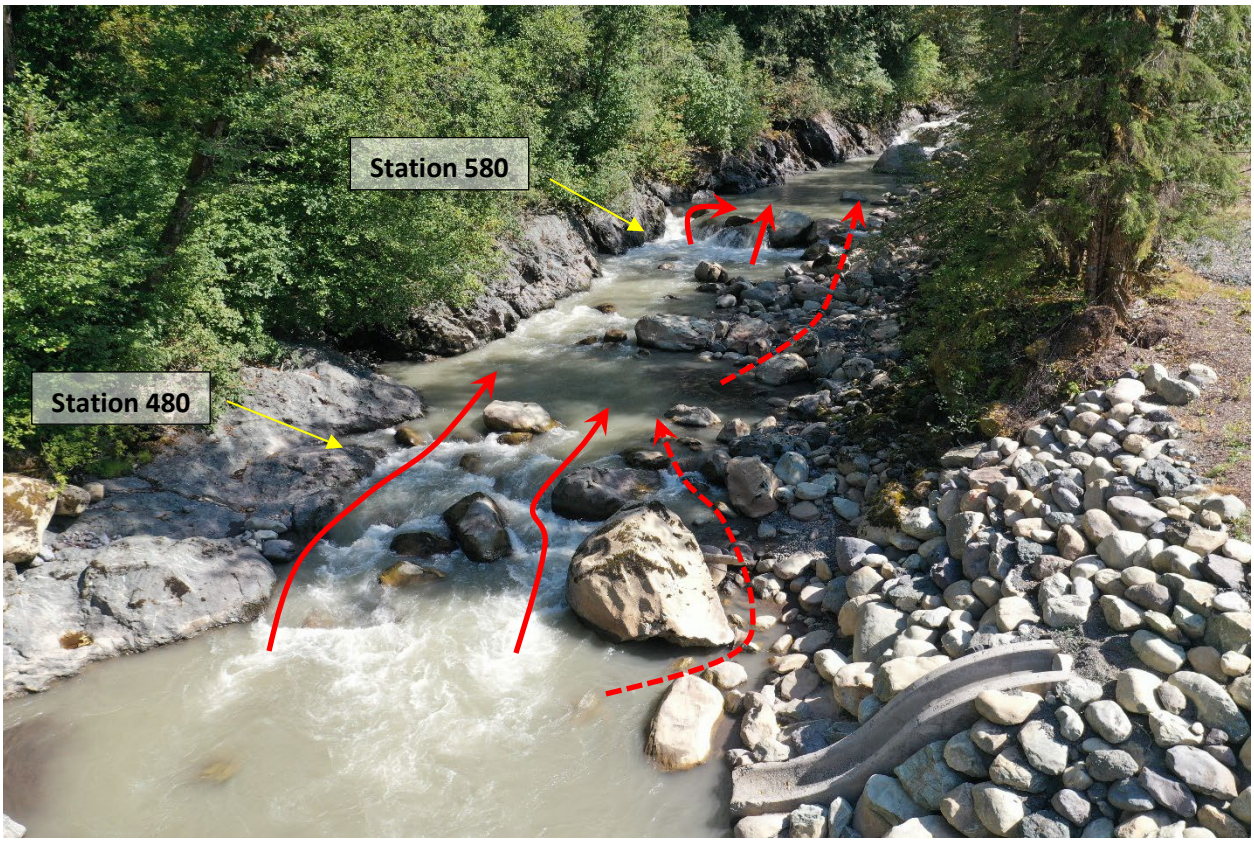

Figure 5.5 Likely passage routes at the observed flow at steps upstream of the fish outlet slide (September 2022). Solid lines = expected primary pathway during lower to mid-flow range; dashed lines = additional routes during mid- and higher flow range.

6 SUMMARY & RECOMMENDATIONS

This report documents the results of geomorphic and topographic surveys after several high flow events occurred, two of those between a 10 and 50-yr recurrence interval, revealing that moderate geomorphic adjustments have occurred. While the threshold for channel lowering was exceeded in both observational pathways, channel adjustments do not currently pose risk for fish passage (Table 6.1). Not only has the simultaneous lowering decreased the risk for dewatering of the main channel, but the readjusted bed maintains a slope of less than 8%. Additionally, boulder reorganization has created more potential pathways for fish and more resting pools.

Table 6.1 Current performance of project relative to channel monitoring metrics.

Monitoring Technique	Monitoring Metric	Thresholds	Decision Pathway	Status as of September 2022
Photo/Visual Survey	N/A Provides indication of channel changes to inform field work.	N/A	N/A	No evidence of impassable hydraulic conditions. Hydraulics in the fish bypass return pool have changed (roughness has increased and depth has decreased).
Digital Elevation Model Development and Analysis	N/A Provides indication of channel changes to inform field work.	N/A	N/A	Regrade during the November 2021 floods occurred channel wide, increasing the number and connectivity of old pathways. The main channel pathway is currently not at risk of dewatering.
Channel Longitudinal Profile derived from Digital Elevation Model	Average water surface elevation slope along low flow centerline.	1. >8% average slope over the entire monitoring site length. 2. >12% slope occurring over a 200 ft length within the monitoring site.	1a. <7% Average (Pass) 1b. >7% (Monitor) 2a. >7% in any 200 ft segment (Monitor) 2b. >10% in any 200 ft segment (Evaluate Adaptive Management Action).	1a: Pass 2a: Localized 200 ft segments between 7 and 8% slope along main left bank flow path and between 7 and 10% slope along right bank flow paths.
Channel Cross Sections derived from Digital Elevation Model	Channel water surface elevation at minimum instream flow	> 3 ft water surface elevation decreases at any channel cross section > 5 ft drop downstream boulder	1. <1 ft decrease (Pass) 2. >1 ft decrease (Monitor/Investigate) 3. >3 ft decrease (Evaluate Adaptive Management Action).	3: Multiple sections along the main flow path exceed 3 ft lowering of the water surface (average of 1.6 ft lowering). Because lowering occurred in main and right flow paths simultaneously, the main channel is currently not at risk of dewatering.

As stated in the one-year monitoring report (NHC 2022), if this or any subsequent field survey effort identified potential concerns of passage, then NHC would recommend the city consider collecting full ground based topographic and bathymetric survey of the bed of the wetted channel to combine with the TLS-grade surface representing the subaerially exposed part of the channel and water surface and using this data to assemble an updated hydraulic model to evaluate fish passage flows. Given the lack of observed risk, this action is not recommended at this time. Pool depths will be surveyed during the low flow site visit in autumn of 2023 to address concerns about fish passage upstream of the bypass return pools across the step pool features. Future monitoring at high and low flows will be necessary to

confirm whether fish passage is maintained for the duration of the 10-yr monitoring period, with the option to pursue more detailed data collection and updated modelling if adverse conditions arise.

7 REFERENCES

Barnard, R. J., Johnson, J. J., Brooks, P., Bates, K. M., Heiner, B., Klavas, J. P., Ponder, D. C., Smith, P. D., and Powers, P. D. (2013). *Water Crossing Design Guidelines*. Washington State Department of Fish and Wildlife, Olympia, WA. [online] Available from: http://wdfw.wa.gov/hab/ahg/culverts.htm.

Bell, M. C. (1991). *Fisheries Handbook of Engineering Requirements and Biological Criteria,* US ARmy Corps of Engineers, North Pacific Division, Portland, OR. 331 pp.

Church, M., and Zimmermann, A. (2007). Form and stability of step-pool channels: Research progress. *Water Resources Research*, 43(3), W03415. doi:10.1029/2006WR005037.

City of Bellingham, and American Rivers (2019). *Middle Fork Nooksack River Fish Passage Project Draft Effectiveness Monitoring & Adaptive Management Plan*.

HDR, R2, and NHC (2019). *Design Criteria Report, Middle Fork Nooksack Fish Passage*. Report prepared by HDR and R2 Resource Consultants for the City of Bellingham.

NHC (2021). *MF Nooksack Channel Monitoring & Adaptive Management As Built Monitoring*. Report prepared by Northwest Hydraulic Consultants for City of Bellingham Public Works. 33 pp.

NHC (2022). *MF Nooksack Channel Monitoring & Adaptive Management One Year Monitoring*. Report prepared by Northwest Hydraulic Consultants for City of Bellingham Public Works. 30 pp.

R2 Resource Consultants (2007). *North Coast Instream Flow Policy: Scientific basis and development of alternatives protecting anadromous salmonids, Task 3 Report.* Report prepared by R2 Resource Consultants for California State Water Resources Control Board, Division of Water Rights. Sacramento, CA.

Zimmermann, A., Church, M., and Hassan, M. A. (2010). Step-pool stability: Testing the jammed state hypothesis. *Journal of Geophysical Research: Earth Surface*, 115(F2), n/a-n/a. doi:10.1029/2009JF001365.

MF NOOKSACK CHANNEL MONITORING & ADAPTIVE MANAGEMENT APPENDIX A

COMPLETE PHOTO DOCUMENTATION AND CROSS SECTION OBSERVATIONS