Photo source: NHC (18 Dec. 2023)

MF Nooksack Channel Monitoring & Adaptive Management
Year 3 Monitoring

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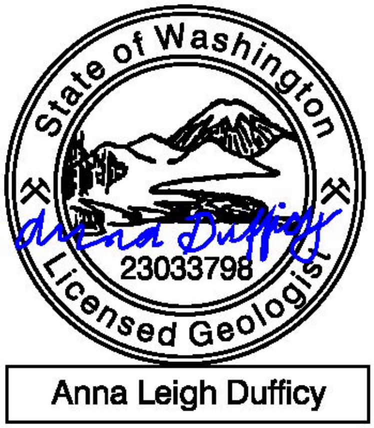

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DISCLAIMER

CREDITS AND ACKNOWLEDGEMENTS

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- Steve Day — Project Engineer, City of Bellingham
- April McEwen — River Restoration Project Manager, American Rivers

The following NHC personnel participated in the study:

- Annie Dufficy — Project Manager and Project Geomorphologist
- Andrew Nelson — Senior Review
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NHC partnered with Wilson Engineering on the as-built survey and Kleinschmidt 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. This report, completed following observations of the river through December 2023 and published in spring 2024, presents results of the year 3 monitoring completed by NHC, in collaboration with Kleinschmidt-R2, to complete this work. This report focuses on the two photographic and qualitative field surveys conducted in 2023 and one fish passage assessment conducted in April 2024. Full reports, summarizing the findings from the four key monitoring metrics, outlined in Table 1.1, were completed in Year 1 and Year 2. The next full monitoring work will be completed in 2024 and reported in 2025.

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% Average (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 three-year monitoring effort and preparation of this report included several survey efforts completed with an Unmanned Aerial Vehicle (UAV) and field photo documentation on two separate occasions: spring high flow and early winter low flow. New topographic surfaces were not compiled in 2023, but will be compiled in 2024.

The focus of this report is to document channel adjustments observed since the Two-Year Monitoring Report, which included assessment of channel response to several floods over the second-year monitoring period (NHC, 2023). Multiple flood peaks approaching or exceeding a 10-yr event and one substantial flood approaching a 50-yr event occurred during the two-year monitoring period. Multiple floods greater than a 2-yr recurrence interval have occurred since the Two-Year Monitoring Report visual and topographic surveys were completed (conducted in September 2022), including one exceeding a 10-yr event. Figure 1.1 illustrates the timing of these various observations relative to flood pulses and their associated stream power that occurred through April 2024. Despite the occurrence of multiple 2 to 10-yr floods, photographic documentation of the reach at the spring high flow (May 2023) and winter low flow (December 2023) revealed that the channel bed remained mostly stable during this monitoring period. This report summarizes the qualitative site visit findings, highlights the continued success of the restored main channel, and provides discussion on the benefits to fish passage in the channel's current state.

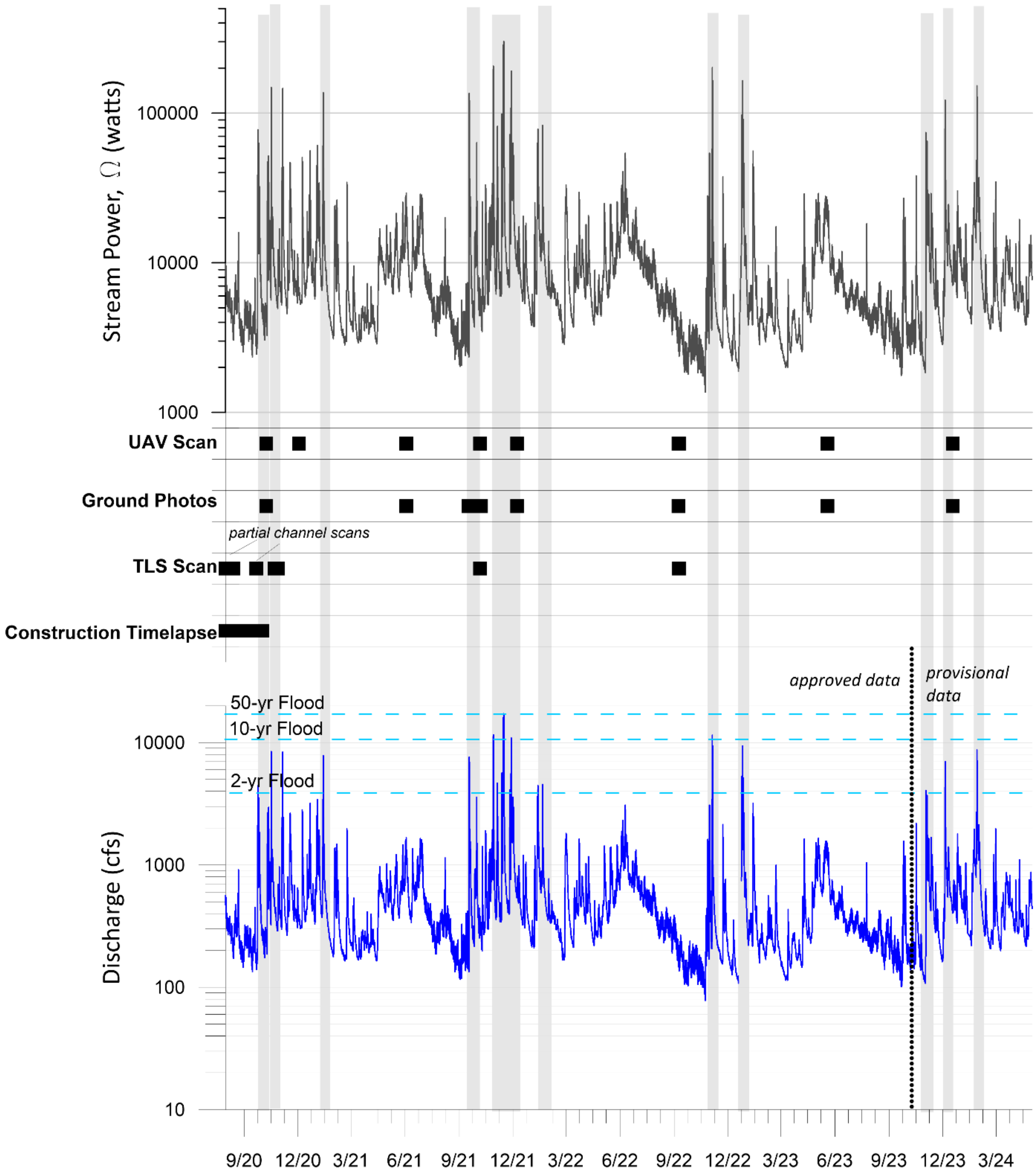

Figure 1.1 Timeline of stream flow, stream power, and observation efforts from August 31, 2019 through April, 2024

This three-year post-construction monitoring report is structured similarly to the qualitative analysis presented in the previous monitoring reports. This report includes 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. 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

Photos were collected at defined photo documentation locations, which were established in the post-construction as-built monitoring report (NHC, 2021) at approximately 20 ft intervals (allowing some flexibility to choose good and accessible vantage points) along the left bank of the channel. These photo transect locations extend 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.

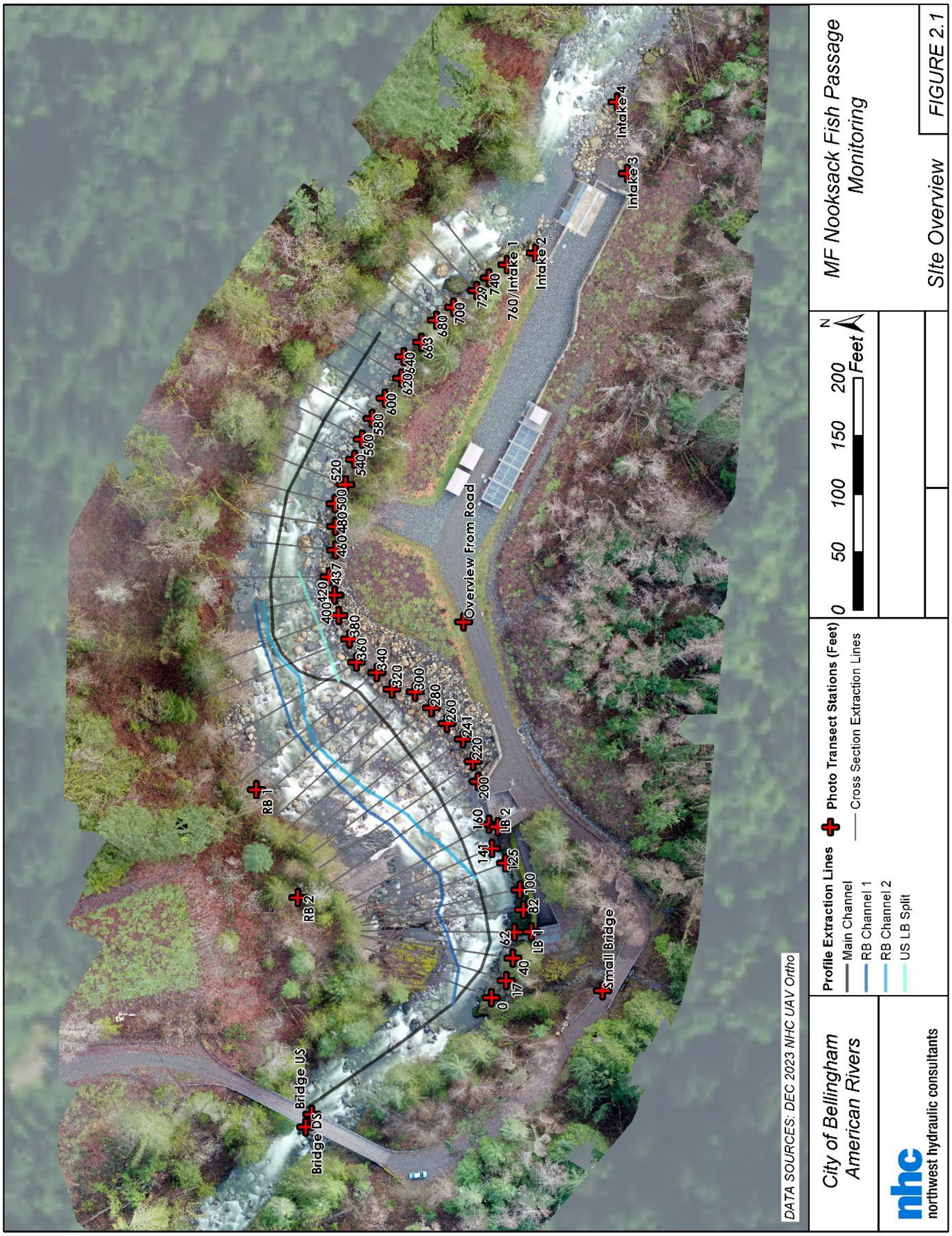

Figure 2.1 Map illustrating monitoring site layout

3 AS-BUILT THROUGH DECEMBER 2023

3.1 Summary of Year 2 Observations (NHC, 2023)

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 tailout in October 2021. 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 energy expected to mobilize individual boulders outside of jammed units. These changes are described in detail in NHC (2023). 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 pool tailout 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 was described in NHC (2023), 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.

3.2 Summary of Past Geomorphic Change Through 2023

Qualitative comparisons of the September 2022 and December 2023 orthomosaic photographs show that very little has changed in the structure of the channel bed, which can be attributed to the stability of the jamming features formed in the November 2021 floods (Figure 3.1). Prior to the November 2021 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 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).

Readjustment of the main channel has increased the complexity of the reach, increasing the total number of pools and flow pathways. Therefore, the designed jams continue to not only maintain passable slopes, but add stable roughness along the perimeter of the left flow pathway from which new step pool lines can form over time. Additionally, reworking of the previously exposed mid-channel bar now connects the right and main channels at a range of flows, which increases the number of potential fish migration routes. Section 4 discusses the ongoing adjustments of the main channel, as well as the minor changes in the primary fish pathways outlined in NHC (2023).

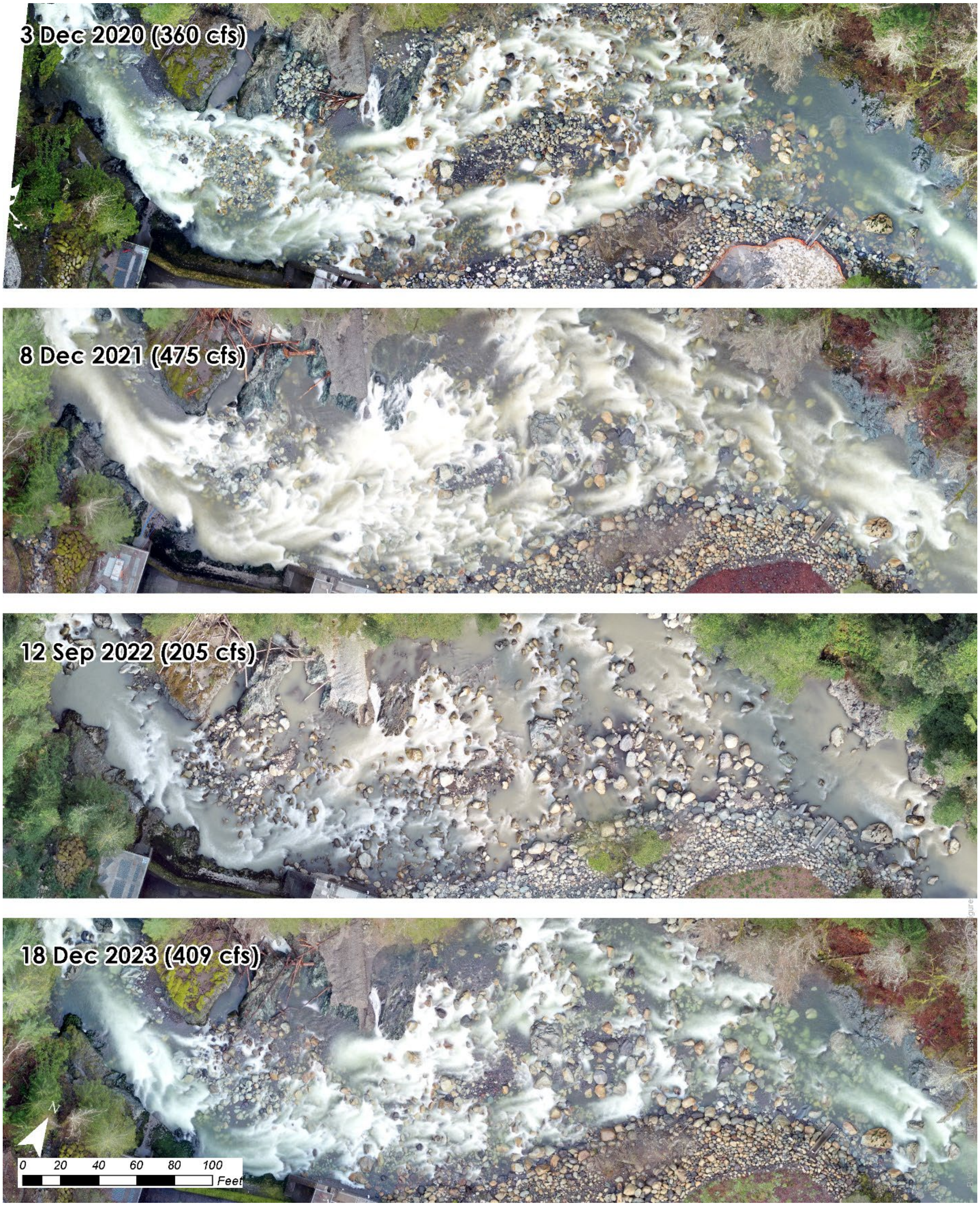

Figure 3.1 Orthomosaic comparisons showing observed channel conditions during monitoring site visits between December 2020 to December 2023.

The relative stability and locations of the designed boulder jams did not change between 2022 and 2023, although some designations have been changed from “unknown” after clear-water photographs were collected at low flows in December 2023. As discussed in NHC (2023), 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 3.2 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 completely destabilized from their jammed state during the floods, Jam 5 and Bonus Cluster 2. These clusters (outlined in red in Figure 3.2) 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. Depth to bedrock also increases in the downstream direction, highlighting the importance of downstream buried stabilizing or bracing boulders that could not be constructed in jams over shallow bedrock. It should be noted that since initial mobilization in 2021, most of the mobilized boulders in Jam 5 have reorganized into a new stable jam.

The status of Jam 1 and Jam 4, which previously had some degree of unknown boulder stability, have since been verified in the clear water photographs from December 2023. The stability of Jam 1 was previously described as “unknown” in NHC (2023) due to high turbidity in the site photographs, but clear water conditions in December 2023 reveal that the boulders have remained stable, with the bottom/downstream line of boulders presumably buried under other rocks. The three boulders closest to the thalweg of Jam 4 were previously designated as unknown, but closer examination of the most recent photographs suggests that at least two of the three boulders had partially or fully destabilized. However, their displacement was minimal and they are currently in a stable position.

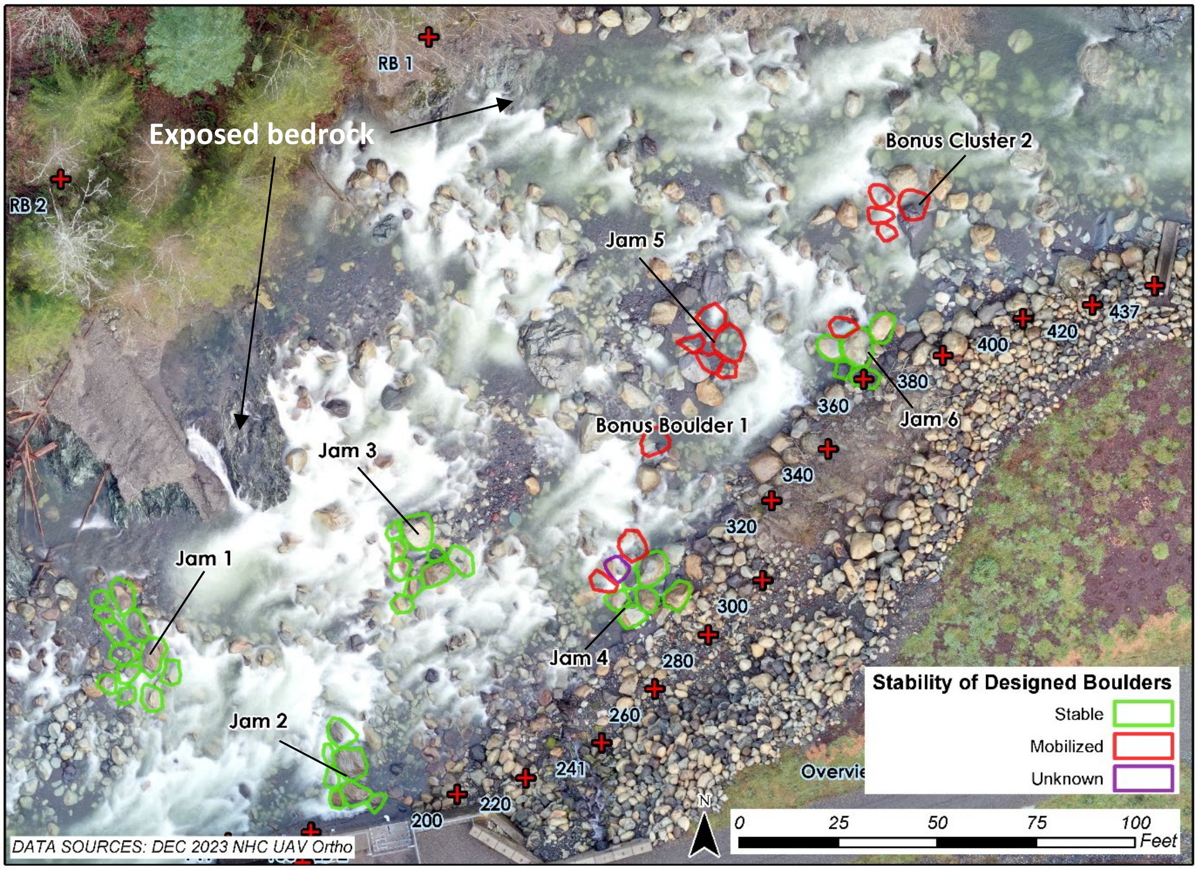

Figure 3.2 December 2023 (410 cfs) orthomosaic documenting relative instability in the restored channel, with engineered boulder cluster jams labeled. Areas of exposed bedrock on the channel bed are also labeled. (Photo: NHC)

3.3 High Flow Fish Passage Conditions Observations

High flow observations were conducted during the May 2023 site visit (1,040 cfs). Reorganization of the entire bed during the November 2021 floods into more stable step-pool arches has created numerous pathways for fish, as seen in the progression of photos in Figure 3.1. There were no notable changes in the flow pathways between the December 2021 high flow site visit and the May 2023 site visit apart from the higher discharge in May, resulting in a wider active channel from greater flow connection across the right and main channels. At this discharge (1,040 cfs), the hydraulic steps between boulder lines are generally backwatered, reducing the height of the steps relative to low flow conditions. The wider active flow area and large number of moderate size step-pool units and pockets diffuse the hydraulic energy overall and prevent the development of velocity barriers. Margins of both the right and left-bank flow paths present areas with adequate depth for adult salmon passage (typically > 1ft) and lower velocities than along the thalweg of each flow path.

Figure 3.3 **UAV oblique photos showing channel evolution at the flow split between the restored left bank channel and right bank pathways in June 2021 (top), December 2021 (middle), and May 2023 (bottom).**

3.4 December 2023 Low Flow Observations

Low flow observations took place in December 2023, several weeks after a flood event (greater than a 2-yr based on provisional data). 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 relatively high amounts of fine sediment observed in September 2022 were absent during the December 2023 site visit, and flows were generally clear. The widespread regrade and channel lowering through the Fish Bypass outlet pool was still apparent during low flows, but does not appear to have downcut any further (Figure 3.4), due to the prolonged stability of the boulder line that formed at the downstream end of the bypass pool in November 2021. In its current configuration, the slide outlet remained perched above the water surface during the visit (410 cfs), which is within the range of operable flows for the bypass. Abrasion of the concrete slide has also exposed rebar near the base of slide near the water's edge. Lowering of the pool resulted in the emergence of a step that had previously been backwatered prior to November 2021, as noted in Figure 3.4. This step has not increased in prominence since September 2022, and similar to steps present along the reach upstream, is not interpreted to adversely affect fish passage, as discussed in Section 4.

As mentioned in Section 3.3 and NHC (2023), 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, which remain connected at low flows of at least 410 cfs (Figure 3.5). The simultaneous regrade of both main channel and right channels has prevented the main channel from dewatering at low flows. 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. Boulders near the top of the main channel near the left bank flow split continue to adjust in a favorable way that is allowing more water into the main channel, whereas previous observations in NHC (2023) raised the concern of main channel dewatering. Section 4 discusses the evolution of the fish passage routes in this area in more detail. 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.

One unresolved concern from the 2022 monitoring was the degree of bedrock exposure along the right flow pathway's channel bed. After review of the UAV photos and videos, most of the exposed bedrock appears to be along the right bank of the channel. Whereas previous concerns noted possibilities of extensive lateral bedrock notches, most of the steps in the photographs appear to be composed of boulders and pools filled with gravel and cobble. Future bedrock exposures will be monitored as the channel continues to evolve, as the depth to bedrock varies across the channel.

Figure 3.4 UAV oblique photos showing channel evolution at the pool outlet near Transect 400c between October 2020 (top, 225 cfs), September 2022 (middle, 152 cfs), and December 2023 (bottom, 410 cfs).

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

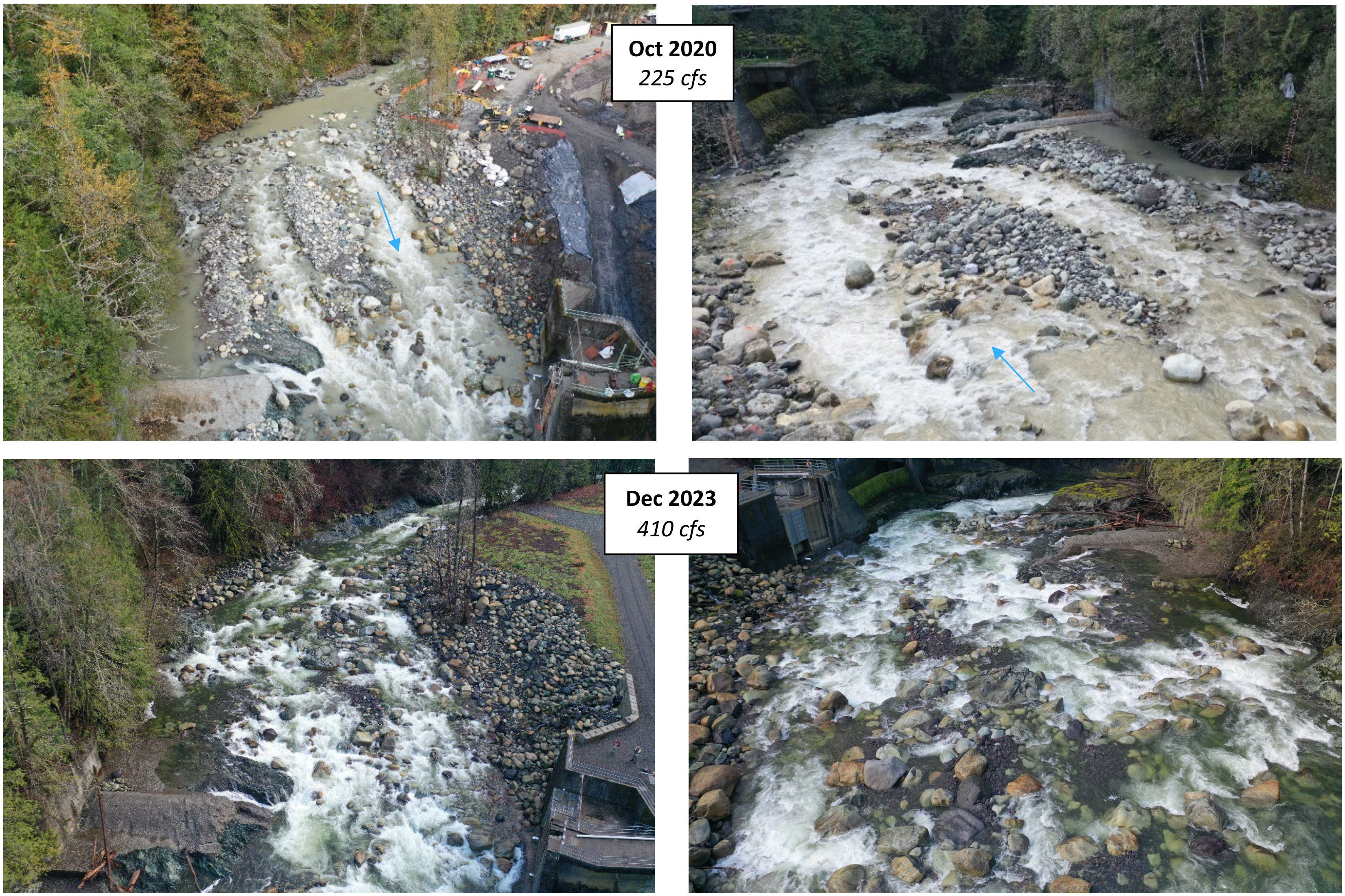

Figure 3.5 Repeat UAV imagery showing low-flow channel comparisons between October 2020 (top) and December 2023 (bottom)

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 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.

The site was visited to further evaluate fish passage conditions in April 2024 when flow at the USGS gage was around 250 cfs. 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 upstream passage when flows were higher, with favorable conditions judged to occur at around 400-500 cfs. The same general routes appeared passable as depicted in the Year 2 report, with a few additional connecting pathways apparent (Figure 4.1). 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. 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 4.2).

Degradation continued along the right side of the channel, with greater potential for upstream passage along the upstream section than in prior years. 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, or main channel. 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 of NHC (2023) 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.

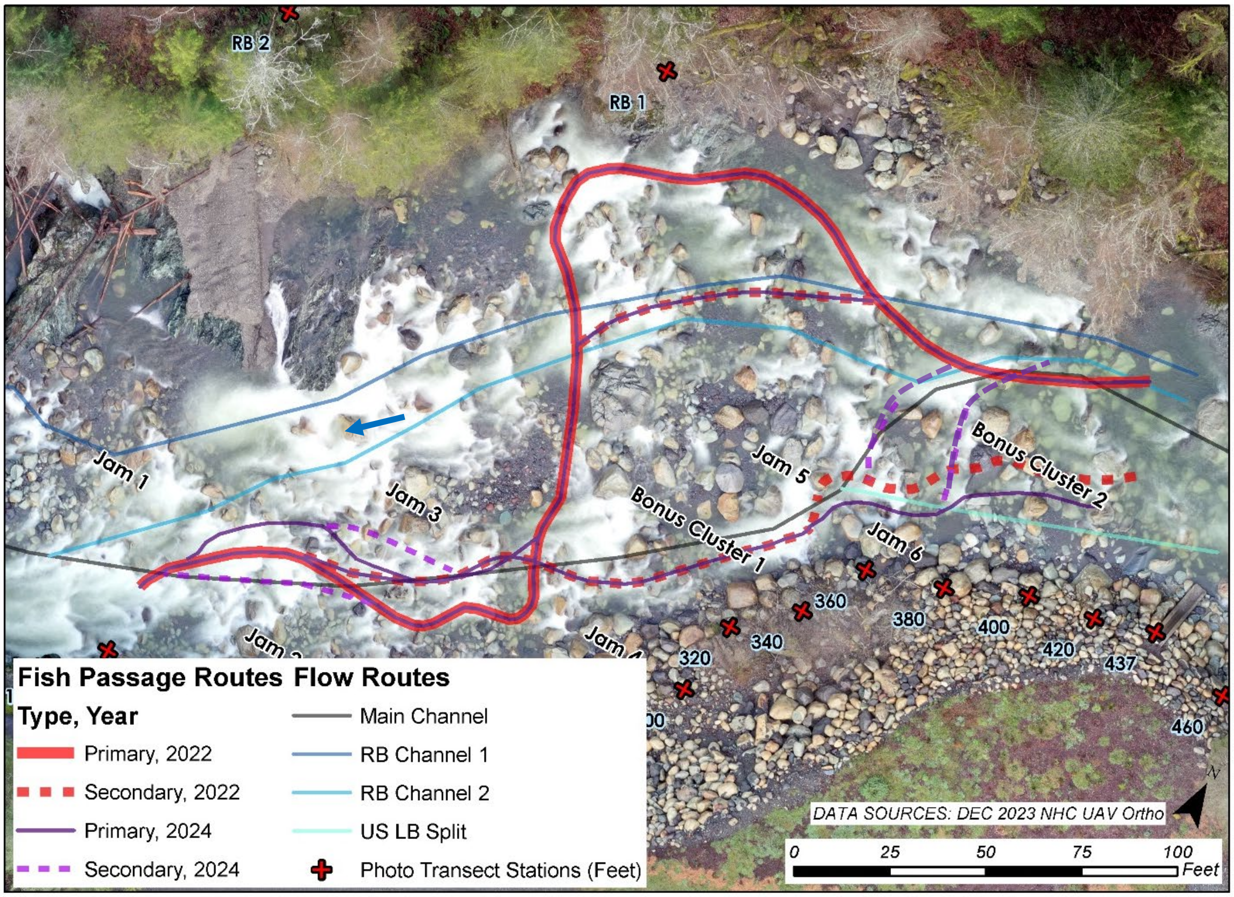

Figure 4.1 Potential upstream passage routes overlaid on December 2023 orthomosaic and relevant monitoring pathways (main channel, RB 1 and RB 2). Solid line = expected primary pathway during lower to mid-flow range; dashed lines = additional routes during mid- and higher flow range. (Photo: NHC)

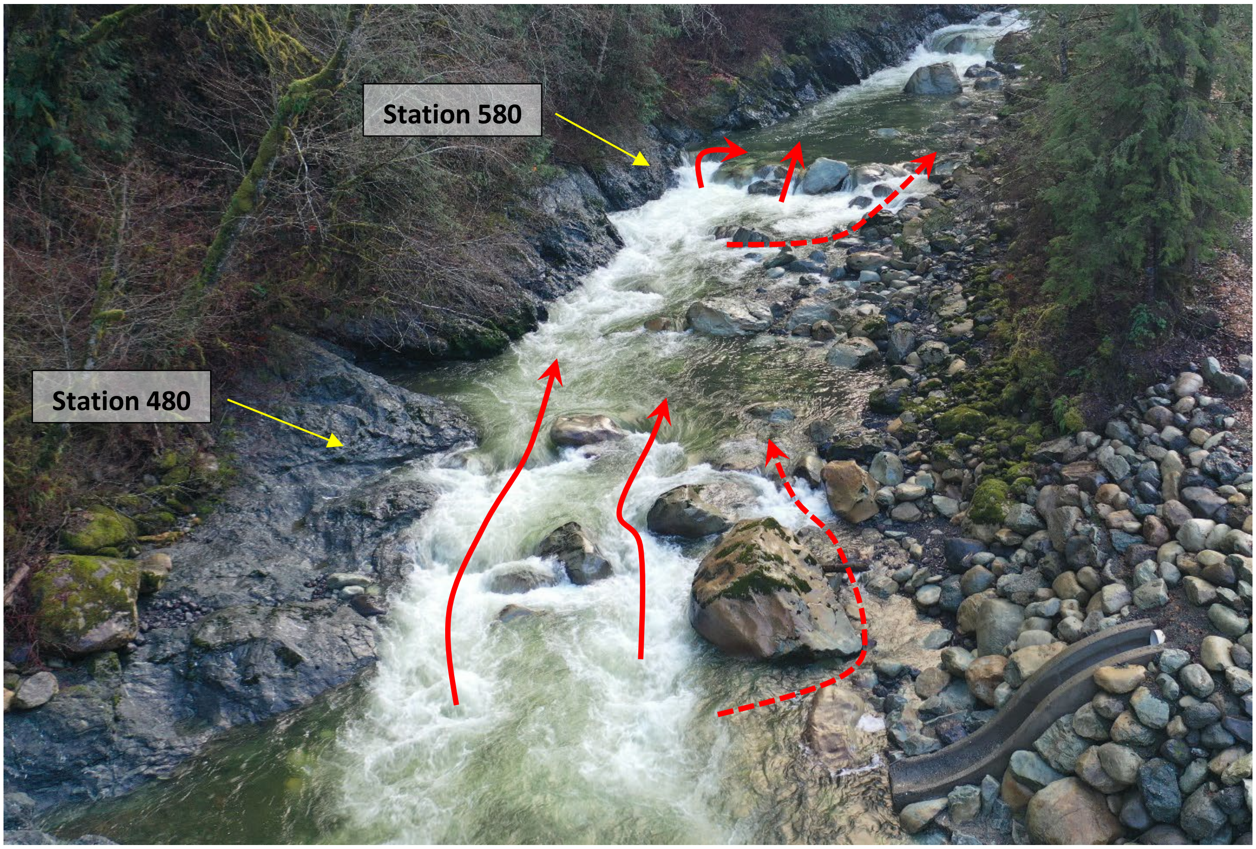

Figure 4.2 **Likely passage routes at the observed flow at steps upstream of the fish outlet slide (December 2023). Solid lines = expected primary pathway during lower to mid-flow range; dashed lines = additional routes during mid- and higher flow range.**

5 SUMMARY & RECOMMENDATIONS

This report documents the results of the qualitative geomorphic assessment from site photos and videos taken during high and low flows in 2023. The primary finding of this assessment is that no meaningful channel bed changes were observed in 2023 compared to the low flow observations in September 2022. This comes after major adjustments occurred in the observation reach after the November 2021 floods (two occurring between a 10 and 50-yr recurrence interval). NHC (2023) documented these changes in detail but did not report any risks for fish passage. Given the lack of visual change from 2022 and the results from the qualitative photo assessment, there continues to be no risk for fish passage.

Table 5.1 Current performance of project relative to channel monitoring metrics.

Monitoring Technique	Monitoring Metric	Thresholds	Decision Pathway	Status as of December 2023
Photo/Visual Survey	N/A Provides indication of channel changes to inform field work.	N/A	N/A	No evidence of impassable hydraulic conditions. Channel bed has not changed meaningfully since 2022. Hydraulics in the Fish Bypass return pool continue to exhibit high roughness and shallow flow depths.
Digital Elevation Model Development and Analysis	N/A Provides indication of channel changes to inform field work.	N/A	N/A	N/A (to be updated in Year 4 Report)
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).	N/A (to be updated in Year 4 Report)
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).	N/A (to be updated in Year 4 Report)

As stated in the previous monitoring reports (NHC, 2022; NHC, 2023), 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. 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. A complete monitoring report will be completed in Year 4 after site visits and topographic surveys are completed in 2024.

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MF NOOKSACK CHANNEL MONITORING & ADAPTIVE MANAGEMENT
APPENDIX A
COMPLETE PHOTO DOCUMENTATION