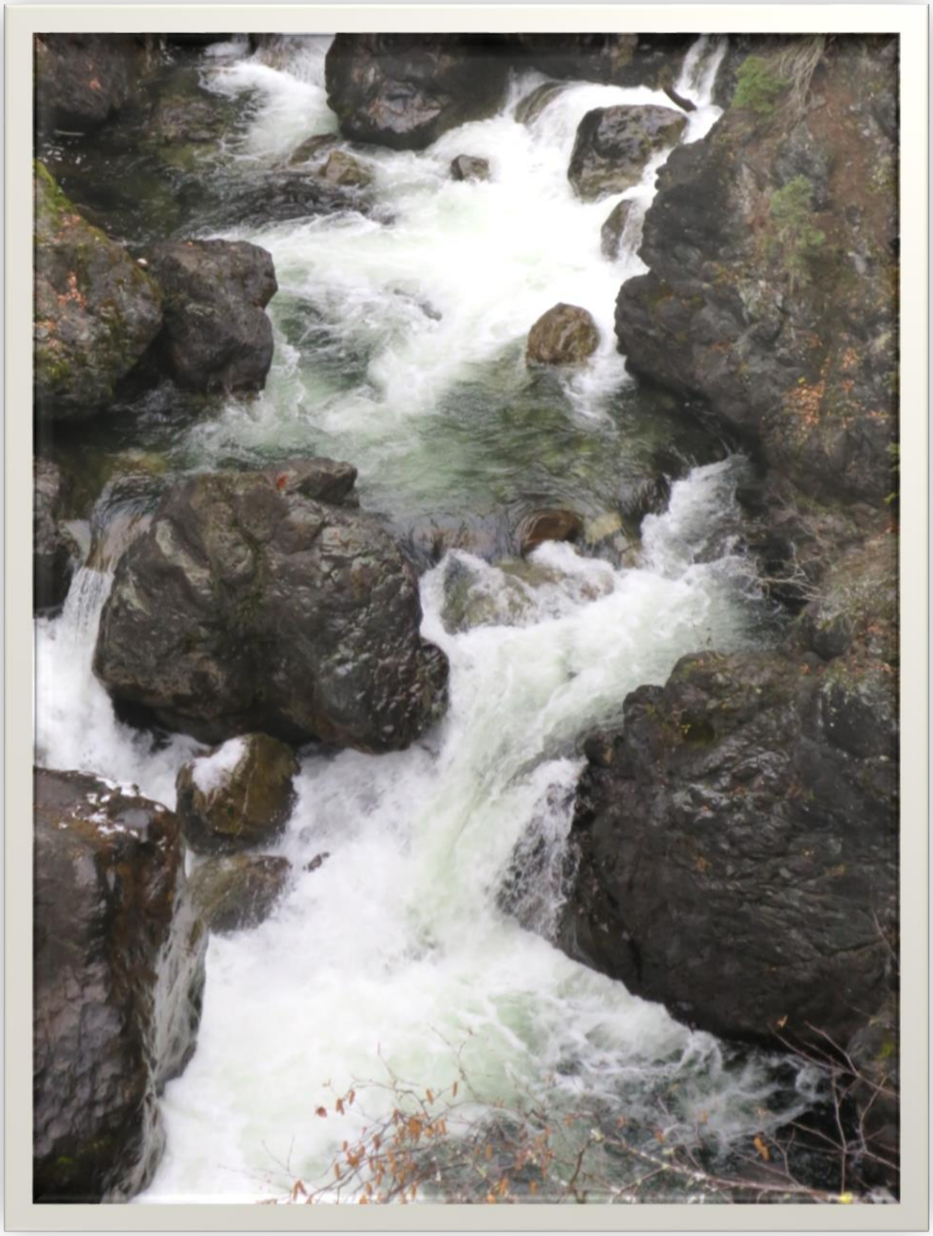
Kuthai Lake access improvement project

2017 Final Report



March 31st, 2018

Taku River Tlingit Fisheries

Executive Summary:

Silver Salmon River is a migration corridor for sockeye salmon destined for Kuthai Lake. Kuthai sockeye escapement has been low for numerous years and does not seem to be recovering. Since 2007 returns to Kuthai Lake have been markedly lower than the long term average. The Kuthai stock is known to have early run timing, passing the lower Taku River in latter June, arriving at the confluence of the Nakina and Silver Salmon Rivers in early to mid-July. Peak enumeration into Kuthai Lake has historically been latter July to early August**.** The lower 700 meters of Silver Salmon River is a canyon reach with a number of boulder obstructions that pose jump height and velocity/turbulence challenges to upstream migration. Previous work and long term observations by TRT Fisheries has noted that the passage obstructions in the canyon may be the cause of these reduced returns. The TRT and the Pacific Salmon Commission are collaborating on this study to explore the cause of reduced returns to Kuthai Lake and to undertake mitigation if feasible. Those assessments have resulted in the ranking of specific sites for passage difficulty. Project activities for 2017 included two site visits, an April trip to conduct hydrometric gauging at Silver Salmon Creek above Kuthai, further assess the migration obstacles and remove a piece of large woody debris from the confluence pool at SR1-1. A second site visit was conducted in July to conduct further assessment of mitigation options, undertake jump attempt monitoring and refine the mitigation options.

Acknowledgements:

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The following groups or individuals should be recognized for their help with this project: Patrick Hudson (Project Hydrologist); Richard Erhardt (TRT Fisheries Biologist); Mark Connor (TRT Fisheries Manager); Angus Mackay and Victor Keong (PSC NF); Atlin Air and Discovery Helicopters (in Atlin, BC).

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Introduction:

Silver Salmon River is a migration corridor for sockeye salmon destined for Kuthai Lake. Kuthai sockeye escapement has been low for numerous years and does not seem to be recovering (See Figure 1, below). Since 2007 returns to Kuthai Lake have been markedly lower than the long term average. The Kuthai stock is known to have early run timing, passing the lower Taku River in latter June, arriving at the confluence of the Nakina and Silver Salmon Rivers in early to mid-July. Peak enumeration into Kuthai Lake has historically been latter July to early August**.** Figure 1 (below) is a summary of escapement to Kuthai Lake from 1992 through 2017.

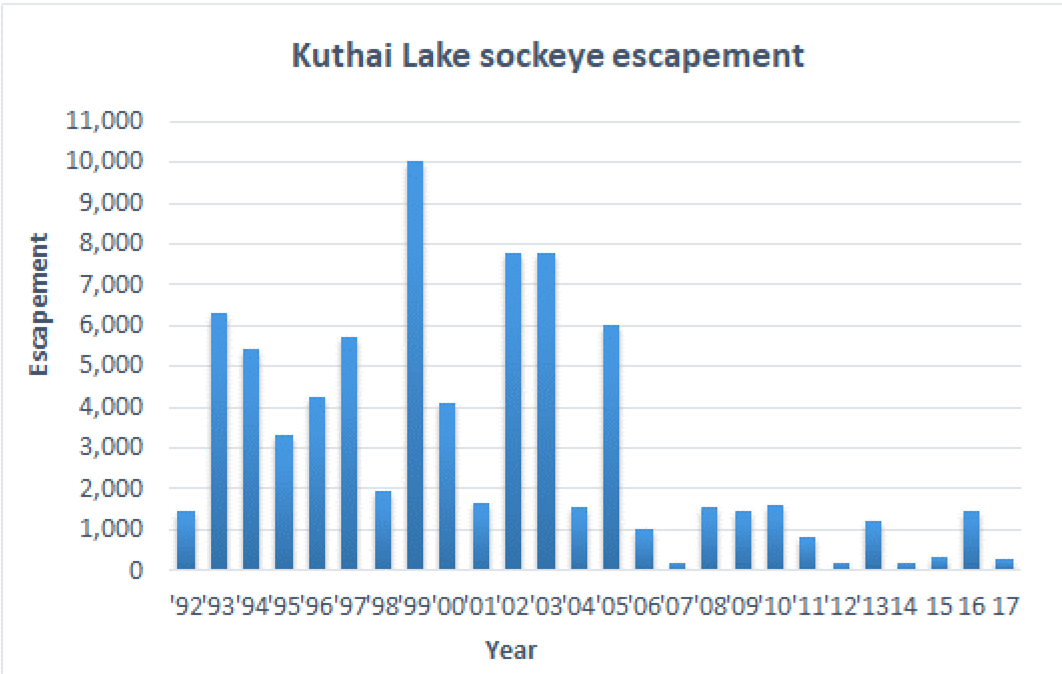

Figure 1: A summary plot of historic escapements to Kuthai Lake: 1992 to 2017

This report is a summary of the project activities of the Silver Salmon River Sockeye access enhancement effort for 2017. The project activities undertaken in 2017 included the following;

- A springtime visit to further assess the passage issues at sites identified in 2016;
- Spot hydrometric gauging at three sites to augment the hydrology database;
- LWD obstruction removal at the furthest downstream site;
- Surveying at select locations in anticipation of the design phase;
- Reporting and engineering consultations / design of a passage approach.

Objectives:

The 2017 project year followed up on the work done in 2016 with a focus on the mitigation of passage issues in a stepwise upstream manner. The specific objectives include the following:

- A springtime visit to further assess the passage issues at sites identified in 2016;
- Spot hydrometric gauging at three sites to augment the hydrology database;

- LWD obstruction removal at the furthest downstream site;
- Follow-up monitoring of sockeye passage throughout the canyon using underwater video and the collection of jump attempt video at select locations;
- Surveying at select locations in anticipation of the design phase;
- Reporting and engineering consultations for the design of a passage approach.

Background:

Project Area:

The Silver Salmon Watershed covers an area of approximately 430 square kilometers of mountain plateau terrain on the lee side of the Coast Mountains in British Columbia Hydrologic Zone 2. Its position on the lee side of the Coast Range translates into lower annual precipitation and unit area runoffs than watersheds further west. Silver Salmon River discharges to Nakina River on river right just downstream of the Nakina Canyon and runs northwest to Kuthai Lake. The river rises abruptly for the first 2 kilometers to a wide valley with Kuthai Lake at the top end. Silver Salmon River then turns to the north east up to a plateau and terminates at Bell Lake.

Geomorphology:

The main stem of Silver Salmon River below Kuthai Lake is an underfit river that meanders across an extensive paleo-channel alluvial deposit formed by mega-floods emanating from southward trending glaciers during the last glacial episode (see Photo 1 below). Glaciers in the basin deposited these alluvial materials during the glacial maxima and pro-glacially during deglaciation and ablation. This type of valley bottom glacial deposit tends to result in hydro-systems with large alluvial aquifers that store and release large quantities of groundwater. The effect of this groundwater influence is to augment low flows and diminish peak flows and produce ideal hydrologic conditions for spawning and rearing of salmonids.

The glacial history of the lower watershed has also shaped the formation of Kuthai Lake and the sockeye spawning areas on its' shoreline. Kuthai Lake has the elongate, serpentine shape consistent with subglacial scour and deposition, the remnants of which form the spawning substrates utilized by sockeye (see Photo 3 below). The southern shore of the lake is formed by a mound of terminal moraine and the paleo-alluvial fan of the upper Silver Salmon River. Kuthai Creek has carved a notch through the moraine and is confined on river left as it follows the toe of the alluvial fan.

The bedrock in the basin is underlain by Paleozoic rocks of the Cache Creek Group (Aitken, 1960). These chert, limestone and argillite rocks can be expected to have relatively high porosity. Aitken (1960) maps the bedrock in the canyon reach as chert, a very durable rock type, although there are also some limestone exposures as well.

Photo 1: The view looking northwest toward Kuthai Lake. Silver Salmon River can be seen in the foreground meandering across the wide alluvial plain of the glacial paleo-channel that underlies the valley bottom. The alluvium of the paleo-channel has high potential for groundwater aquifers that likely give the Silver Salmon River a stable flow regime and high groundwater ratio.

Hydrology:

The Silver Salmon watershed lies in the rain shadow of the Coast Mountains in the northwestern corner of BC Hydrologic Zone 2 (Yukon Plateau). There are no long term hydrometric stations in the watershed or in nearby hydrologically similar watersheds so estimates of hydrologic parameters can only be determined by project gauging, regional hydrologic analysis or hydraulic geometry. Hydrometric gauging done for this project was undertaken to provide index flows to provide hydrologic context for the assessment of obstructions in the canyon reach. Figure 2 is a chart of the average monthly flows for the Taku River USGS hydrometric station 08BB005 near Juneau Alaska.

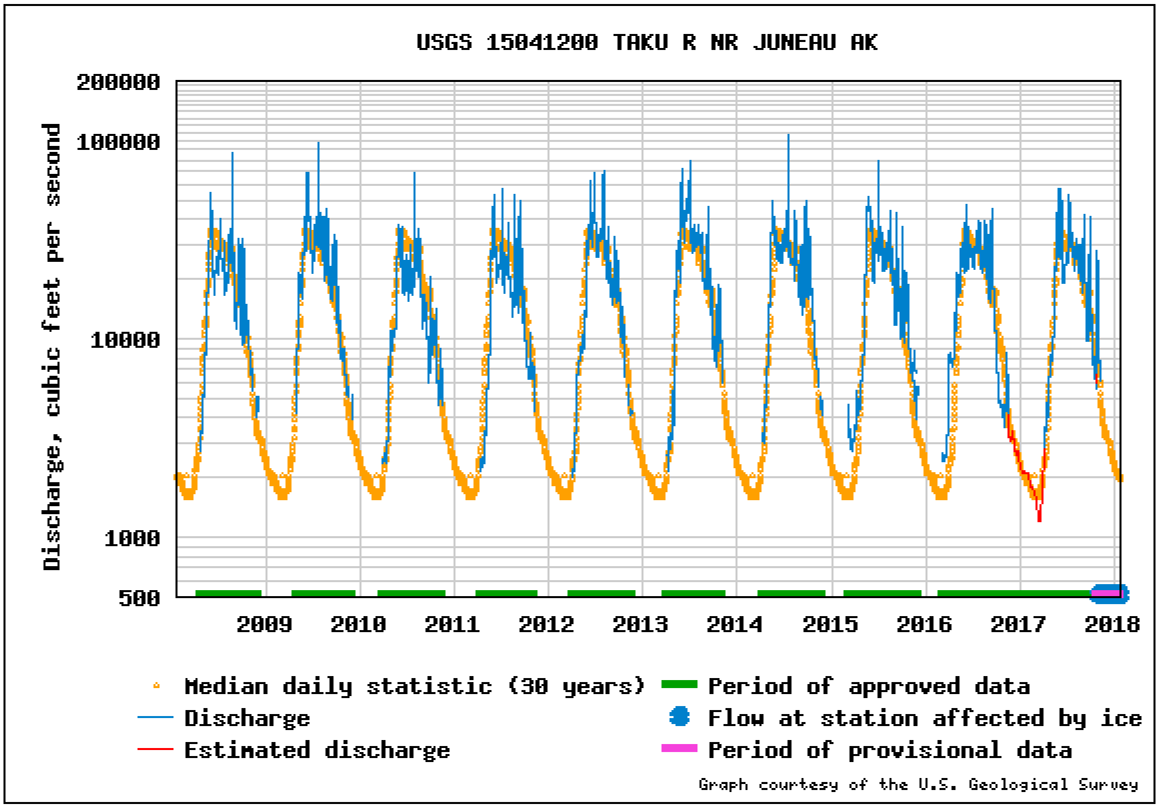

Figure 2: A summary hydrograph for station Taku River near Juneau for the period 2009 through 2018.

Figure 2 shows the annual hydrograph for the USGS Taku River near Juneau for the period 2009 through 2018. The hydrograph shows a mixed hydrologic regime (nival snowmelt and glacial melt) pattern with highest flows in the spring and summer and very low flows in the winter. Of course this station captures glacial outburst discharges during the summer which do not occur in the upper watershed but they average only about 18 hours in duration once or twice a year. As the figure indicates, the annual minimum flow is in February, the snowmelt peak is in June and isolated glacial outburst floods coming the Tulsequah watershed can be seen as the highest peaks in June, July and August each year. The descending (fall) limb has high flows into October due in part to the influence of Pacific onshore fall storm systems.

The watershed is in the transitional zone between the wetter Engelmann Spruce Subalpine Spruce (ESSF) / Sub Boreal Spruce (SBS) zones west of Silver Salmon River and the much drier Boreal White and Black Spruce (BWBS) / Sub-Boreal Spruce Biogeoclimatic zones to the east. Most of the watershed is forested aside from high alpine areas and areas of high water table and wetlands in the valley bottoms.

Photo 2: Bell Lake (aka Silver Salmon Lake) at the headwaters of Silver Salmon River. Photo date: October 27, 2016.

Photo 3: Glacio-fluvial deposit on the eastern shore of Kuthai Lake that supports sockeye spawning (July 2016). Note the partially dewatered spawning dunes near the shoreline.

Fieldwork Summary:

To note: Specific field sites in the canyon are portrayed in the Appendix photos for reference.

The 2017 field program included a spring and summer site visit with the following activities;

- **Spring Site Visit:** Further assessment of the passage challenges in the lower canyon section, hydrometrics at the established spot gauging locations, removal of 1 piece of LWD at the lowermost passage challenge (site SR1-1), assessment of icing issues in the canyon, and collection of cross sectional data for future analysis.
- **Summer Site Visit:** The main scope was to observe the progress of sockeye through the canyon to assess passage difficulty and estimate the success of the springtime LWD removal. Hydrometric gauging was conducted as well as more site surveying. A traverse of the canyon was conducted with the underwater camera gear to check the progress of sockeye migrants upstream.

Results:

Field Assessments:

April Site Visit:

A site visit was conducted between April 7th and the 13th to conduct low flow assessment in the lower Silver Salmon canyon. The focus was on the lowermost section of challenges because the overall strategy for access enhancement involves addressing issues in an upstream direction and because the lowermost pool (SR1-1) was noted to have fish holding in the pool during previous years that eventually backed out to the main-stem Nakina indicating that something was limiting passage success. Also a piece of LWD was noted at the head of the staging pool at SR1-1 that was suspected to be the instream feature limiting passage.

Conducting field assessments in April was instructive as it allowed the assessment of the nature of instream ice in terms of total depth and percent cover. Ice cover was extensive across the active channel with an estimated 60% coverage at the time of the site visit.

Ice cover was well anchored to instream boulders and banks but also included shelf ice and bridging over pools and steps. Ice formation appears dynamic as there were numerous places where there were internal voids and overflow / through-flow paths and glaciering indicating lateral flow shifts and ice damming. This is not surprising given the cold microclimate in the canyon due to cold air ponding from the plateau and the shading of the canyon walls (even in the summer there is little direct solar insolation).

Photo 4: Ice cover in the upper canyon sub-reach (SR3) at the time of the site visit on April 9th, 2018.

The cold micro-climate combined with the high vapor pressure and spray associated with turbulence and strong base-flows in the winter leads to thick ice accumulations that persist into the freshet period. It is assumed that very cold air temperatures combined with high base flows from the lake and wetland aquifers on the plateau results in frazil ice accumulations that contribute to icing and backwatering in the canyon. Photo 5 (below) was taken during the spring site visit and includes an internal void (in the center of the photo) indicating internal flow paths indicating a dynamic ice formation process. The issue of dynamic ice formation and high levels of ice formation is relevant to this project as it speaks to the viability of installing a fabricated aluminum steep-pass structure versus a rock notch style of steep-pass. The high degree of ice formation and its persistence raises some risks around the fabricated aluminum structure as it may indicate a higher risk of ice damage that is not likely in the case of a rock cut steep-pass.

Photo 5: Ice profile at SR1-1 (the confluence pool) showing abandoned internal flow structure suggesting complex ice dynamics and flow paths.

Site Survey:

A limited site survey was conducted to obtain cross sectional and long profile data for design purposes. This was done to gather data for a proposed potential mitigation option involving backwatering the pool at SR1-1. Since that time a piece of woody debris was removed from the head of the pool, which, according to the migration monitoring conducted in July 2017 appears to have reduced the migration back-up at this location. As a result we are not currently considering mitigation works at this location. The survey included benchmarking a staff gauge at SR1-1 for future use and the collection of 2 cross sections that may be useful to model flows or estimate channel stability in the future. The long profile data has been reduced and converted to a gradient estimate for the cascade section directly above SR1-1 and is included in the analysis section.

LWD Removal:

Migration period monitoring in 2016 indicated a backlog of sockeye in the pool at the first challenge at site SR1-1. Underwater video and aerial observation indicated that there was a single piece of LWD obstructing the staging pool at this location that was degrading the passage (See photos 6 and 7 below). This LWD piece was cut during the 2017 spring site visit. The piece was eventually blown out during high flows later in the freshet period

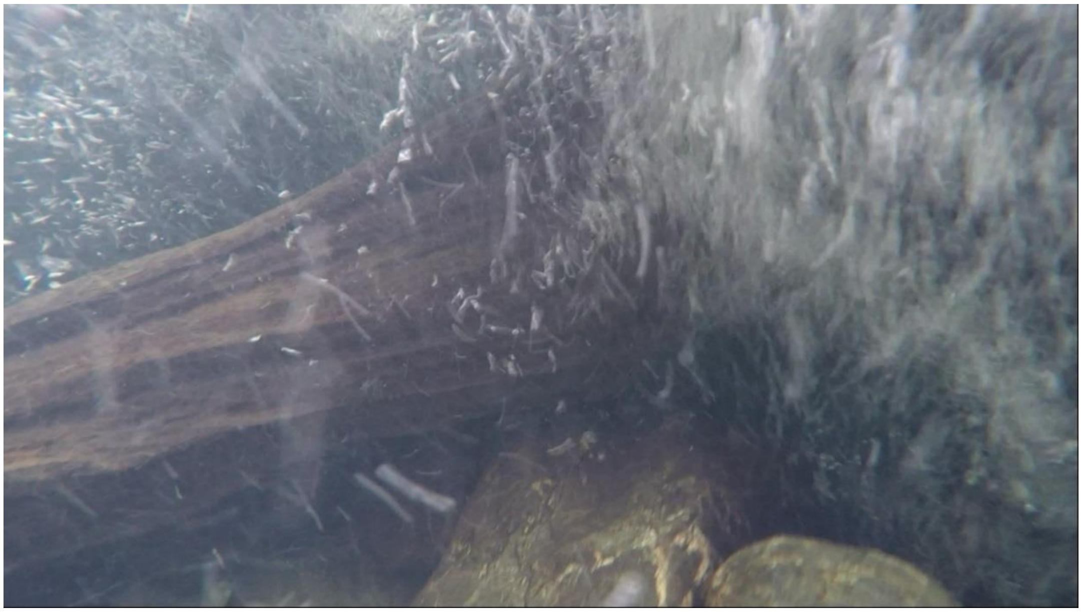

Photo 6: Underwater view of a LWD piece lodged at the transition between the cascade and pool in site SR1-1.

Photo 7: Aerial view of LWD piece at the transition point of the pool at SR1-1 (July 2016).

July Site Visit:

Activities during the July site visit included fish passage monitoring conducted by foot traverse, underwater video and jump attempt monitoring in the upper reach (SR3-3). Some cross sectional surveying was conducted for future design and modeling purposes and the "Nakina Below the Weir" and "Silver Salmon Above Kuthai" hydrometric stations were gauged.

Fish Passage Monitoring:

Fish passage monitoring was conducted by foot and wading traverse. A camera, attached to a telescoping pole, was used to check for fish at selected locations in the canyon. The traverse indicated that there were a small group of sockeye in the pool at SR1-1 but there were also a number of individuals noted upstream of that dispersed throughout the rest of SR1 and SR2 (the alluvial reach). Moving upstream, sockeye were noted in SR3 (the upper canyon) with the largest number making jump attempts at SR3-3. The traverse continued upstream to the top of the canyon where two fish were observed indicating that they were passing the upper canyon, albeit with some difficulty. More detailed jump attempt monitoring was conducted in SR3 to provide a more detailed assessment of the passage difficulties there. The jump attempt monitoring at SR3 is detailed below.

Jump attempts were observed at SR3-3 and SR3-5 (the Mushroom) on three successive days between July 29th and August 5th, 2017. Visual counts were made that included fish that were airborne below the respective challenge. Jump attempt rates are used here as a surrogate for the number of fish that are holding below a given challenge. While this was not a quantifiable estimate of the total number of fish holding we assume that the jump rate estimates reflect the relative abundance of fish holding below each respective challenge. Estimating the success of each jump was not always obvious but confirmed successful jump attempts were noted. A summary of the jump attempts is included in Table 1 below.

Table 1: Summary of Jump Attempt Monitoring			
Date	**Site**	**Jump Rate (per second)**	**Observation Time (seconds)**
July 29	**SR3-3**	**.98**	**727**
July 29	**SR3-5**	**.10**	**816**
July 30	**SR3-3**	**.81**	**600**
July 30	**SR3-5**	**.11**	**600**
August 5	**SR3-3**	**.27**	**600**
August 5	**SR3-5**	**.07**	**600**

Table 1: A summary of the jump attempt monitoring conducted during the summer of 2017. The table compares the jump attempts observed at SR3-3 and SR3-5 in the upper Silver Salmon canyon.

Table 1, above is a summary of the jump attempt monitoring conducted in July and August of 2017. Observation times are all at least 600 seconds to ensure a minimum observation period and similar sampling times between observation events. Figure 3 (below), is a plot of the jump attempts at the two locations over time. The plot shows that the jump attempt rate was highest at SR3-3 throughout the observation period.

Analysis:

Jump Rate Monitoring and Wading Survey:

The wading traverse from SR1 to SR3 was conducted to confirm the resolution of the passage difficulty associated with a piece of LWD lodged at the head of the pool at SR1-1 that was removed in the spring to mitigate the sockeye bottleneck observed in previous years. The results indicate that the LWD removal has successfully mitigated the bottleneck as a small number of fish were observed in the pool at SR1-1 (based on an underwater camera scoping), fish were observed throughout the rest of SR1 and 2 and there was a large number of fish holding in SR3, particularly below SR3-3.

The objective of the jump rate monitoring is to estimate the passage difficulty posed by the two SR3 challenge locations being monitored (SR3-3 and SR3-5) Figure 3 (below) suggests that the largest number of fish (highest jump rate) were located below site SR3-3 throughout the monitoring period. From this we deduce that SR3-3 is the least passable challenge in this series of upper canyon steps. It is not possible to say definitively how many of these jump attempts were successful as some of the fish disappear into the turbulence after attempting to jump and there are likely interstitial paths that are not readily observable. Of the jump attempts observed at SR3-3 none were confirmed successes and the majority were confirmed failures. The jump attempt observations at SR3-5 included several confirmed successful attempts. Figure 3 shows that during the monitoring period the pool at SR3-3 is holding the most fish and it takes a week for the numbers to drop. During that period the numbers of fish holding above (SR3-5) does not increase indicating that fish are navigating SR3-5 more easily. It is interesting to note that the total sockeye escapement to Kuthai Lake for 2017 was 299 individuals. Given that the jump attempt rate at SR3-3 showed an average attempt rate of about 1 per second for the July monitoring (July 29th and 30th) that translates to a cycle rate (time between jump attempts for an individual fish), assuming the entire 300 fish (the 2017 total escapement) was in the pool below SR3-3, of about 1 jump every 5 minutes. This seems unlikely given the fact that the jump attempt monitoring showed fish attempting the obstacle at SR3-3 for a number of days. Energetically this would be unsustainable as it doesn't leave much time for recovery. More likely is that there were many more fish holding in the pool below SR3-3 and that mortality at SR3 is quite high. Using an average cycle rate of 10 minutes this translates to an estimated 600 fish holding below SR3 which suggests a 50% mortality between the upper reach of the Silver Salmon canyon and Kuthai Lake.

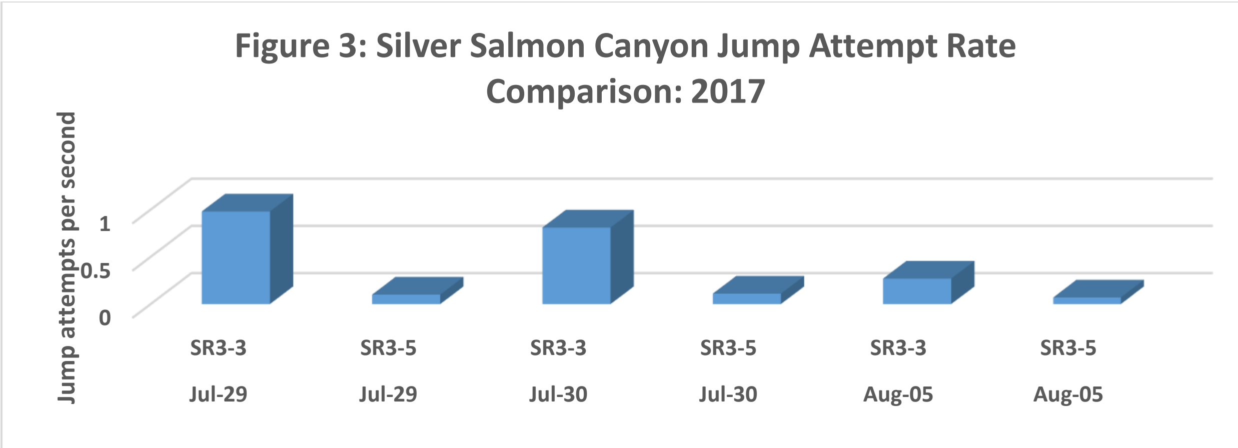

Figure 3: A comparison of jump attempt rates at SR3-3 and SR3-5 that shows the passage of sockeye during the migration period in 2017.

Hydrology:

The hydrology results for 2017 include the addition of spring and summer spot gauging data for stations "Nakina Below the Weir" and "Silver Salmon above Kuthai". The 2016 pressure transducer data for "Silver Salmon Above Kuthai" was downloaded during the 2017 spring site visit. The pressure transducer data has been reduced to a summer time (open water) partial duration series, corrected for barometric pressure and a rating curve developed. The 2016 summer hydrograph developed from this data is included below.

Figure 4 shows the hydrograph for the spawning period in 2016. On average the first fish begin arriving at the weir below Kuthai Lake around July 15th. Superimposed on the hydrograph is daily precipitation from Environment Canada at the nearest weather station (Atlin). The fit between summer precipitation and streamflow trends looks good as the major precipitation events are correlated with stormflow events of similar magnitude. A lag time correction may improve the fit (shifting the precipitation data back one day) but was not applied. The left of the hydrograph shows the end of the 2016 freshet descending limb and the transition to summer base flows. On the right side the onset of fall storms is evident with the coincident peaks in flow and a rise in base flow. The plot identifies the summer low flow period that provides the best flow conditions for migrating the canyon which is roughly the discharge range between .75 and 2 cubic meters per second at the index station (Silver Salmon Above Kuthai). This translates to a flow range for the Silver Salmon canyon, based on a scaling of flows of respective watershed areas, between 1.4 and 3.75 cubic meters per second. This corresponds with canyon flows in the recurrence range below the 2 year recurrence interval according to the regional flood frequency curve developed for the site.

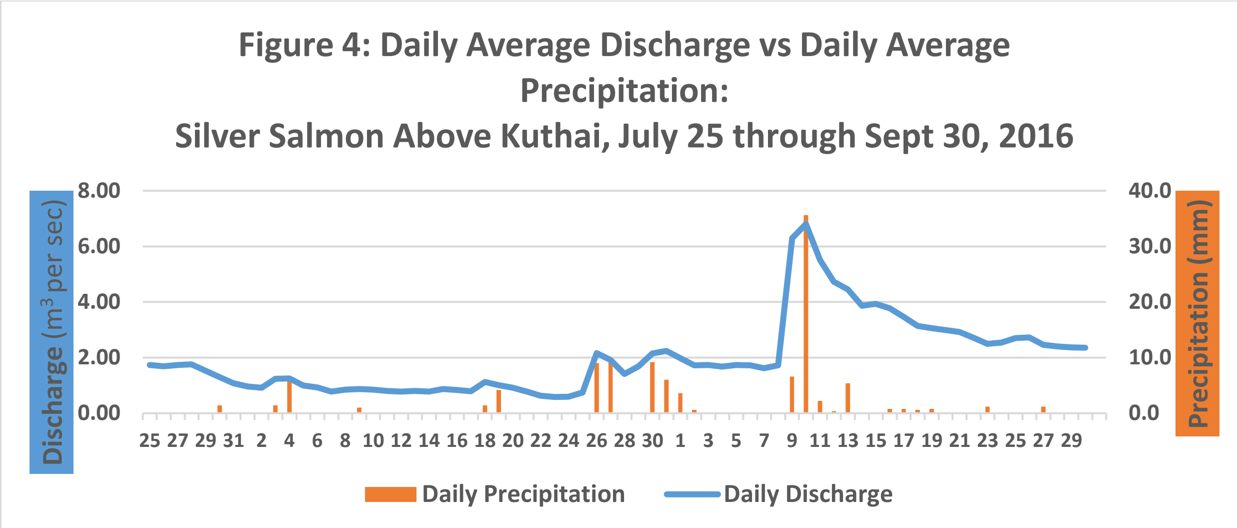

Figure 4: Open water hydrograph for the 2016 season, Station "Silver Salmon Above Kuthai". Precipitation (Atlin Airport) is included on the secondary axis

Migration Analysis:

A brief migration analysis is included here to better understand the issues around Silver Salmon migration delay and mortality. It is also useful as far as highlighting follow-up metrics that can be used to estimate the efficacy of mitigation. The first question to answer is to what degree does migration period discharge affect migration delay and migration mortality? To answer this we created a partial duration series of average July monthly flows for the period 1993 through 2017 from the USGS Taku River gauge data near Juneau (USGS station 15041200). This series was ranked from largest to smallest to normalize the data and plotted against the mid return date for sockeye arriving at Kuthai. “Mid return date” is the number of days after July 1st at which 50% of the total escapement has passed through the weir at Kuthai. Mid return date was selected to give a central tendency estimate of run return timing. The plot is shown below in Figure 5.

Figure 5 shows that there is an increase in the “mid return date” of total escapement to Kuthai Lake from the 2004 run year to 2017. The “mid return date” has increased by 10 days (from July 23rd to Aug 2nd) since 2004 suggesting that there is an average migration delay that started in 2004 and has persisted ever since. Averaging the July average monthly flow rankings over the two periods (before and after 2004) indicates that the period 1993 to 2003 had an average flow ranking of 14.5 versus 11.8 since 2004. The highest July flow rates in the series have occurred since 2004 and in particular during 2005, 2006 and 2007 (the #1 ranked flow).

The 10 day migration delay has a metabolic cost that can be quantified using the migration energy consumption estimates determined by Rand and Hinch (1998). By tracking the swimming speed of sockeye in the Fraser Canyon (Early Stewart run) they were able to estimate the range of energy consumption rates for sockeye migrants at different locations in their migration. They estimated that constricted reach (Fraser Canyon) daily average energy consumption rates were up to 3800 times the standard metabolic rate whereas more moderate, unconstructed reaches resulted in energy consumption rates that were only 0.1 times standard metabolic rate. They also estimate that about 84%

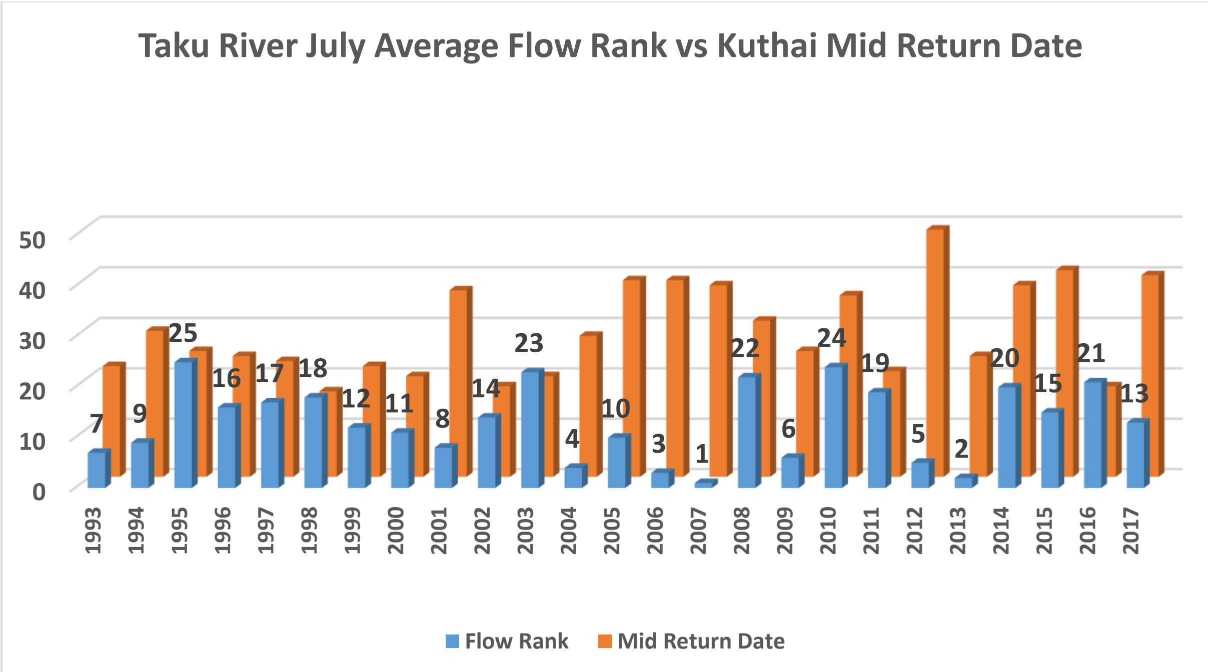

Figure 5: A plot of Taku River July mean flow rank vs the mid-return date (days after July 1st required to pass 50% of the annual escapement) past the weir at Kuthai. Mean monthly flows are ranked from largest to smallest so the shortest orange columns represent the largest July flows. Data labels are the July Average flow ranks.

of the total energy reserves of sockeye migrants was expended for locomotion, 8.4 % was expended for gonadal development and 7% was expended for standard metabolism. This means that the metabolic costs of migration through constricted and higher velocity reaches like Village Falls and the Silver Salmon canyon is very high. Migration delays in concert with difficult passage conditions can pose a serious mortality risk in terms of energy depletion, migration mortality and spawning success. Other mortality risk factors like predation, water temperature and exposure to high dissolved gas pressures (the Silver Salmon Canyon is likely supersaturated during the migration period) can also add metabolic cost per unit migration delay. Given the estimated 10 day migration delay and the results of the jump attempt monitoring, which showed a large number of fish below SR3-3 for a period of 5 days, the cost of migrating the Silver Salmon canyon is likely significant. We are hoping to refine the transit time for the Silver Salmon canyon during the summer 2018 field program by tracking radio tagged individuals.

A set of correlation analyses was conducted of the data to estimate the degree to which selected migration metrics follow observed trends. Correlation coefficients range from 1 (completely correlated) down to zero (not correlated). Negative correlation coefficients are also possible if the two metrics being tested vary in opposite directions (a rise in one value is correlated with a drop in the other). The following correlation analysis was conducted;

1. Average June Taku River monthly flow vs overall mid return date. This metric was selected to assess whether average July or June flow numbers correlate more strongly with the mid return date and are thus a more appropriate estimate of mean velocity along the migration route, the first order factor in migration rate;

2. Average July Taku River monthly flow vs overall mid return date;
3. Average July Taku River monthly flow vs total escapement to Kuthai Lake. This metric was selected to estimate to what degree the variation in flows accounts for the variation in total return;
4. Average July Taku River flow vs period 1 (1993 to 2003) mid return date. This metric and #5 is used to estimate the degree to which average July flow predicts the mid return date between the period before 2004 and after that. This is a metric that is useful to estimate if there has been a change in the flow / return date metric between the two periods;
5. Average July Taku River flow vs period 2 (2004 to 2017) mid return date.

Table 2 Correlation Analysis Results:	
Metric	**Correlation coefficient (r)**
Average June Taku River monthly flow vs overall mid return date	**0.16**
Average July Taku River monthly flow vs overall mid return date	**0.30**
Average July Taku River monthly flow vs total escapement to Kuthai	**-0.23**
Average July Taku River flow vs period 1 (1993 to 2003) mid return date	**0.39**
Average July Taku River flow vs period 2 (2004 to 2017) mid return date	**0.13**

Table 2: A summary of the results of Correlation analysis used in the migration investigation.

The results of these correlations indicate the following;

1. The first two correlations indicate that July average flow is a better predictor of flow effects (as a surrogate for average channel flow velocity) than June average flow. This eliminates June flow as a metric. The correlation of July average flows to mid return date is relatively weak indicating that factors other than flow velocity are contributing to the poor returns. The factor most likely to be implicated in the poor returns is migration difficulty at constricted and complex reaches like Village Falls and Silver Salmon canyon based on the observed monitoring and energy balance effects.
2. The monthly flow vs total escapement correlation results indicate a low degree of correlation between the two metrics although there is some correlation that may be significant. What it does indicate that the correlation between the two metrics is negative, higher flows result in lower returns, which is intuitive as monthly average flow is a surrogate measure of average flow velocity. This makes sense since in the absence of any constricted reaches and instream difficult passage elements we would expect the total energy consumption for locomotion to be a good predictor of migration exhaustion and mortality.
3. The comparison of July average flow to period 1 and 2 mid return date indicates that prior to 2004 July average flows was a threefold better predictor of mid return date. This in turn suggests that something has changed in the migration corridor between the two periods, which we assume to be shifts in channel architecture (mobile boulder and sediment adjustments due to high shear stress events), LWD effects due to higher average July flows and the higher July flows alone.

During higher than normal July mean flow periods, like the 2004 through 2007 period, large amounts of large and small woody debris become mobilized and move downstream. This debris is conveyed downstream or can become trapped at obstacles or constrictions in the channel. In the case of Nakina River, which is for the most part very uniform in cross section and straight in planform, woody debris can be transported long distances before becoming re-lodged at channel obstructions or constrictions. Several kilometers downstream from the confluence of the Silver Salmon and Nakina Rivers is Village Falls, a stepped rock boulder cascade channel constriction that has a number of flow paths through the boulder pile that offer bypass routes around the falls. These boulder pile by-pass flow paths ("sneaker channels") offer migrating salmonids the opportunity to navigate the falls without ascending the main flow cascade. The boulder pile also has a high woody debris capture efficiency by virtue of its many protruding boulders and right angle planform turns. Small woody debris "strand lines" of floated and re-deposited material are reliable field indicators of peak flows as they represent the maximum elevation of the water surface in the year they were formed. In the case of Village Falls a strand line of large and small woody debris is evident at the head of the boulder pile sneaker channels that is likely obstructing passage. The fact that there were bears in the boulder pile fishing at the time of the photo indicates that sockeye were attempting to by-pass the falls during the 2017 migration window. The obstruction was clearly significant as there were a large number of sockeye and some Chinook holding below the falls.

Photo 8: An overhead view of Village Falls downstream of the confluence with Silver Salmon River. The red arrow indicates the head of one of the "sneaker channels" that allow for high flow passage around the main steps of the falls. The brown arrow shows 2 Grizzlies fishing in the boulder pile in July 2017. Also visible is a strand line of large and small woody debris at the head of the by-pass channels.

A similar scenario has played out in the confluence pool at Silver Salmon (SR1-1) where a single piece of LWD had lodged in the cascade to pool transition and was accumulating small woody debris that resulted in passage delays and sockeye that eventually backed out and wasted in the main stem.

Mitigation Follow-up Metrics:

Fish passage mitigation works need clear and quantitative follow-up metrics to provide a basis for assessing whether the mitigations that are being applied are working as expected. This is needed to assess any risks of the mitigation itself and to support Adaptive Management of the effort. The following is a list of mitigation follow-up metrics, based on the migration analysis detailed above and an assessment of the trends in escapement and hydrology that can be used moving forward to assess the efficacy of the project works;

1. **Mid Return Date**: Tracking of mid return date is a solid mitigation assessment metric as it speaks directly to migration delays and relies on data that is already being collected at the weir. Mid Return Date was selected as it is a stable measure of the mean arrival time at Kuthai. Mid return dates that are more in line with the long term trend (before 2004) can be interpreted as an indicator of mitigation success. If mid return dates stay where they are or become later that would be an indicator that the mitigation is not working or there are other issues not being addressed.
2. **Jump Attempt Analysis:** Jump attempt monitoring is a more direct measure of the degree of passage difficulty associated with the most arduous obstacles in the canyon (based on the analysis conducted to date). The data is relatively easy to collect and should provide a repeatable estimate of passage difficulty and migration delay at the mitigation location (Sub Reach 3, challenge 3 through 5).
3. **Canyon Transit Time:** The total transit time for fish migrating through the canyon is a key metric to assess the migration bottleneck posed by the entire canyon as opposed to specific measures for select obstacles. In the 2018 field season we are hoping to track radio tagged fish through the canyon and estimate transit time. Reduced transit time would be seen as an indicator of mitigation success and longer transit times would suggest that the mitigation is ineffective or there are other issues not being addressed.
4. **Total Return to Kuthai:** The ultimate goal is to bring the escapement numbers back to historic so the total return to the lake is a good measure of mitigation efficacy as it integrates all of the potential factors in the migration timing. This also uses data that is already being collected at the Kuthai weir.
5. **Correlation Statistics; Average Monthly July Flow vs Mid Return Date and Average Monthly July Flow Versus Annual Escapement to Kuthai Lake:** These are longer term metrics that can be used to detect future changes to migration difficulty based on the logic that as the correlation between monthly flow and return and total escapement improve then the other factors related to obstructions and LWD accumulations must be declining.

Passage Enhancement Design:

The analysis here indicates that there has been a migration delay since 2004 that coincides with a large reduction in escapement to Kuthai Lake. The initiation of this migration delay corresponds to a period of higher than normal average July flow which has brought new woody debris into the channel that appears to have "blinded off" some of the smaller, critical migration paths and by-passes at both Silver Salmon and Village Falls. We have to consider that this period of high flows may have also have resulted in shifts in channel architecture (mobile boulder and sediment adjustments due to high shear stress events), LWD effects due to higher average July flows and the higher July flows alone that have all conspired to increase fish passage difficulty. Migration analysis indicates that the delay in returns to the lake is a significant mortality risk. Given that, and the drastic reduction in escapement to Kuthai Lake a mitigation plan is warranted.

Three years of monitoring and assessment have indicated that a significant migration delay is attributable to the jump height/ velocity obstacle at site SR3-3 so this site has been chosen as the location most likely to have positive results from mitigation. The objective of the mitigation is to reduce the migration bottleneck and associated migration delay at SR3-3 by creating a small by-pass structure. Design criteria for the by-pass are as follows;

1. The by-pass must require little to no ongoing maintenance due to the difficulty accessing and working at the site;
2. The by-pass must be durable enough to not be adversely affected by high flows, icing, sediment and woody debris accumulation and bear damage;
3. No changes to instream boulders should be undertaken to ensure that unanticipated keystone shifts are avoided;
4. The by-pass should be sized to accommodate migrating adult sockeye and Chinook;
5. The by-pass should be inlet controlled to constrain flow velocities and allow for the maintenance of passable flows over a range of high and low water years, and;
6. There must be sufficient attraction flows at the outlet to ensure migrants will use it.

Two alternative styles of by-pass have been considered as mitigation options, 1) a welded aluminum "Alaska Steeppass (SP)" style structure (Photo 9, below), and 2) a rock notch (RN) bypass (Photo 10, below) cut into the native bedrock. As can be seen from the example in Photo 9, the Alaska Steeppass structure is (usually) an aluminum structure that is fabricated off site and would need to be flown in by helicopter after being trucked from the Lower Mainland. This is essentially a closed structure where fish swim into the outlet and navigate up the baffled section to the inlet.

The Steeppass can be width and gradient sized to accommodate any species although accommodating larger species (like Chinook) would scale the overall structure upwards with a commensurate increase in fabrication and deployment cost. The top and bottom of the Alaska structure would need to span from pool to pool to allow for acceptable entrance and exit velocities which makes it more vulnerable to icing.

Photo 9: An example of an Alaska Steeppass structure.

The second option is a Rock Notch bypass where a design notch is cut into the native bedrock to create a bypass channel. This design is based on an analog similar to the natural “sneaker channels” found elsewhere in the canyon. The notch is designed to have an appropriate hydraulic geometry for the site insofar as it is matched to the swimming abilities of the target species. Unlike the Alaska Steeppass, the notch does not have to fully span from pool to pool it just needs to have an entry channel that reduces the total jump height and a “landing pad” that is elevated above the lower pool residual elevation. Fish passage enhancement is achieved by reducing the total jump height and improving the hydraulics for better swimming performance. The “landing pad” is a widening in the bottom of the notch with a trapezoidal cross section that allows easy jump access. It is designed to be deeper on one side than the other which will allow jumping migrants to find it and be directed to the deeper side for good hydraulic purchase and swimming performance.

***Photo 10: A conceptual design configuration for the rock notch design option*.**

An assessment of the two options under consideration was conducted by comparing them to critical design criteria. (See Table 3 below.)

Table 3: Comparison of two options for fish by-pass structure in the Silver Salmon Canyon.			
Criteria	**Alaska S/P**	**Rock Notch**	Notes
Little to no maintenance (due to sediment and woody debris clearing and structure damage from high flows and bears).	X	√	The S/P would be prone to debris trapping and sediment and ice accumulation and would require maintenance.
Durability.	X	√	The rock notch would be cut from the local bedrock which is a very durable chert that would be resistant to abrasion. The S/P would be prone to abrasion, damage from woody debris, ice and potentially bear vandalism.
Keystone shifts.	√	√	Both structure types could conceivably be implemented without affecting keystone boulders in the channel although the S/P would require some rock modification to be placed in the proper orientation.
Sized for Chinook and Sockeye	X	√	Both structures could conceivably be sized for both species although the S/P structure would have to be significantly increased in size to accommodate Chinook (given the confined nature of the design) and this may make it difficult or impossible to construct while meeting the design criteria.
Inlet control.	√	√	Both structure could be inlet controlled.
Attraction flows sufficient.	√	√	Both designs could provide sufficient attraction flows.
Cost and cost risk.	X	√	Overall cost of the fabrication for the S/P design is likely higher than the notch and ongoing maintenance cost would be high for the S/P and low to none for the notch in most years.

Table 3: A comparison of the two design options for passage enhancement at site SR3-3.

The results of the comparison clearly indicate that the notch structure is the preferred option based on relative maintenance costs, durability, species specific sizing and overall cost and cost risk. For these reasons we are proceeding with the implementation of the design phase for the rock notch and not pursuing the S/P option. We have contracted Northwest Hydraulic Consultants to assist with the preparation of the notch design and to provide design drawings for construction. BAT construction, a rock scaling company out of Kamloops BC with extensive work experience with this kind of project, has been selected as the rock works contractor.

Risk Assessment:

Assessing risk is an essential component of any proposed enhancement program. The main risks associated with this access enhancement project can be broken down into the following categories;

1. **Uncertainty Risk:** This is the risk associated with the accurate determination of the drivers, causes and resulting mitigation approach. Assuring that the underlying issues with respect to sockeye returns to Kuthai Lake are sufficiently well understood is a primary risk for this type of project. The mitigation works need to adequately address the issues that are driving the low returns.
2. **Regulatory Risk;** This is the risk associated with obtaining any required permits and approvals in a timely fashion that does not interfere with the project timelines and critical path. The works require a “Notification” under the BC Water Sustainability Act which needs to be in hand before the works can proceed. The project timelines are tight with a narrow spring window for instream works due to the need to complete the work during low flow.
3. **Implementation Risk**; This is the risk associated with the actual implementation of the works including things like the spring (flow dependent) work window, ensuring that the rock works for the rock notch excavation is well controlled and the rock removal is limited to the target rock in the design, the risk of unintended channel response to channel modification, and the environmental risks associated with minor spills and contamination.

These risks are addressed in the project plan by the following means;

1. **Uncertainty Risk;** Uncertainty risks are well managed in this project since the returns to the lake are precisely known due to the long term monitoring of escapement at the Kuthai weir. Since the main issue to be addressed is poor returns to the lake we are very certain that the poor returns are a serious issue. Uncertainty in the drivers and causative factors of the decline are addressed by the assessments and monitoring detailed above that identify historic high July average flows, the redistribution of woody debris and minor shifting of channel keystones as the main factors involved in poor migration access. The assessment of bypass channel blockage at Village falls and the successful mitigation of lower canyon passage by LWD removal both testify to the fact that the drivers have been properly identified. Perhaps the largest risk in this category is associated with ensuring that the access mitigation actually addresses the issues and results in improved escapement to Kuthai Lake. This risk is addressed by the development of a detailed “Mitigation Follow-up Program” using a set of five mitigation follow-up metrics that will be used to assess the success of the mitigation works.
2. **Regulatory Risk:** Regulatory risk is addressed through the timely submission of the WSA Act Notification, good communication with the Provincial regulators and the consultations with the TRT, DFO and Alaskan Regulators that has been ongoing since the beginning of the project.
3. **Implementation Risk:** Risks to the implementation timeline (spring site visit) are being adaptively managed by tracking Taku River flows and gathering information on conditions on the ground from TRT citizens and local pilots. There is a degree of flexibility in the actual deployment date that should allow for the timely implementation of the works within the low flow window. The rock works are being designed with the support of professional Engineers at

Northwest Hydraulics and the team at Bat Construction so this should mitigate risks around implementation of the design. The actual volume of rock needed to be removed to construct the rock is very small (about 1 cubic meter) which tends to mitigate the project implementation risk. Environmental risk during the spring work window is managed by the fact that the window is outside of the adult sockeye migration timing, the conditions during the low flow period tend to reduce the number of resident fishes in the canyon and sockeye smolt out-migration from Kuthai Lake occurs in mid-May with a delay in the time it takes for them to reach the canyon where the work is proposed. The rock works are quite small so the environmental risk is managed there by limiting the potential for drilling to impact water quality. The drilling will involve electric powered hand drills which eliminates the potential for fuel spills and associated contamination. The project team has a set of environmental management objectives and means (spill kits, no need for drilling fluids, and spill management procedures) to ensure that there will be no unforeseen impacts during the three days that the work is anticipated to take.

Implementation:

Final design of the mitigation works for Silver Salmon is expected to be complete by March 31st 2018. The original implementation plan in the 2018 proposal suggested that we would likely proceed with a velocity reduction hydraulic structure, utilizing a spring survey, summer design / fabrication stage and fall installation. Feedback from the Transboundary Technical Committee was that this approach, and the associated contracting needs would be difficult to achieve within the timeline of one field season. After the data analysis, criteria consideration and risk assessment in this report, clearly the rock notch mitigation is a better option. Therefore we have decided to complete this design by March 31st and plan to carry out the construction in late April. This will allow for a late fall site visit to undertake minor adjustments to the rock notch should the summer monitoring of jump attempts indicate that this is necessary.

The general approach to implementation is therefore to complete the rock notch work in late April, monitor the passage success of it through jump attempt monitoring and transit time telemetry monitoring in July and then undertake a fall site visit to undertake any adjustments that may be necessary. A more detailed scope of work is provided in Table 4 below;

Table 4: Scope of Work and Timeline for 2018									
Scope item	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Field Planning and Logistics, site visit 1.									
Mobilization to Nakina for site visit 1; **- Install safety system rock anchors for rockworks;** **- Install mount bracket for video jump monitoring;** **-Rock works implementation;** **- Hydrometric gauging;**									
Field planning and logistics, site visit 2.									
Mobilize to Nakina for site visit 2. **- Telemetry monitoring for SS canyon transit time estimate;** **- Jump attempt monitoring at SR3-3;** **- Hydrometric gauging;** **- Install data loggers for temperature monitoring during migration period;** **- Conduct dissolved gas monitoring during migration period;** **- Conduct hydrometric station servicing.**									
Reporting; **1) Summarize and analyze summer jump attempt and transit time monitoring, prepare fall site visit scope and logistics.**									
Mobilize to Nakina for site visit 3; **- Conduct as-built survey;** **- Make minor adjustments to the works;** **- Download data loggers at hydrometrics site “Silver Salmon above Kuthai”;** **- Download temperature data loggers.**									
Reporting; **-Prepare annual report.**									

Table 4: A summary of the scope of work and timeline for implementation of the 2018 project activities.

References:

Atlin weather Station (station 1200560) downloaded from: climate.weather.gc.ca/historical_data/search_historic_data_e.html on March 1st, 2018.

Taku River monthly flow for Station *Taku River Near Juneau* (15041200), https://waterdata.usgs.gov/usa/nwis/uv?site_no=15041200 downloaded January 15th, 2018.

Rand, Peter S., and Hinch, Scott G., 1998. Swim speeds and energy use of upriver migrating sockeye salmon (Oncorhynchus nerka): simulating metabolic power and assessing risk of energy depletion. Can. L. Fish. Aquat.Sci. 55: 1832-1841.

Appendix: Site Panorama Photos

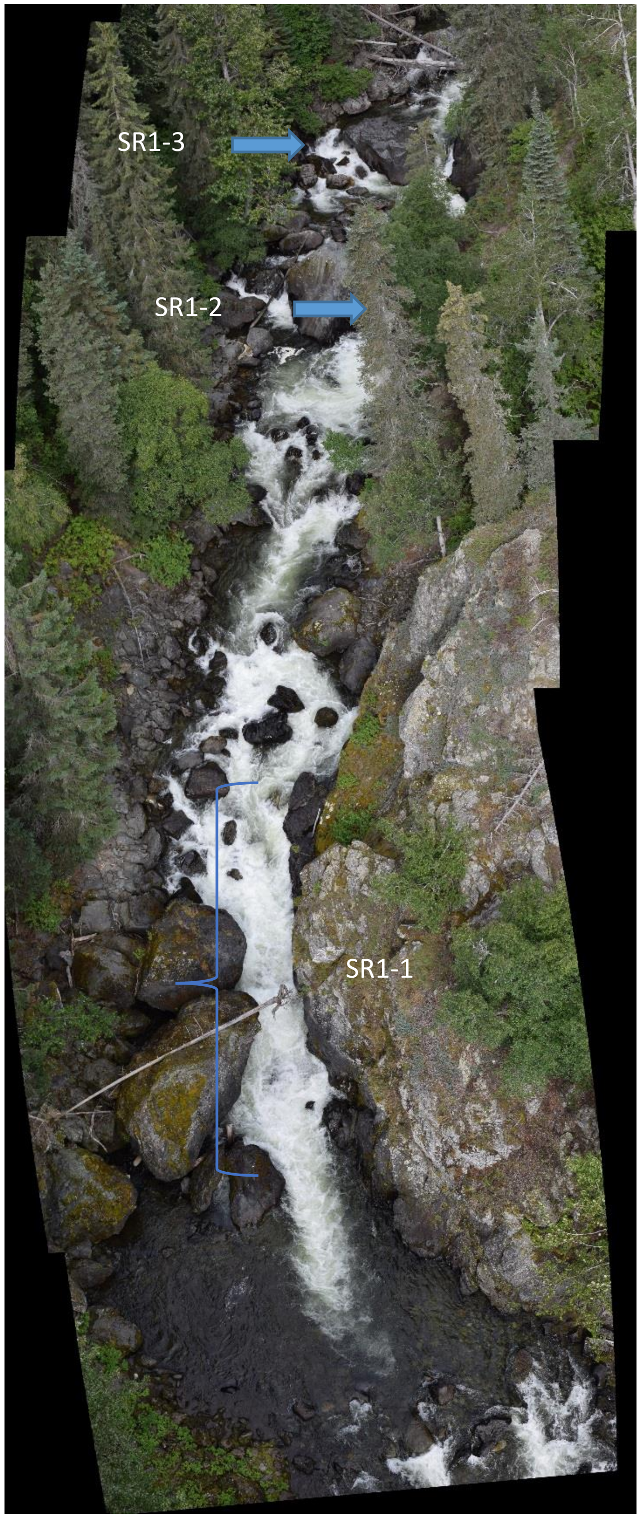

Photo A1: The three passage obstructions in the lower Silver Salmon canyon. Picture date July 2016.

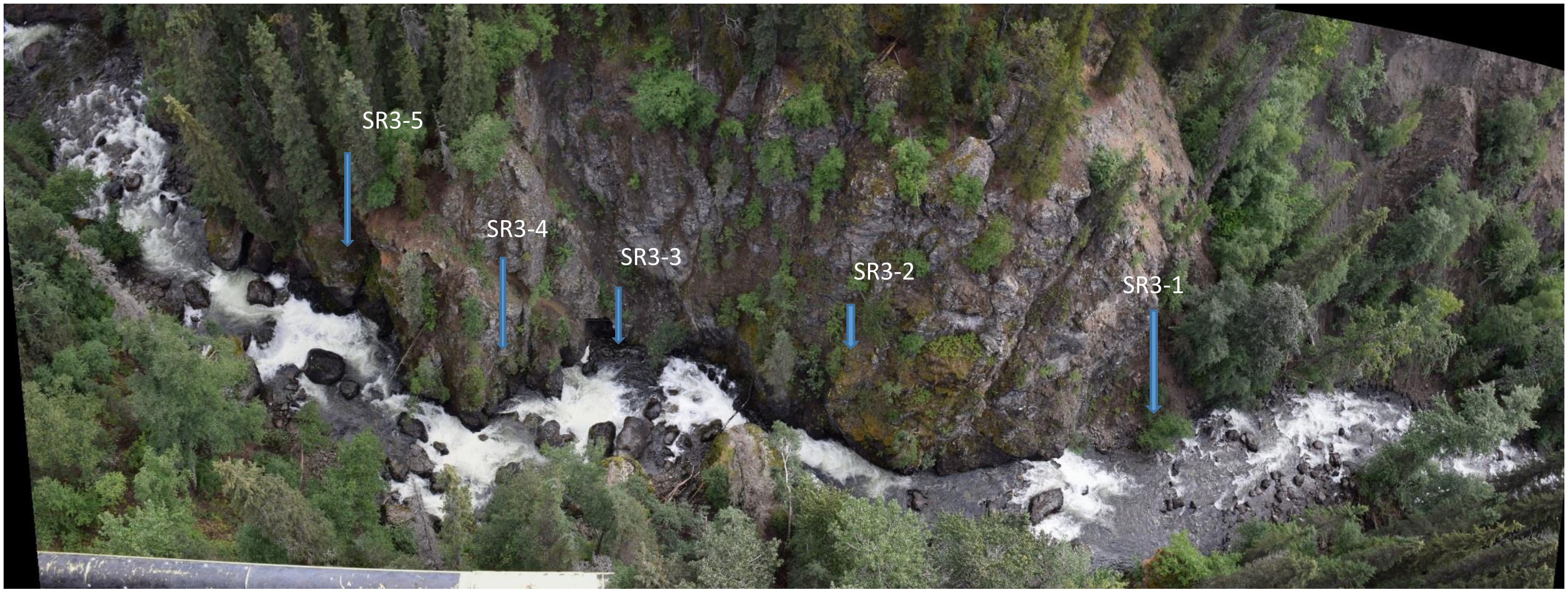

Photo A2: The upper Silver Salmon canyon obstacles. Photo date July 2016.