MF Nooksack Channel Monitoring & Adaptive Management
Year 1 Monitoring

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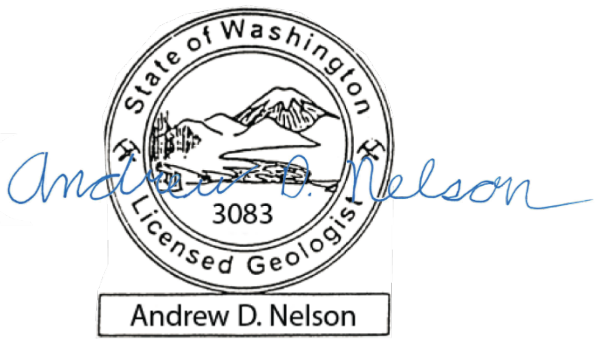

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- Andrew Nelson — Project Manager & Lead Geomorphologist
- Annie Dufficy — Project Geomorphologist
- Jaron Brown — Project Hydraulic Engineer
- Amiana McEwen — Project Hydraulic Engineer
- Barry Chilibeck — Senior Review & Fish Passage Assessment

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) (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 2021 and published in spring 2022, presents results of the Year 1 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 first-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 three separate occasions: spring high flow, one year post construction, and an added site visit to document post-November flood conditions. New topographic surfaces were compiled from the survey data to document changes from the as-built condition composite surface of fall 2020.

As presented in the post-construction monitoring report, construction of the restored regraded reach of the river channel was completed just before the first high flow pulse (a storm-triggered flow above the late-summer baseflow discharge and potentially capable of modifying the channel boundary). Following this first high flow event, autumn storms came in fast sequence. Therefore, rather than contemporaneously capturing as-built conditions as originally envisioned, survey efforts occurred between the high flow pulses, showing ongoing geomorphic adjustments of the channel in response to the high flow pulses. This resulted in slightly less comprehensive documentation of the as-built condition than was imagined, but better temporal resolution documenting the initial channel adjustments.

The focus of this report is to document channel adjustments observed and measured since the Post-Construction Monitoring Report (December 2020-December 2021). Figure 1.1 illustrates the timing of these various observations relative to flood pulses and their associated stream power that occurred through December 2021. Photographic and surveyed documentation of the reach at the spring high flow and one-year mark revealed that the channel bed remained mostly stable during the official one-year monitoring period compared to as-built conditions. This report includes monitoring data beyond the one-year post-construction period to document changes that occurred to the reach during a series of October and November atmospheric river events that brought historic rainfall and flooding to Northwest Washington. This period includes multiple flood peaks approaching or exceeding a 10-yr event and one substantial flood on November 15, 2021 approaching a 50-yr event. These magnitudes of flow were anticipated in the design process to result in localized transport of individual boulders and some settlement or shifting of the larger boulder jams (City of Bellingham and American Rivers, 2019).

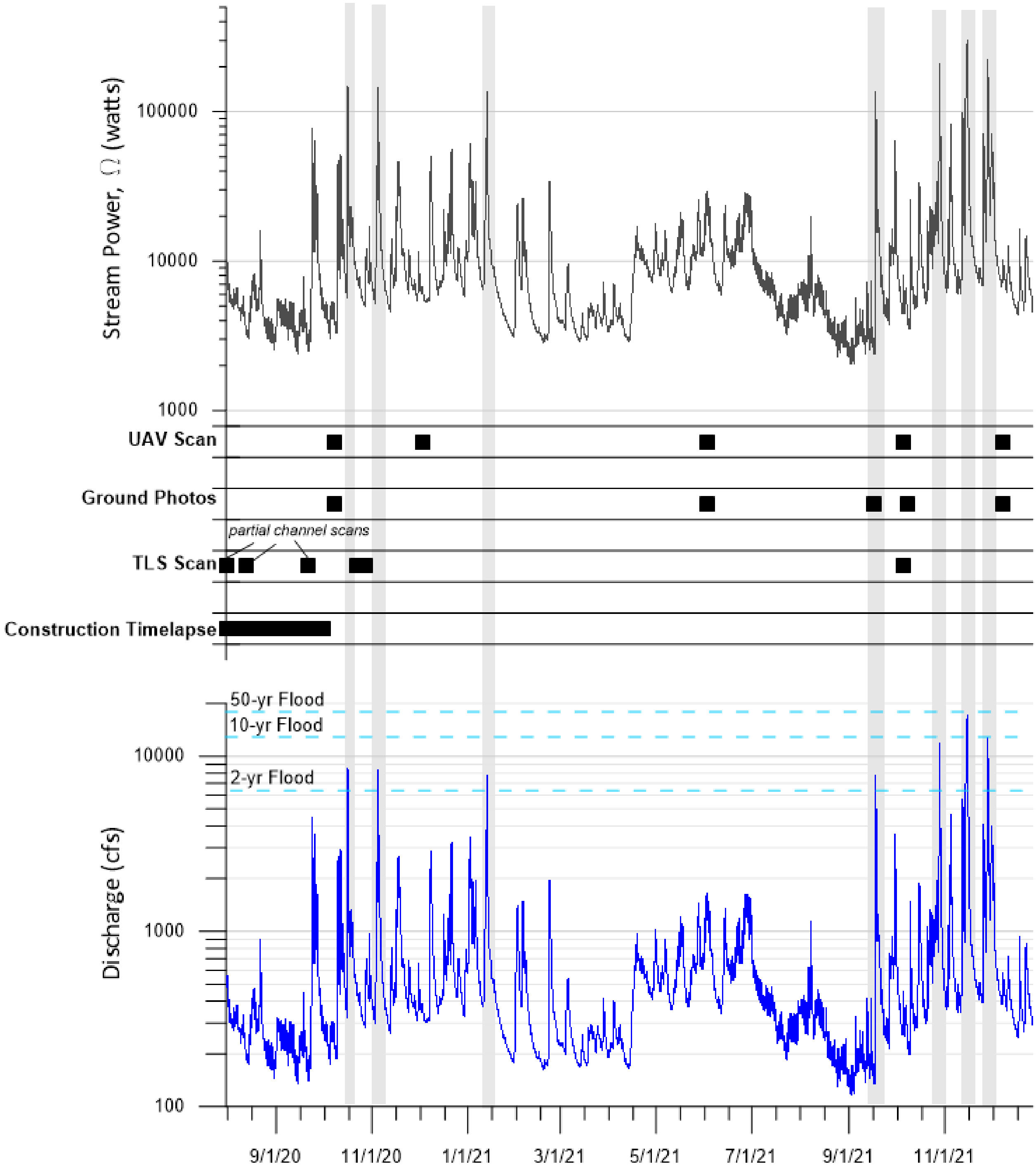

Figure 1.1 Timeline of stream flow, stream power, and observation efforts from August 31, 2019 to December 31, 2021

This one-year post-construction monitoring report is structured with an overall site-scale narrative describing the layout of the monitoring observations, key observations during the spring high-flow and one-year monitoring site visits, and changes observed in the autumn of 2021 following the one-year monitoring window. 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.

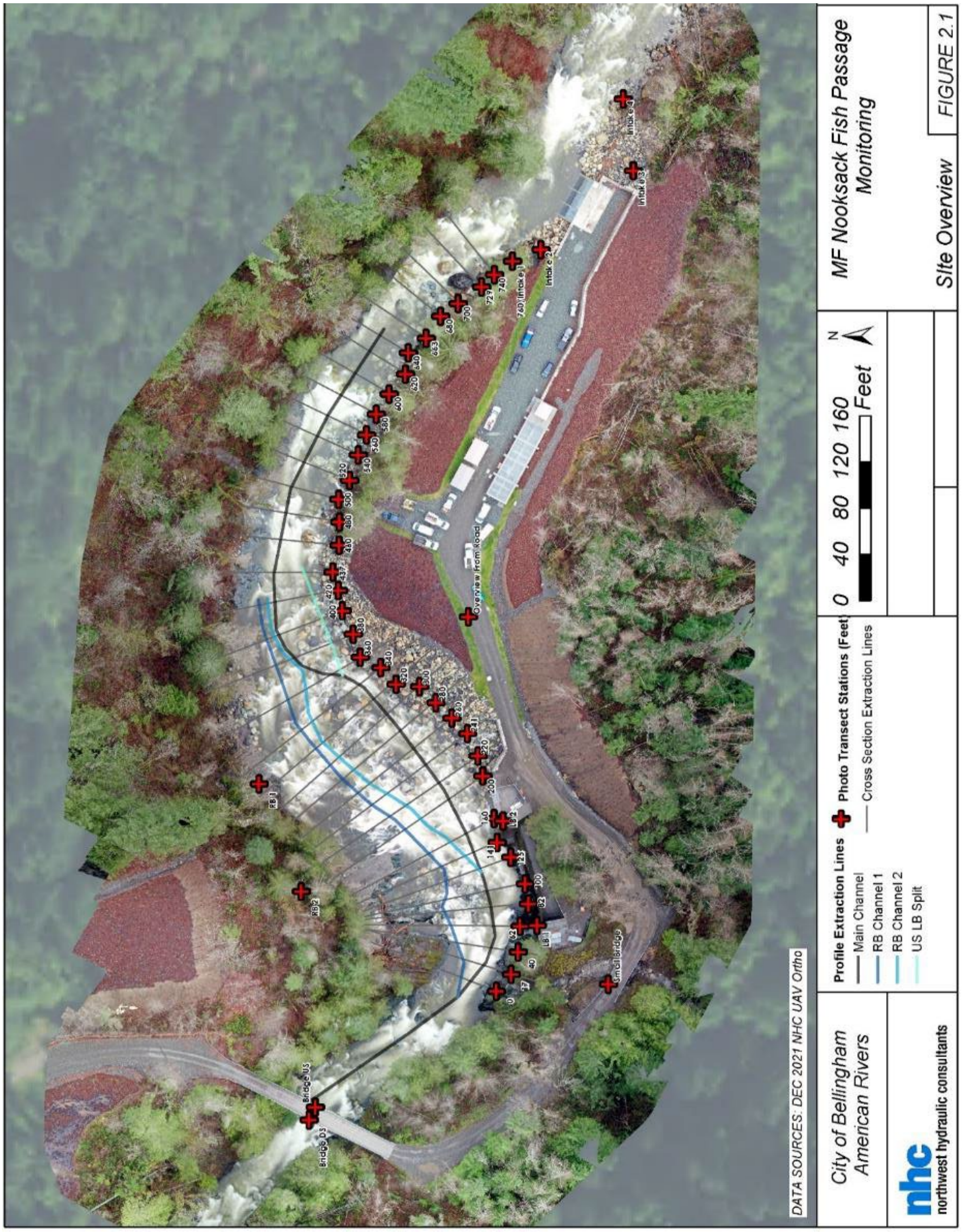

Figure 2.1 Map illustrating monitoring site layout

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

3 DECEMBER 2020 THROUGH OCTOBER 2021

3.1 Geomorphic Changes

The regraded reach was extremely stable between December 2020 and October 2021, when only subtle changes occurred to the bed along the dominant left and right bank channels (Figure 3.1 and Figure 3.2). This is particularly true of the left bank channel where boulder jams were installed to control the grade. The boulder jams have remained stable, though individual overexposed boulders up to 2 m in diameter shifted and moved short distances (e.g., 3 to 10 m). Small boulders have also shifted in similar extents in the right bank channel where fewer boulder jamming structures exist.

Lack of any major bed change between December 2020 and October 2021 is not surprising, considering that the post-construction channel had already been conditioned by substantially larger flow events during autumn of 2020 (Figure 1.1).

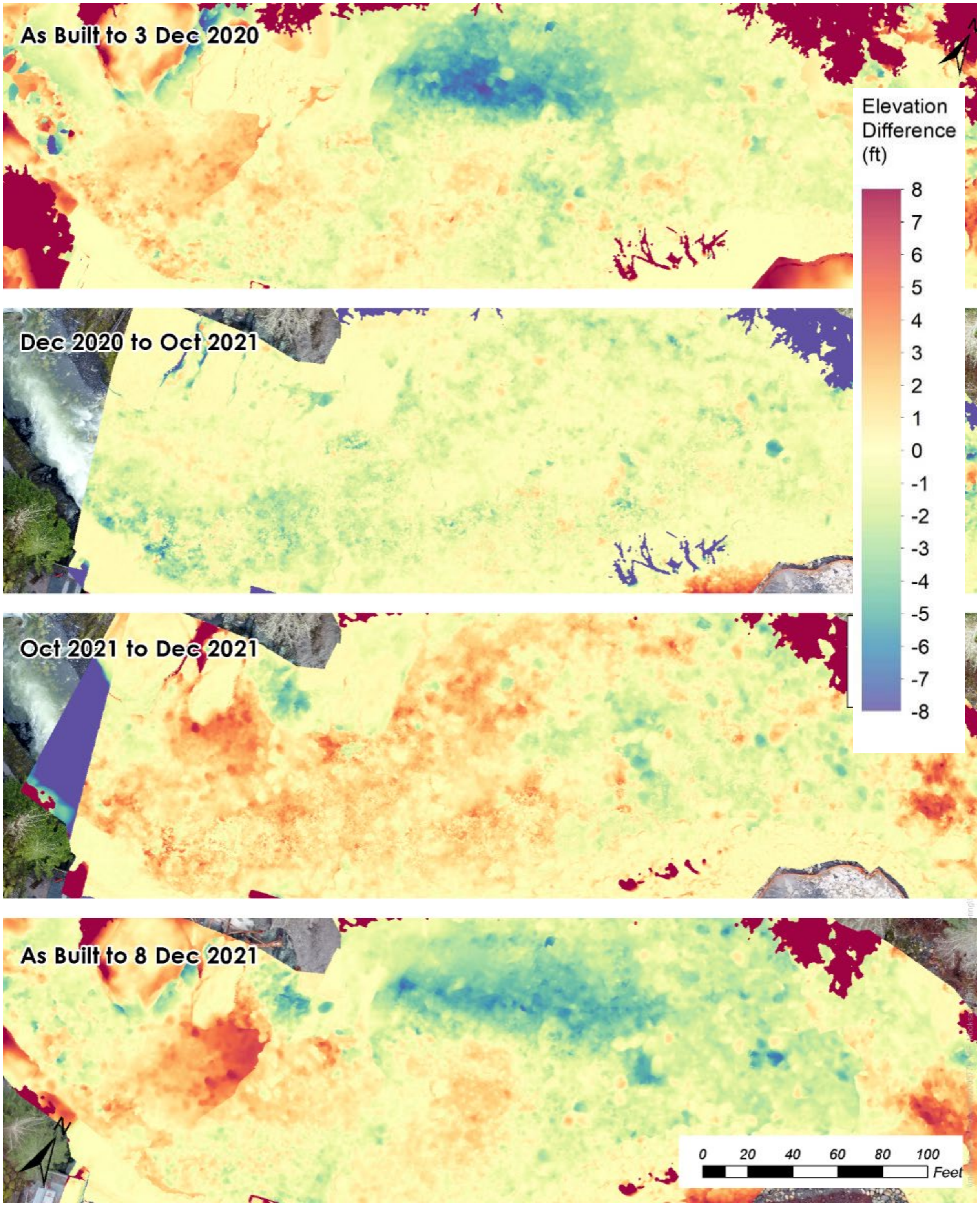

Figure 3.1 DEM surface comparisons showing differences between the design surface and as-built surface (top) and between the as-built surface and subsequent topographic surfaces. Red colors indicate aggradation and blue colors degradation.

Figure 3.2 Orthomosaic comparisons showing observed channel conditions during monitoring site visits between December 2020 to December 2021.

3.2 High Flow Fish Passage Conditions Observations

Observations of the channel during high flow conditions (1200 cfs) in June 2021 did not identify any concerns related to fish passage through the regraded reach. At this discharge, the hydraulic steps between boulder lines are generally backwatered, reducing the height of the steps relative to low flow conditions. The lack of channel confinement through the regraded section allows moderately higher flows to expand in width, diffusing the hydraulic energy and preventing the development of velocity barriers. Margins of both the right and left-bank flow paths, especially around the mid-channel boulder-cobble bar where boulder-scale roughness reduces velocity, include areas with adequate depth for adult salmon passage (typically > 1ft) and lower velocities than along the thalweg of each flow path.

Figure 3.3 compares flow conditions of the right and left bank flow split during the June 3 high flow monitoring visit, as compared to as-built low flow conditions (October 2020) as well as the most recently observed conditions in December 2021.

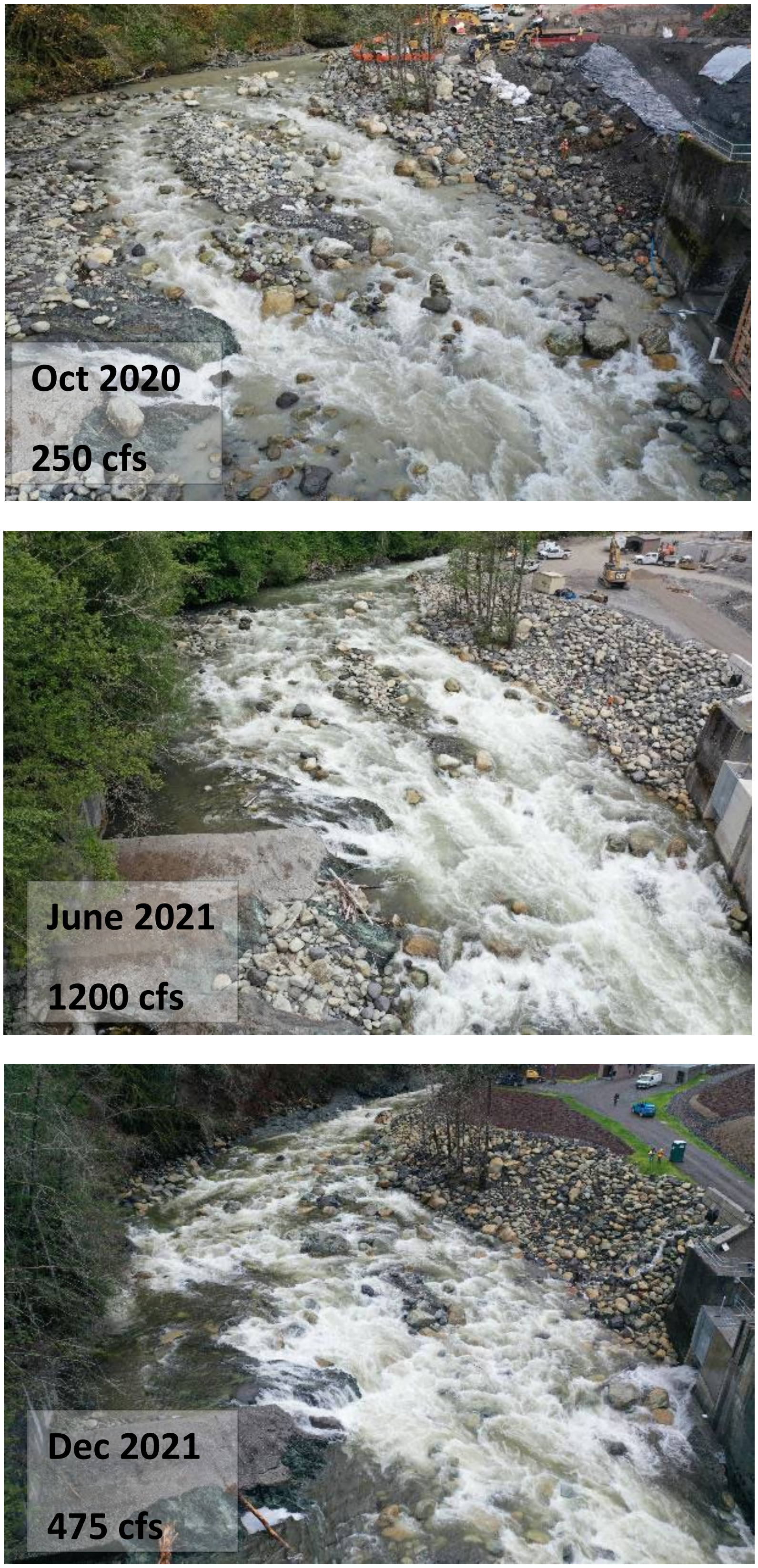

Figure 3.3 UAV oblique photos showing channel evolution at the flow split between the restored left bank channel and right bank pathways in October 2020 (top), June 2021 (middle), and December 2021 (bottom).

4 NOVEMBER 2021 FLOOD IMPACTS

Significant changes occurred to the channel bed during the November 2021 floods, which exceeded the threshold expected to mobilize boulders not part of the boulder jams. These changes are evident in Figure 3.1, Figure 3.2 and Figure 3.3. Boulder transport has 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 has continued along the right bank flow pathway, resulting in mobilization of boulders forming the hydraulic control for the Fish Bypass outlet pool and converting that feature from a pool to a rapid. This has also, likely, reduced the proportion of the flow following the designed left bank flow path during lower flow conditions. Relatively minor changes have occurred in the restored left bank pathway in comparison, suggesting that the boulder jams effectively held the designed channel in place during the flood.

Individual boulder movements are difficult to track in the right bank pathways due to over-topping flow obscuring the boulders and bed, but 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 path 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). It is currently unknown how widespread bedrock exposures are in this right bank channel due to high flows obscuring the channel bed at the time of the December 2021 observations. Future monitoring visits at wadable low flows that do not obscure the bed will be necessary to document how the bedrock controls evolve over time. 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.

Figure 4.1 shows some channel bed changes within the flow split between station 180 and the fishway at 437 feet. Overall, minor adjustments occurred in the restored left bank pathway due to boulder cluster stability, which prevented the same degree of bed mobility and large-scale reorganization as observed in the right bank channel. Boulder cluster instability appears to increase upstream with proximity to the pool outlet, between stations 320 and 437, but the bed has since reorganized into a more stable arched step-pool morphology. Select boulder movements can be seen in Figure 4.1, where displacements range from 12 to 25 feet.

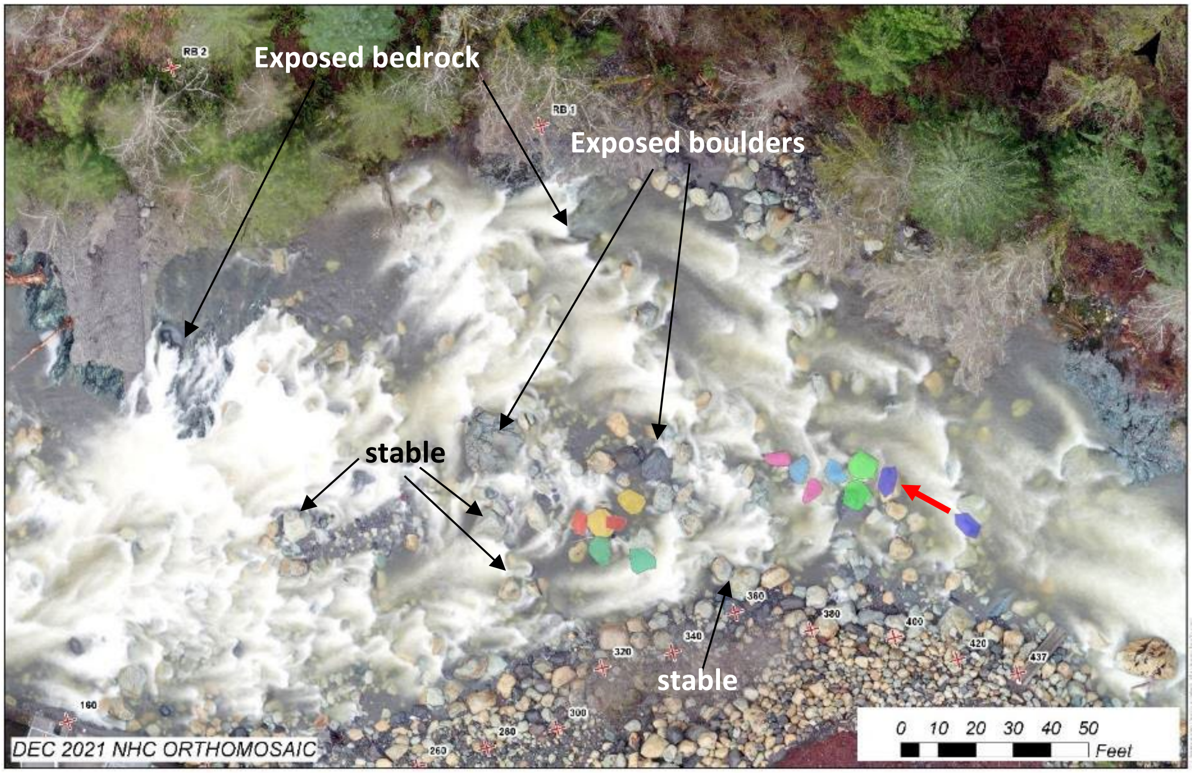

Figure 4.1 December 2021 orthomosaic documenting relative instability in the restored channel. Boulder transport during the November 2021 flood is symbolized by colored boulders, where each pair of colored boulders represent an individual boulder's location in October 2021 and December 2021. Boulders that did not move in the November 2021 flood are labeled as "stable" or "exposed" if bed lowering around the boulders exposed them to the surface. (Photo: NHC)

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 roughening of the Fish Bypass outlet pool upstream of the flow split. Lowering of the midchannel bar has created wider flow pathways in the right bank channel. Most of the midchannel bar was submerged during the December 2021 site visit, suggesting that these previously distinct channels are now connected during relatively low flows (475 cfs). As predicted, the channel has regraded through the Fish Bypass outlet pool as transport and reorganization of the pool outlet boulders has significantly roughened the channel upstream in the previously backwatered pool reach (Figure 4.2). Observation of this location during low flow conditions will be important to discern that depths in front of the Fish Bypass outlet remain adequate to prevent injury.

The flood-induced geomorphic regrade changes to the right bank channel appear to have partially dewatered the restored left bank main channel. This change in flow inputs at the top of the main channel is, however, partially compensated by the new flow inputs across the now-connected midchannel bar.

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). The December 2021 SfM surface covering this area is approximate, due to the presence of turbulent water over the bed in much of the area; comparison of water surface elevations against stable bedrock in the right bank pool between bedrock features upstream of the bar (Figure 3.2) shows the water surface has substantially increase in this area, qualitatively confirming the presence of aggradation on the bar. 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.

Figure 4.2 Pool outlet comparison at Transect 400c between September 2021 (left) and December 2021 (right)

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 5.8% in the December 2021 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 October 2021 slopes are consistently below 8%, except the reach between the 200 and 300-ft stationing that is between 8 and 10%. The right bank flow paths have lower average slope, but localized areas that are slightly steeper, with slopes between 9 and 10%. 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 October 2021 apart from the channel steepening shown in the main channel between the 200 and 300-ft stationing.

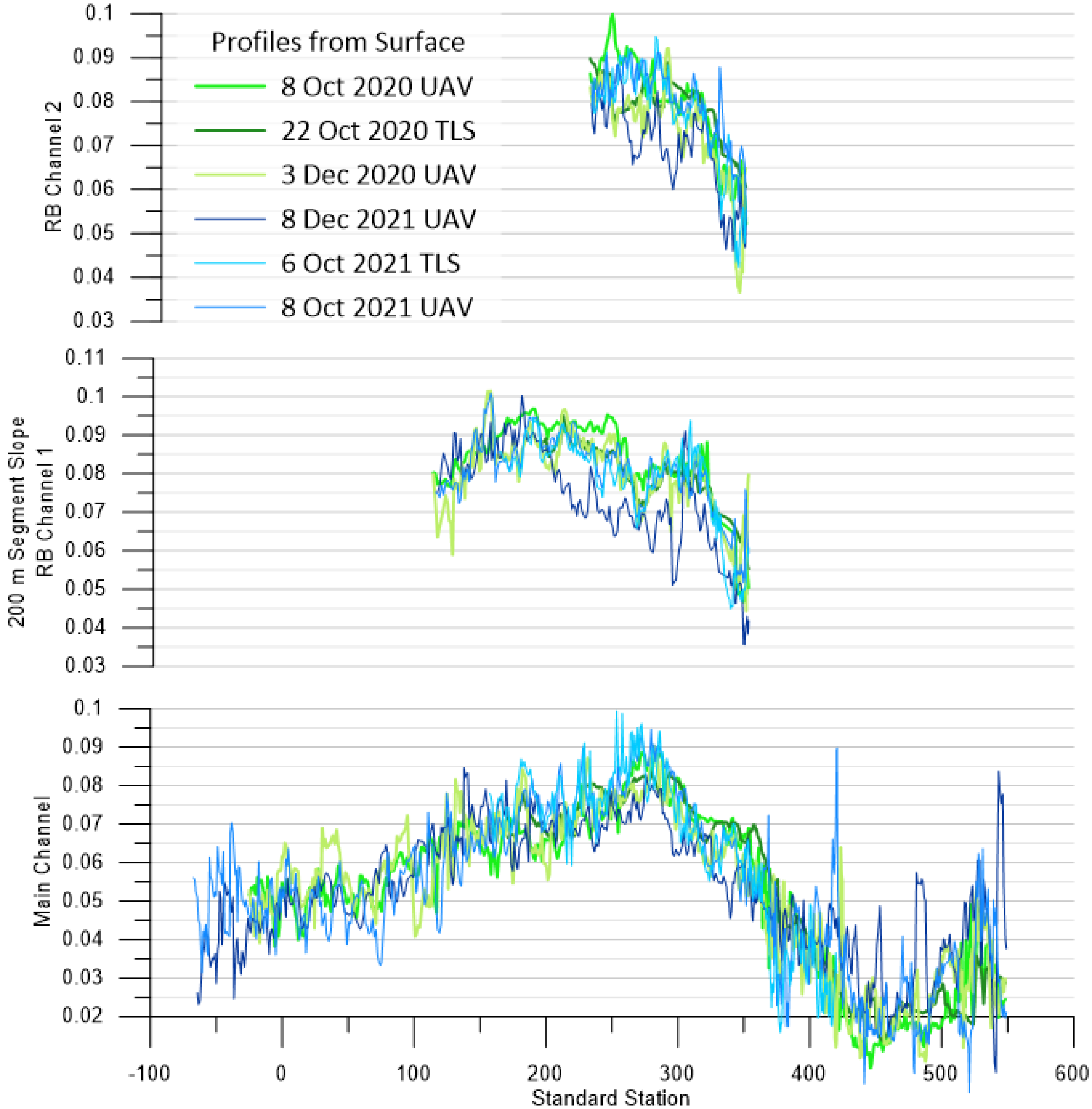

Figure 5.1 Plots showing 200 ft segment average slopes for each monitoring DEM.

Along the main channel, the December 2021 slopes are more consistently below 8%, including the reach between the 200 and 300-ft stationing. There is one steeper reach around station 130 ft that exceeds an 8 percent slope, as well as steeper slopes starting at the 420-ft stationing in the bypass return pool and extending upstream. 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 4.1, and therefore reflects channel regrade following bed mobilization and reorganization during the autumn 2021 floods. The first and second right bank flow paths (RB

Channel 1 and RB Channel 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 Cross Section Water Surface Elevation Decrease for October 2021

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. Given significant topographic changes observed in comparisons between the as-built DEM and subsequent monitoring (Figure 3.1), localized decreases in the water surface elevation exceeding these thresholds are clearly present along the secondary right bank flow pathway. Therefore, separate values for the water surface were tabulated for the constructed main left bank flow pathway, 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.

Results were computed for the October 2021 TLS surface and therefore to do not represent changes that have occurred to the channel during and after the November 2021 floods. The UAV surface created in December 2021 does not provide the same TLS-grade accuracy for extracting water surface elevations and was therefore not used in this analysis. Further surveying is required to analyze the post-flood channel modifications.

These results (Table 4.1) show 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, thus indicating further monitoring or investigation. Water surface elevations along the secondary right bank flow pathway have decreased by up to 6.8 ft as the new right bank channel continues to develop, 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 Channel 1 and RB Channel 2), therefore, did not represent a functional impairment to fish passage or the function of the Main Channel flow pathway as designed.

Photo and slope documentation of the right bank channel, main channel and Fish Bypass outlet pool in Section 3.1, Section 5.2, and Appendix A indicate that regrade has occurred through the Fish Bypass outlet pool between October 2021 and December 2021 (Figure 4.2). While the regrading of the right bank flow pathways to a lower slope opens a valuable secondary fish passage route, the relative changes in water surface elevations and the depths of water within this pool are currently unknown. If erosion has, or continues to, lower the bed elevation of the right bank flow pathways below the Main Channel flow pathway, then it could result in dewatering of the design flow pathway (main left bank channel) during low flows. Therefore, continuing sediment mobilization along all flow pathways requires monitoring to continue.

Table 5.1 Observed water surface elevations in October 2021 (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 275 cfs		Observed Water Surface 06 Oct. 2021 (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	NA	NA	NA	NA	NA
17	827.7	NA	NA	NA	NA	NA
40	827.8	NA	NA	NA	NA	NA
62	828.2	828	NA	828	NA	NA
82	829.6	829.3	830.15	829.15	0.55	-0.15
100	829.8	829.7	830.2	830.41	0.4	0.71
125	832.3	829.8	831.4	831.62	-1	1.82
141	832.9	833.1	831.6	833.5	-1.3	0.4
160	834	833.9	832.2	834.75	-1.8	0.85
200	837.2	837.3	835.9	835.3	-1.3	-2
220	838	838	837.5	835.9	-0.5	-2.1
241	839.2	845.7	838.9	839	-0.3	-6.8
260	840.2	845.8	839.2	840.6	-1	-5.2
280	843.2	845.9	841.4	841.6	-1.8	-4.3
300	844.7	846.8	843.68	843.86	-1.02	-2.94
320	846	848.3	844.4	845.5	-1.6	-2.8
340	846.9	849.25	846.5	847.1	-0.4	-2.15
360	848.9	850.4	848.5	849	-0.4	-1.4
380	851.9	851.9	851	851.2	-0.9	-0.7
400	852.5	852.5	851.1	851.2	-1.4	-1.3
420	852.7	NA	852	NA	-0.7	NA
437	852.8	NA	852.2	NA	-0.6	NA

5.4 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. The wide planform, multiple passage opportunities and potentially variable fish movement behaviours make it difficult to quantitatively determine passage conditions or be deterministic in assessment.

Site photos and videos were examined in detail to visually determine potential fish movement pathways through the regrade reach. This included areas of stream channel where fish would either transit or stay on station and utilize a variety of swimming behaviours. 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 during the November 2021 flood, in some cases approaching thresholds in the MAMP triggering consideration of adaptive management actions, there were no hydraulics within the channel that appeared adverse for volitional passage at the flows observed. Connectivity for adult passage appeared to be highly likely, and multiple potential pathways appeared possible for transit of the regraded reach. The bed structure through the left bank flow path remain very similar to the as built condition, while the right bank flow path continues to evolve diffusively, with channel widening and a reduction in the overall slope, which would be expected to both increase hydraulic complexity and fish passage over a broad range of flows. The one meaningful concern at this time is the potential for continued adjustment of the right bank flow path to result in the combination of both the following two conditions:

1) Exposure of a bedrock feature (e.g. shallow shelf or large step) along the right bank flow path which prevents fish passage.
2) Dewatering of the left bank flow path at lower flows resulting in formation of depth barriers to fish passage along that route.

At present, there is no positive indication that the first condition is occurring, and so we recommend continued implementation of the monitoring plan with full site survey during low flow conditions in late summer or early autumn 2022.

Although additional detailed survey of the bed and hydraulic analysis equivalent to that reported for the as built condition (NHC, 2021) would provide additional information, qualitative interpretation does not identify any major concerns for fish passage through the site. Therefore, we 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.

6 SUMMARY & RECOMMENDATIONS

Results of the one-year monitoring study reveal that minor changes occurred to the channel between December 2020 and October 2021. Channel longitudinal profiles and water surface changes were identified to exceed thresholds for continuing monitoring in some locations, but did not exceed thresholds that would trigger adaptive management activity (Table 6.1).

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

Monitoring Technique	Monitoring Metric	Thresholds	Decision Pathway	Status as of December 2021
Photo/Visual Survey	N/A Provides indication of channel changes to inform field work.	N/A	N/A	No evidence of impassable hydraulic conditions, but potential adverse geomorphic adjustment observed. Hydraulics in the fish bypass return pool have changed dramatically.
Digital Elevation Model Development and Analysis	N/A Provides indication of channel changes to inform field work.	N/A	N/A	Erosion along the right bank flow pathway and pool outlet in November 2021 has an unknown impact on channel hydraulics along the major fish pathways.
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	1. <1 ft decrease (Pass) 2. >1 ft decrease (Monitor/Investigate) 3. >3 ft decrease (Evaluate Adaptive Management Action).	As of October, 2021, many individual cross sections exceed 1 ft of apparent decrease in water surface elevation. No sections along the main flow path exceed 3 ft lowering of the water surface. Updated TLS survey (2022) recommended to complete documentation of channel response to November 2021 Flood.

Several high flow events occurred shortly after the one-year monitoring window, two of those between a 10 and 50-yr recurrence interval, resulting in moderate geomorphic adjustments. While these changes have been photo-documented, NHC recommend completion of the full planned monitoring survey that would be triggered by a flood of this magnitude in order to further evaluate for fish passage concerns. This survey should be completed during low flow in late summer or early Autumn, 2022, in which a TLS-grade topographic surface of the exposed channel bed will be created. If this field survey effort identifies 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 subarially exposed part of the channel and water surface and using this data to assemble an updated hydraulic model to evaluate fish passage flows.

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MF NOOKSACK CHANNEL MONITORING & ADAPTIVE MANAGEMENT

APPENDIX A

COMPLETE PHOTO DOCUMENTATION AND CROSS SECTION OBSERVATIONS