Sheep Creek
Water Quality Monitoring Report
2015 – 2017

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Cover photo: Upstream view of Sheep Creek from monitoring site NESHP01, September 2015.

Project Highlights

The Columbia Basin Water Quality Monitoring Project (CBWQ) is an environmental stewardship project funded by Columbia Basin Trust. Under the CBWQ, the Salmo Watershed Streamkeepers Society conducted water quality monitoring in Sheep Creek from 2015 to 2017. This site was located at a downstream section of the creek, near the confluence with the Salmo River. Because of this location, the influences on creek health from most developments were reviewed (e.g., historical mining/tailings leaching, regional landfill leaching, motorized recreational traffic, and forestry activities). The four components monitored were: benthic macro-invertebrate community using Canadian Aquatic Biomonitoring Network (CABIN), water quality, water temperature, and hydrologic characteristics (i.e., velocity and streamflow).

The CABIN model determined NESHP01 to be stressed in 2015, and potentially stressed in 2016 and 2017. These results were evident through several benthic macro-invertebrate community metrics that were outside of the range of the reference group mean. Specifically NESHP01 had higher total abundance, lower proportion of Ephemeroptera, Plecoptera, and Trichoptera orders of taxa (EPT), higher proportion of Chironomidae, and higher proportion of two dominant taxa. Although assessed to be stressed in 2015, the benthic macro-invertebrate community metric results were similar to the other years, and were not worse. The 2015 results appeared to only have a poorer condition based on fewer taxa being present than were expected based on the reference group mean.

The reasons for these benthic macro-invertebrate community outcomes appeared to most likely be related to habitat conditions. In 2015, average velocity was lower, and the percent composition of gravel was higher than both the reference group mean and the other years sampled. The cause for the stressed and potentially stressed outcomes (amongst all years) may also be related to limitations of the reference group, as Reference Group 4 was only comprised of 12 reference sites. The annual changes in invertebrate community may have also been a result of natural variability.

The chemical water quality was good at NESHP01. There was only one guideline for the protection of aquatic life not met, zinc (8.1 µg/L in September 2015). However, the exceedance may not be cause for concern, as it was only slightly higher than the long term guideline (7.5 µg/L), the guideline was met in 2016 (5.4 µg/L), and both values were considerably lower than the short term (maximum) guideline of 33 µg/L.

Monthly average water temperatures at NESHP01 did not show a notable difference amongst the years sampled. Water temperature guidelines for Bull Trout rearing, spawning, and incubating were often not met. Bull Trout are known to use upstream areas where more suitable water temperatures exist in the watershed (Decker 2010). Instantaneous streamflow data indicated similar hydrologic conditions amongst the three years sampled.

The three-year baseline monitoring program provides some understanding of natural conditions and variation. This baseline will be valuable to help assess changes over time.

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1 Introduction

Community-based water quality monitoring in the Columbia River Basin plays an important role in gathering baseline information to understand watershed function and potential influences of concern. This information can help inform management decisions, to ensure that aquatic ecosystems are preserved, which in turn will contribute to maintaining sustainable communities. It is imperative that current and future water quality and quantity concerns be assessed in the Columbia River Basin as environmental change poses substantial risk to ecosystem and societal health. Changes in land use and climate change have the potential to substantially alter water quality and quantity in the Columbia River Basin (Carver 2017). Current and future reductions in snow accumulation (Barnett et al. 2008) and glacial ice (Jost et al. 2012) have been shown to result in reduced water supply in the Columbia Basin, particularly for the low flow summer periods (Burger et al. 2011). Lower stream flow leads to a reduced ability for streams to dilute pollution, potentially resulting in substantial water quality issues. In addition to climate change, the diverse land uses of the Columbia River Basin, including: recreational and industrial development, stream flow regulation, municipal and industrial waste water, and non-point source pollution present a challenge for water quality management.

A first step in addressing present and future water quality and quantity issues is developing community awareness and involvement. The Columbia Basin Water Quality Monitoring Project (CBWQ) had its beginnings at a 2005 Watershed Stewardship Symposium sponsored by Columbia Basin Trust (CBT), where the Columbia Basin Watershed Network was born. A key resolution from that meeting was for CBT to build capacity for watershed groups to monitor water quality in their watersheds. Consequently, on a sunny weekend in June 2006, representatives from watershed groups from across the Columbia Basin met in Kimberley to attend a monitoring workshop with Dr. Hans Schreier and Dr. Ken Hall from the University of British Columbia (UBC). At the end of the workshop Mainstreams agreed to coordinate the Columbia Basin Water Quality Monitoring Project and four groups began water quality monitoring in September 2007 with the following goals:

1. Develop a science-based model for community-based water quality monitoring;
2. Establish online accessibility to water quality data; and,
3. Link the monitoring project with community awareness activities.

All told, twelve watershed stewardship groups have participated in the project. Data collected by these groups can be found at the CBWQ website www.cbwq.ca.

As a part of the CBWQ, the Salmo Watershed Streemkeepers Society (SWSS) conducted water quality monitoring in Sheep Creek from 2015 to 2017. The following four components were monitored: benthic macro-invertebrate community using Canadian Aquatic Biomonitoring Network (CABIN) methods, water quality, water temperature, and hydrologic characteristics (i.e., velocity and streamflow). This report presents the data, result analyses, relates biological results to physical monitoring findings, and provides recommendations for future stream health monitoring.

In 2014, in addition to monitoring NESHP01, monitoring took place at NESHP02 and NESHP03 on Sheep Creek. The sites are located at:

NESHP01	49.14128 N	-117.25862 W
NESHP02	49.13353 N	-117.16692 W
NESHP03	49.15972 N	-117.09243 W

Water chemistry, temperature and CABIN monitoring were conducted at all three sites in 2014. This year of study was conducted outside of the regular CBWQ; however, this data can be found at www.cbwq.ca.

Ongoing funding from CBT has been and continues to be key to keeping this unique project, guided and administered by community watershed groups, operating until June 2018.

1.1 Sheep Creek background

Sheep Creek, is located near the village municipality of Salmo, in the West Kootenay Region of BC (Figure 1). Sheep Creek was primarily chosen for monitoring, as it is the Salmo River Watershed's most biologically active tributary system for Bull Trout spawning and rearing (Nellestijn 2015) and an important breeding stream for Harlequin Ducks (Pers Comm. M. Machmer), a population of increasing concern (provincially ranked as S4B,S3N[1] (BC Conservation Data Centre [BC CDC] 2018). Sheep Creek has been disturbed historically through mining and deforestation, activities that appear to be gaining momentum again in the watershed. There was also a regional landfill (decommissioned in 2015) on the south side of the Sheep Creek watershed that may contribute leachate impacts to the creek. Finally the Sheep Creek watershed is becoming an increasing attractive location for motorized recreation.

Monitoring under the CBWQ program occurred in 2015 to 2017 at site NESHP01. NESHP01 was selected because it was near the mouth of the creek and downstream of activities/developments that could influence creek health. The water quality monitoring site on Sheep Creek has extensive riffle habitat, is easily accessible from the road, and has a permanent bridge that allows for consistent staff gauge measurements to be taken (Figure 2).

The following overview description of Sheep Creek comes from the Sheep Creek Nutrient Addition Study (Decker 2010):

> Sheep Creek comprises 11% of the total Salmo River Watershed area. The mainstem of Sheep Creek is approximately 18 km long. Spring freshet in Salmo River tributaries normally peaks in late May, with the highest flows occurring each year between April and July. Channel gradient, estimated from 1:50,000 topographic maps, ranges from 2% to 6% in Sheep Creek. A large debris jam restricts Bull Trout access upstream of 12.2 km. Upper portions are highly entrenched and heavily shaded by a mature second-growth conifer forest.

The following biogeoclimatic zones occur in the watershed (MacKillop and Ehman 2016):

- Low elevation / valley areas: West Kootenay Dry Warm Interior Cedar – Hemlock (ICHdw1);
- Mid elevation areas: Ymir Moist Warm Interior Cedar – Hemlock (ICHmw4);
- High elevation areas: Salmo Wet Hot Engelmann Spruce – Subalpine Fir (ESSFwh3); and,
- Along ridge lines: Ymir Wet Mild Engelmann Spruce – Subalpine Fir (ESSwm3).

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[1] 3 = special concern, vulnerable to extirpation or extinction, 4 = apparently secure (BC CDC 2018)

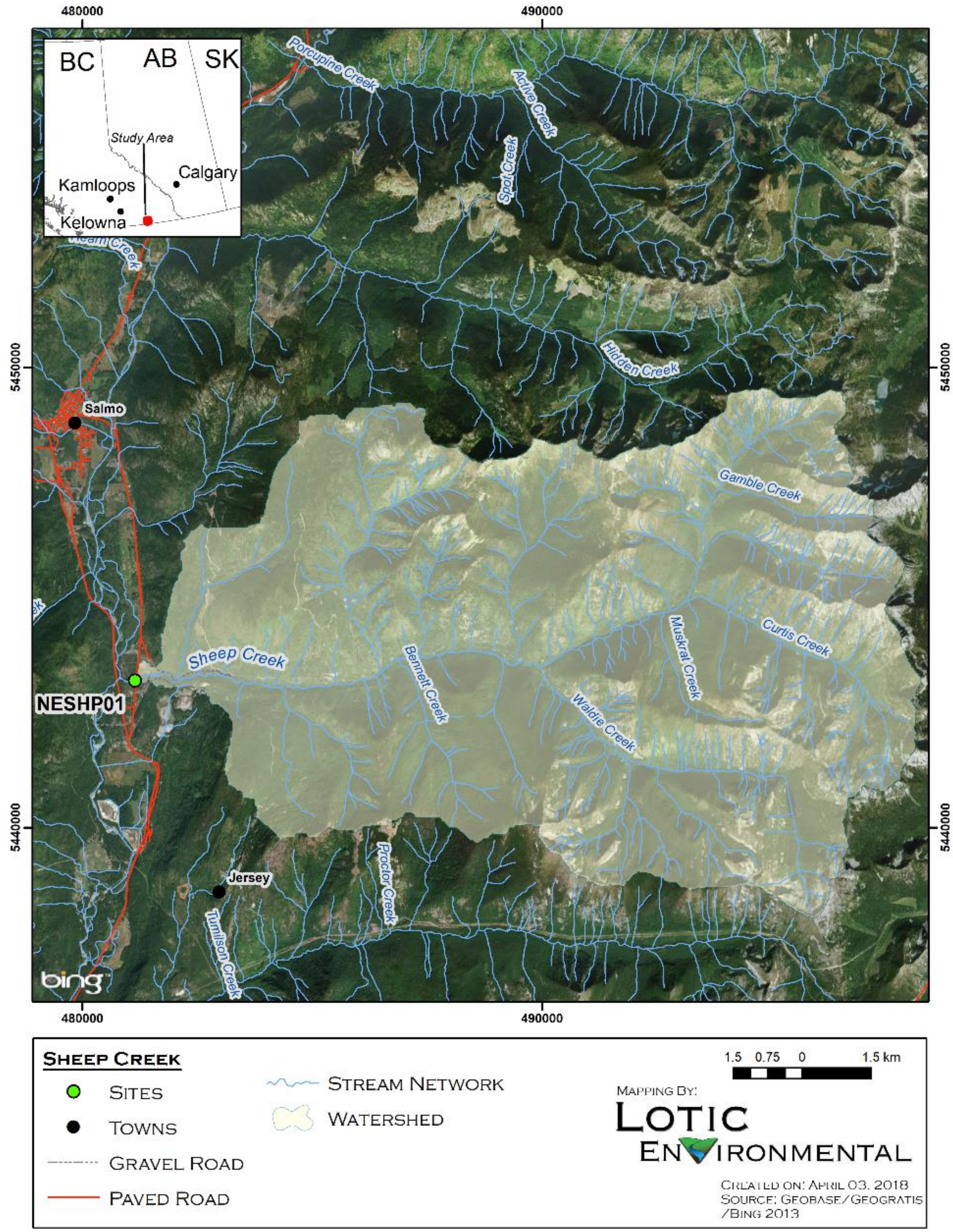

Figure 1. Sheep Creek monitoring location

Figure 2. Downstream view of site NESHP01, Sept 23, 2015.

Land uses

Mining was the primary historic land use, with gold, lead and zinc targets in this area. As many as 3,000 people lived in the Sheep Creek Watershed during the peak mining era from the early 1900's to the early 1940's and 50's. The population began to diminish in the 1950s. Approximately 320 km of underground shafts and drifts remain in the Sheep Creek Watershed, which has likely disturbed the hydrology. As well, approximately 6 hectares of creekside abandoned mine tailings exist, and these likely continue to impact water quality (Heinbuck and Nellestijn 2000). Stamp mills, support beams, and structures related to large-scale mining practices and wood powered steam driven machinery, resulted in large-scale deforestation throughout the watershed. A significant portion of the Sheep Creek Watershed is privately owned due to historic mining activities. Mining claims also cover significant sections of the watershed. Mining efforts continue in the Sheep Creek Watershed, mostly at an exploratory level, but there is potential for mining activities to increase to full operation again.

BC Timber Sales has increased the extent of their forestry activities in the Salmo River Watershed, including the Sheep Creek Watershed. The Salmo Watershed Streamkeepers Society is in on-going conversation with forestry leaders to reduce the accumulated impacts of deforestation, including restricting logging within Community Watersheds.

Fish community

The fish community in the Sheep Creek Watershed is comprised of five native and one non-native species (Table 1). Two of these fish species are of conservation concern. Bull Trout (interior lineage*)* and Westslope Cutthroat Trout are recognized as a species of Special Concern in BC and by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC; BC CDC 2018). Additionally, Westslope Cutthroat Trout are listed as a species of Special Concern throughout their range in British Columbia under the federal Species at Risk Act (BC CDC 2018).

Table 1. Fish species historically documented in Sheep Creek (Source: BC MoE 2018a)

Species - common name	Scientific name
Native species	
Bull Trout	*Salvelinus confluentus*
Westslope Cutthroat Trout	*Oncorhynchus clarkii lewisi*
Rainbow Trout	*Oncorhynchus mykiss*
Slimy Sculpin	*Cottus cognatus*
Longnose Dace	*Rhinichthys cataractae*
Non – native (naturalized)	
Eastern Brook Trout	*S. fontinalis*

Wildlife

Knowledge of wildlife presence and use within the Sheep Creek watershed is limited, therefore a combination of species lists from Steeger et al. (2003), and MacKillop and Ehman (2016) have been used as reference. These lists indicate four wildlife species of conservation concern may be found in the Sheep Creek Watershed:

Caribou (*Rangifer tarandus*)
- BC List: Red
- COSEWIC: Endangered
- Federal Species at Risk Act (SARA): 1 – Threatened

Grizzly Bear (*Ursus arctos*)
- BC List: Blue
- COSEWIC: Special Concern

Little Brown Myotis (*Myotis lucifugus*)
- COSEWIC: Endangered
- SARA: 1 – Endangered

Western Toad (*Anaxyrus boreas*)
- COSEWIC: Special Concern
- SARA: 1 – Special Concern

2 Methods

2.1 Data collection, data entry, and initial data presentation, completed by CBWQ stewardship group

Overall, data were collected following the CBWQ Operating Procedures (CBWQ 2012) and the CABIN Field Procedures for Wadeable Streams (Environment Canada 2012a). SWSS completed all field work, entered data into the standardized forms from Mainstreams, entered data onto the CABIN website (minus invertebrate data), and ran CABIN data analytics. Mainstreams Environmental Society downloaded data into standard forms, and conducted initial analyses (i.e., summary graphs, and CABIN site reports).

Benthic macro-invertebrates

CABIN sampling was conducted once a year in the fall. Invertebrate samples were analysed by Pina Viola Taxonomy following CABIN laboratory methods (Environment Canada 2012b). Data were entered into the online CABIN database and site reports were prepared using the CABIN analysis tools.

Water quality

Laboratory water quality analyses were completed by Maxxam Analytics (Burnaby, BC). In 2015 - 2017 NESHP01 was monitored (spring through fall). Generally, the following data were collected:

a. Monthly - total suspended solids (TSS; 2015-2016), orthophosphate, calcium (2017), and *in situ* (field measured) data. *In situ* data were dissolved oxygen (DO), water and air temperature, specific conductivity, pH, and turbidity.

b. Once each year (coinciding with CABIN monitoring) - in addition to the parameters above, inorganics (i.e., alkalinity, bicarbonate, carbonate, hydroxide), nitrate, nitrite, total nitrogen, sulphate, and metals were sampled.

c. Once in 2016 - a duplicate and a blank sample.

The transpose add-in tool created by Devin Cairns (Blue Geosimulation) was used to automate the addition of new water quality data from Maxxam into the existing CBWQ datasets. Using the add-in tool, users opened MS Excel files from Maxxam and chose which MS Excel file to append the new data into. The add-in matched parameter names in the files and converted units (e.g., between µm and mg), flagging the data cells that were successfully transferred.

Stream temperature

Hourly average stream temperature (°C) was measured using a HOBO Pro V2 temperature logger. Measurements were taken for the period September 25, 2014 – September 30, 2017. The data were downloaded into a spreadsheet, and descriptive statistics (daily maximum, minimum, and average) were calculated. Monthly averages were also calculated.

Hydrometric data

From spring through fall 2015 - 2017, monthly streamflow and velocity data were collected. Velocity is the speed of water and is measured as a unit of distance per time (m/s). Streamflow, also known as discharge, is a measure of the volume of water moving through a stream channel in a given amount of time (m^3/s).

Depth (m) and velocity were measured using a Swoffer 3000 flow meter. Measurements were collected at regular length intervals across the stream. Streamflow was calculated using Equation 1, where the Wetted Stream Width (m) and Average Depth (m) were determined in the stream profile.

Equation 1: Streamflow (Q)

$$\mathrm{Q} = \sum (d_1 - d_0) w_1 v_1 + \cdots + (d_n - d_{n-1}) w_n v_n$$

Where, Q is discharge (m^3/s)
d is distance from shore (m)
w is water depth (m)
v is velocity (m/s)

2.2 Analysis overview

Following the data collection and preparation described above completed by the CBWQ, Lotic Environmental Ltd. completed analyses and reporting. This included completing a quality assurance/quality control review (QA/QC) of data, comparing results to applicable guidelines, interpreting results, and providing recommendations.

The Reference Condition Approach (RCA) in CABIN was used to determine the condition of the benthic macro-invertebrate community at the test site (as sampled by the CBWQ group), by comparing the test site results to a group of reference sites with similar environmental characteristics. The Analytical Tools function in the CABIN database was used to run four analyses to review invertebrate test site data (Steps 1a – 1d in Figure 3): BEnthic Assessment of SedimenT (BEAST), River Invertebrate Prediction and Classification System (RIVPACS), community composition metrics, and habitat metrics. Water quality (Step 2), stream temperature (Step 3) and hydrometric (Step 4) analyses followed to provide an overall understanding of stream condition.

The reference model used in the RCA analysis was the Preliminary Okanagan-Columbia Reference Model (2010) provided in the online CABIN database. Because the model was still considered preliminary, with some potential data gaps, caution was exercised when interpreting RCA results (obtained from Steps 1a to 1d). Furthermore, it was important that all subsequent analyses (Steps 2 – 4) were conducted.

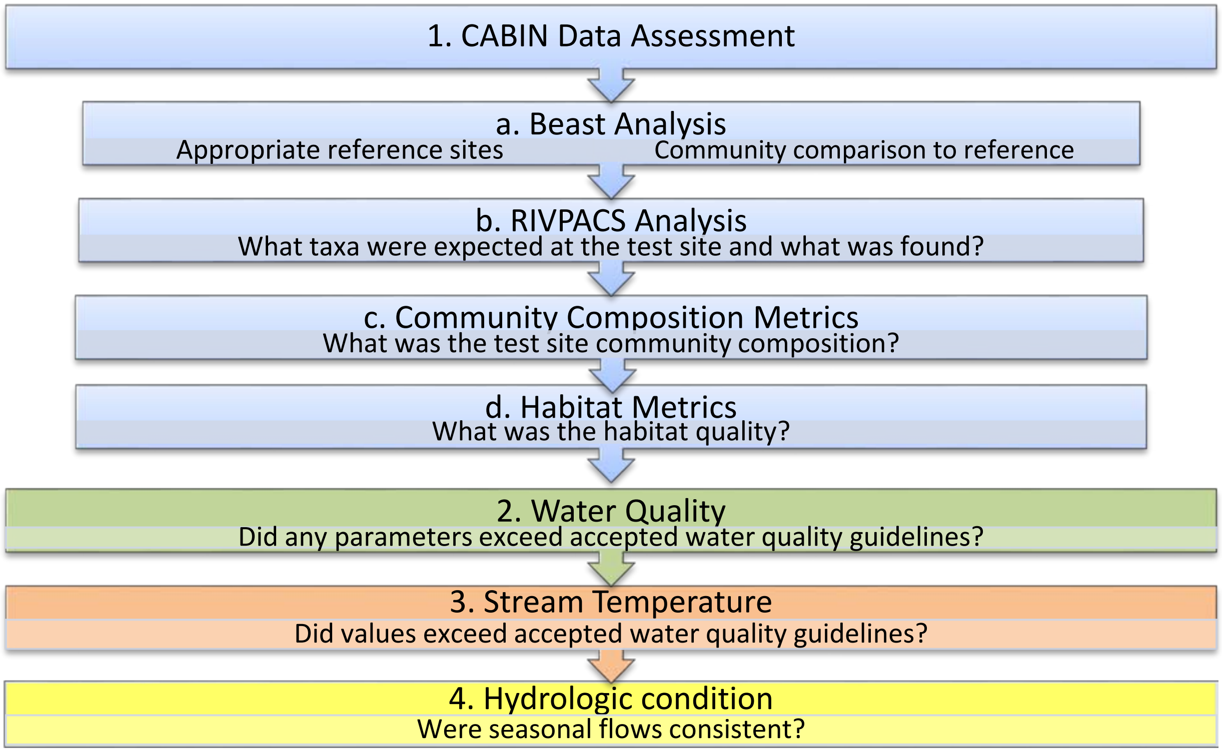

Figure 3. Stream condition analysis steps.

2.3 CABIN data analysis

Reference Condition Approach: BEAST analysis and site assessment

BEAST analysis was used to predict test sites to a reference group from the Preliminary Okanagan-Columbia Reference Model provided by Environment Canada through the CABIN database. BEAST used a classification analysis that determined the probability of test site membership to a reference group based on habitat variables (Rosenberg *et al.* 1999). Habitat variables used to predict group membership in the Okanagan-Columbia reference model were latitude, longitude, percent area of watershed with a gradient <30%, percent area of watershed with permanent ice cover, and average channel depth.

CABIN model hybrid multi-dimensional scaling ordination assessment was then used to evaluate benthic community stress based on divergence from reference condition. This analysis placed test sites into assessment bands corresponding to a stress level ranging from unstressed to severely stressed. In the ordination assessment, sites that were unstressed fell within the 90% confidence ellipse around the cloud of reference sites, which means that their communities were similar or equivalent to reference (Rosenberg *et al.* 1999). Potentially stressed, stressed and severely stressed sites indicate mild divergence, divergence, or high divergence of the benthic community from reference condition (Rosenberg *et al.* 1999).

RIVPACS analysis

RIVPACS ratios were calculated in the Analytical tools section of the CABIN database. RIVPACS analysis relied on presence/absence data for individual taxa. The RIVPACS ratio determined the ratio of observed taxa at test sites to taxa expected to be present at the test site based on their presence at reference sites. A RIVPACS ratio close to 1.00 indicated that a site was in good condition, as all taxa expected to be present were found at the test site. A RIVPACS ratio >1.00 could indicate community enrichment, while a ratio <1.00 could indicate that the benthic community was in poor condition.

Community composition metrics

Benthic community composition metrics were calculated in the CABIN database using the Metrics section of the Analytical Tools menu. A collection of relevant measures of community richness, abundance, diversity, and composition were selected to describe the test site communities. Using metrics, indicator attributes were used to interpret the response to environmental disturbances. Metrics are complimentary to an RCA analysis.

2.4 Water quality data analysis

Water quality QA/QC

Raw data were first subjected to a quality control evaluation to assess the accuracy and precision of the laboratory and field methods. For all water samples analysed, the laboratory assessed accuracy through the use of matrix spike, spiked blank, and method blank samples. As well, the laboratory measured precision through duplicate sample analysis. As per standard practice, all laboratory quality control results were reviewed and confirmed to meet standard criteria prior to proceeding with processing of field samples (Maxxam 2012).

Field duplicates were submitted to the laboratory to measure both field sampling error plus local environmental variance. Duplicate review was based on relative percent difference (RPD) as determined by Equation 2. For duplicate values at or greater than five times the Reportable Detection Limit (RDL), RPD values >50% indicated a problem, most likely either contamination or lack of sample representativeness (BC MoE 2003). Where RPD values were greater than 50%, the source of the problem was determined, and the impact upon the sample data ascertained (BC MoE 2003). If data were found to be within acceptable ranges, subsequent analyses included only the first of the duplicate samples.

Equation 2: Duplicate sample quality control

Relative Percent Difference = (Absolute difference of duplicate 1 and 2/average of duplicate 1 and 2)*100

$$\text{RPD} = \left(\frac{\text{Duplicate 1} - \text{Duplicate 2}}{(\text{Duplicate 1} + \text{Duplicate 2})/2} \right) \times 100$$

Field blank data were collected to monitor possible contamination prior to receipt at the laboratory. Field blanks were collected using laboratory issued de-ionized water. Field blank results were analysed using Equation 3. Field blank values that were 2 times greater than the reportable detection limit were considered levels of alert (Maxxam 2012, Horvath pers. comm.). Field blank values that exceeded the alert level were reviewed in more detail to identify the potential source(s) for contamination; additionally, other data collected on that day were compared to historical data to identify if there were anomalies possibly related to contamination.

Equation 3: Field Blank sample quality control

$$\text{Blank x difference} = \frac{\text{Field Blank Value}}{\text{Reportable Detection Limit (RDL)}}$$

Guideline review

A guideline is a maximum and/or a minimum value for a characteristic of water, which in order to prevent specified detrimental effects from occurring, should not be exceeded (BC MoE 2018). Water quality results were compared to the applicable provincial and federal guidelines for the protection of aquatic life and drinking water. Exceedances of guidelines were flagged to provide an understanding of the potential impacts to aquatic life or drinking water.

When there was more than one guideline for a parameter, the following hierarchy was applied to determine the guideline that would apply (BC MoE 2016):

a. BC Approved Water Quality Guidelines (BC MoE 2018b)
b. BC Working Water Quality Guidelines (BC MoE 2017)
c. The Canadian Environmental Quality Guidelines (Canadian Council of Ministers of the Environment [CCME] 2017), or Health Canada (2017).

When both long-term and short-term exposure guidelines were available, the long-term guideline was used in the review, since sampling was assumed to have occurred under ‘normal’ conditions.

2.5 Stream temperature analysis

Stream temperature statistics (daily maximum, minimum, and average) were graphed. The results were reviewed against the BC stream temperature guidelines for the protection of aquatic life and drinking water that were most applicable to the monitored site. The aquatic life guidelines are dependent on the fish species (mostly salmonids) found in the stream for different life stages (rearing, spawning, and incubation) (BC MoE 2018b).

2.6 Hydrometric data analysis

Hydrometric data were reviewed for consistency and anomalies. Streamflow results were graphed, with seasonal patterns qualitatively compared among the years.

3 Results

3.1 CABIN results

Reference Condition Approach: BEAST analysis and site assessment

For NESP01, CABIN BEAST analysis determined the highest probability of reference group membership was to Group 4 in all years (Table 2). The CABIN results were thus compared with Reference Group 4, which includes 12 streams, mostly from the Columbia Mountain and Highlands Ecoregion, with an average channel depth of 23.6 ± 11.1 cm. The test site’s average depth ranged from 22.3 and 25.3 cm, and was thus within the Reference Group mean. A comparison of other individual test site habitat attributes with the reference model means, and the ordination plots are included in the Site Assessment Reports (Appendix A). The CABIN model assessed NESHP01 as stressed in 2015, and potentially stressed in 2016 and 2017.

Table 2. CABIN model assessment of the test site against reference condition as defined by the Preliminary Okanagan-Columbia Reference Model; assessment, prediction of reference group and probability of group membership.

Site	2015	2016	2017
NESHP01	**Stressed** Group 4; 81.2%	**Potentially stressed** Group 4; 82.0%	**Potentially stressed** Group 4; 81.9%

RIVPACS analysis

The RIVPACS ratio at NESHP01 was lowest in 2015 (0.70), and highest in 2016 (0.87) (Table 3). The ratios corresponded with the numbers of families of taxa not present at the test site that were expected based on the reference group mean. Specifically, 2015 had the most taxa not present, 4 families, compared to 2016 and 2017 that had 2 to 3 families absent, respectively. The results support the model results above, indicating an improvement in the invertebrate community in 2016 and 2017, compared to 2015.

Table 3. RIVPACS Observed:Expected Ratios of taxa at test sites. Taxa listed had a probability of occurrence >0.70 at reference sites and were not observed at the test site. Condition indicated as shaded background*.

Site	2015	2016	2017
NESHP01	0.70 Capniidae, Nemouridae, Perlidae, Taeniopterygidae	0.87 Perlidae, Taeniopterygidae	0.79 Perlidae, Perlodidae, Taeniopterygidae

***CABIN model condition:** unstressed, potentially stressed, stressed, severely stressed.

Community composition metrics

Key metrics that were reviewed in detail (Table 4) include: total abundance; percent composition of Ephemeroptera (mayfly), Plecoptera (stonefly), and Trichoptera (caddisfly) orders (EPT); percent composition of Chironomidae (non-biting midges) taxa; percent composition of the two dominant taxa; and total number of taxa.

Table 4. Benthic macro-invertebrate community composition metrics measured in 3 min kicknet samples at NESHP01, 2015-2017. Condition indicated as shaded background*

Metric	Reference Group 4 (mean ± std dev)	NGMAT01		
		2015	**2016**	**2017**
Total abundance	587 ± 299.1	3150.0	4725.0	4712.5
% EPT taxa	87.7 ± 7.4	44.8	55.3	27.4
% Chironomidae	7.4 ± 6.4	32.7	21.9	47.6
% of 2 dominant taxa	57.9 ± 14.2	43.7	43.3	59.1
Total number of taxa	19.3 ± 3.7	27	28	25

***CABIN model condition:** unstressed, potentially stressed, stressed, severely stressed.

Total abundance of organisms found at the test site can be influenced by many factors including type of stress and the organisms involved (Rosenberg and Resh 1984). Abundance may increase due to nutrient enrichment but decrease in response to toxic effects such as metals contamination or changes in pH, conductivity and dissolved oxygen (Environment Canada 2012c). Total abundance at NESHP01 was higher than the reference group mean (587 ± 299.1 organisms) in all years sampled. The 2015 value of 3150 organisms was closest to the reference group mean, indicating that this metric was not a particular concern.

The percent of the community made up by individuals of any taxon, either at the family or order level, will vary depending on the taxon's tolerance to pollution, feeding strategy and habitat requirements (Rosenberg and Resh 1984). EPT orders of insects are typically indicators of good water quality. In all years at NESHP01, percent EPT was lower than the reference group mean (87.7 ± 7.4%). Percent EPT in 2017 (27.4%) was the lowest of all years monitored, further indicating that 2015 did not necessarily have a poorer condition relative to the other years sampled. Conversely, Chironomidae (non-biting midges), are generally tolerant of pollution. In all years percent Chironomidae was higher than the reference mean (7.4 ± 6.4 %). Again the 2015 value (43.7%) was not the poorest, 2017 was highest (47.6%).

Relative occurrence of the two most abundant taxon is a metric that can relate to impacted streams, since as diversity declines, a few taxa end up dominating the community. Opportunistic taxa that are less particular about where they live replace taxa that require special foods or particular types of physical habitat (Environment Canada 2012c). At NESHP01, the percent of two dominant taxa were within the reference group mean (57.9 ± 14.2 %) in all years but 2016 (43.3 %).

Taxa richness is the total number of taxa present for a given taxonomic level. There is usually a decrease of intolerant taxa and an increase of tolerant taxa with disturbance (Environment Canada 2012c). However, overall biodiversity of a stream typically declines with disturbance (Environment Canada 2012c). Taxa richness ranged from 25-27 at the test site over the three years, which were higher than the reference group mean (19.3 ± 3.7 taxa).

Habitat Conditions

Key physical habitat conditions that could influence benthic macro-invertebrate community health were provided for comparison amongst the sampling years (Table 5). Average velocity in 2015 (0.11 m/s), was a characteristic that was lower than both the reference group mean (0.48 ± 0.22 cm), and the other years sampled (0.27 – 0.50 m/s). In 2015, percent gravel (13 %) was also outside the reference group mean (3 ± 3 %), and that of the other years (ranged from 9-1%). There were other habitat characteristics that were outside the reference group range in 2016 and 2017, which likely contributed to these sites being assessed as potentially stressed.

Table 5. Select physical habitat characteristics for the predicted reference group and NESHP01 during CABIN sampling.

Parameter	Reference group mean ± std dev	2015	2016	2017
Average depth (cm)	23.6 ± 11.1	22.3	25.8	25.3
Average velocity (m/s)	0.48 ± 0.22	0.11	0.50	0.27
% Cobble (6.4 - 25.6 cm)	51 ± 15	33	31	63
% Pebble (1.6 – 6.4 cm)	37 ± 20	41	41	29
% Gravel (0.2 – 1.6 cm)	3 ± 3	13	9	1
% Sand (0.1 – 0.2 cm)	0 ± 0	0	0	0
% silt and clay (<0.1 cm)	0 ± 0	6	8	0

Overall, there were several benthic macro-invertebrate community metrics that were outside of the range of the reference group mean, indicating why NESHP01 was not assessed to be unstressed in all years. Although assessed to be stressed in 2015, the metric results were similar to the other years, and were not necessarily worse. The 2015 results appeared to only have a poorer condition based on the RIVPACS assessment of fewer taxa present than were expected. The reasons for these outcomes was unconfirmed. General water quality was good; and water temperature, and stream flow were relatively stable in all years sampled. However, average velocity and percent gravel in 2015, were two habitat conditions that were different than both the reference group mean and the other years sampled. The cause for the stressed and potentially stressed outcomes may also be related to limitations of the reference group, as Reference Group 4 was only comprised of 12 comparable reference sites.

3.2 Water quality results

Water quality QA/QC

The relative percent difference for the 2016 parameters sampled in duplicate, indicated that all parameters were below the concern level of 50%, indicating a high degree of precision in data collection and lab procedures (Appendix B1). Also, all field blank parameters analyzed were below the alert level, indicating that the samples were contaminant free and analysed with precision.

Guideline review

Water quality results were generally good for the three sites. The turbidity stood out as indicating a stable environment, since values remained low (<2 NTU) even during the freshet. Water quality results met all non-metal parameter’s (Appendix B2), and all but one metal parameter’s (Appendix B3) guideline for the protection of aquatic life and/or drinking water guidelines. Exceedance details are as follows:

Total zinc: Zinc was 8.1 µg/L at NESHP01 on September 2015, exceeding the BC Approved guideline for the protection of aquatic life of 7.5 µg/L. The exceedance may not be cause for concern, as it was only slightly higher than the long term guideline, it was considerably lower than the short term (maximum) guideline of 33 µg/L, and the 2016 value (5.4 µg/L) met the guideline.

Zinc ranks fourth among metals of the world in annual consumption, and is found in an array of products (BC MoE 2018b). Zinc is an essential element in trace amounts for plants and animals, but can be toxic in high concentrations (BC MoE 2018b). Soluble or dissolved zinc is readily available for biological reactions and therefore considered most toxic (BC MoE 2018b). The zinc guideline may thus be interpreted in terms of the dissolved metal fraction when the total zinc concentration in the environment exceeds the guideline (BC MoE 2018b). For this reason, if there is a reason for ongoing concern, future sampling should include dissolved metals to confirm if there is a potential for impact on aquatic life.

3.3 Stream temperature results

Temperature plays an important role in many biological, chemical, and physical processes. The effects of temperature on aquatic organisms are listed in the technical appendix for the BC MoE approved water quality guideline (Oliver & Fidler 2001), with the following generally occurring in aquatic organisms as water temperatures increase:

- Increased cardiovascular and respiratory functions, which in turn may increase the uptake of chemical toxins.
- Increased oxygen demand, while the dissolved oxygen content of water decreases.
- Reduced ability to cope with swimming demands, which is compounded by biological stresses such as predation and disease.
- In waters where dissolved gases are supersaturated, elevated water temperatures may worsen the effects of gas bubble trauma in fish.

Monthly average water temperatures for the three years sampled at NESHP01 were not notably different between the years (Table 6); at least not in a manner that might explain why the benthic macro-invertebrate community was stressed in 2015 and potentially stressed in 2016 and 2017. Monitoring over a longer time period would be required to determine trends.

Table 6. Monthly average (Avg) and standard deviation (SD) in daily average stream temperature (°C) from 2014 – 2017 at NESHP01.

Month	2014		2015		2016		2017	
	Avg	SD	Avg	SD	Avg	SD	Avg	SD
January	-	-	1.17	0.78	1.77	0.84	0.77	0.88
February	-	-	2.57	0.85	2.59	0.69	1.00	0.82
March	-	-	3.37	1.24	3.75	0.50	2.79	0.84
April	-	-	4.53	0.75	5.69	0.29	4.42	0.48
May	-	-	6.58	1.00	9.29	0.50	5.26	0.59
June	-	-	7.14	2.58	9.29	1.40	7.78	1.46
July	-	-	13.98	2.60	12.55	1.47	13.19	1.46
August	-	-	13.80	1.27	13.47	0.82	13.65	0.83
September	10.39	0.62	9.74	1.29	9.35	0.81	10.56	1.97
October	7.55	1.05	7.30	1.55	5.98	1.21	-	-
November	2.55	2.47	2.79	1.85	5.01	0.97	-	-
December	1.66	1.19	1.67	1.05	1.01	1.09	-	-

*Data were collected for only part of the month

Because of Bull Trout's presence in Sheep Creek, stream temperature data were compared to the guidelines for Bull Trout. In general, summer stream temperatures regularly exceeded the optimal Bull Trout rearing temperature of 15ºC (Figure 4). These fish likely seek out deeper cooler waters than what this site offers during the warm summer months. The water temperatures also exceeded the optimal Westslope Cutthroat rearing temperature maximum (16 ºC) in the summer months.

Bull Trout spawning generally occurs from mid-September to late October and often is initiated when water temperatures drop below 9ºC (McPhail 2007). The maximum daily temperatures at NESHP01 exceeded the optimal spawning temperature guideline of 10ºC through September of all years. Bull Trout are known to use upstream areas where more suitable water temperatures exist in the watershed (Decker 2010). If spawning occurred near the monitoring site, it may occur in other locations, like where groundwater-surface water interactions are high (Baxter and Hauer 2000), as these areas provide relatively consistent year-round water temperatures (i.e., approximately 5ºC) (Meisner *et al.* 1988). Also, if spawning had occurred near the monitoring site, the minimum temperature guideline during egg incubation is 2ºC. Temperatures at NESHP01 were below the minimum guideline regularly in the winter. Again, this may be a site-specific condition related to the temperature logger location, and does not preclude the potential for successful Bull Trout incubation elsewhere in the creek, particularly in areas with groundwater upwelling.

The stream temperatures exceeded the drinking water temperature guideline of 15 ºC in the summer. The drinking water guideline is an aesthetic objective. Temperature indirectly affects health and aesthetics through impacts on disinfection, corrosion control and formation of biofilms in the distribution system (Health Canada 2017).

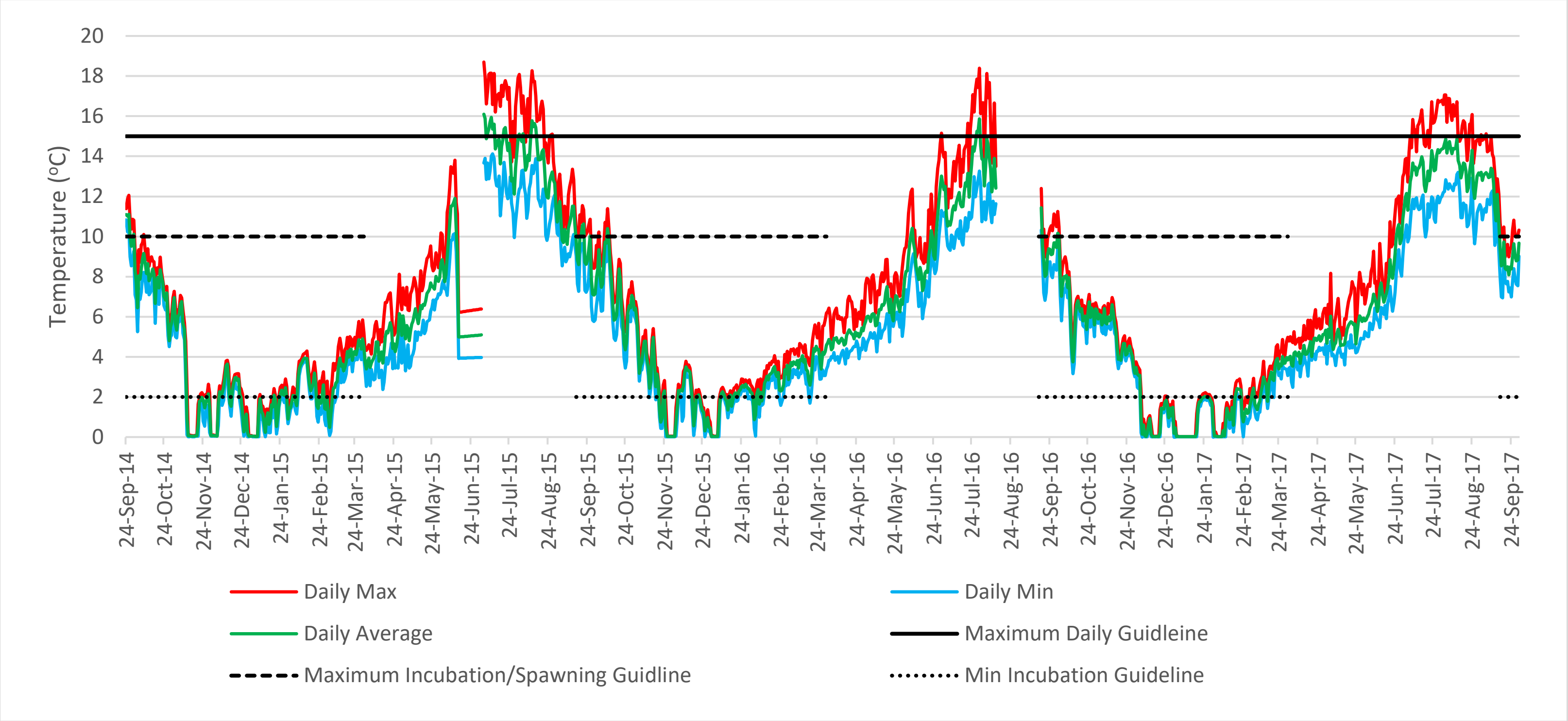

Figure 4. Daily average stream water temperatures in Sheep Creek (NESHP01) from September 24, 2015 to September 30, 2017 (note June14 to July 2, 2015 anomaly). The guidelines presented are for the protection of aquatic life for streams with Bull Trout present (BC MoE 2018b).

3.4 Hydrometric results

Streamflow plays an important role in stream ecosystems, influencing aquatic species distributions, water quality (especially turbidity, dissolved oxygen content and stream temperature), physical habitat (especially substrate characteristics), and fish life history traits (e.g., spawning time).

Instantaneous streamflow data were collected on a monthly basis from spring through fall in 2015-2017, with the exception of during the highest flows when it was unsafe to wade in the stream (Figure 5). Spring freshet (i.e., high flows due to snowmelt and/or heavy rain) started as early as April and extended through to June, with the maximum flow measured to be 8.45 m^3/s, on May 26, 2015. Flow decreased through the summer to a base level of approximately 1 m^3/s in all years sampled. It is normal for this base level to be maintained through the fall and winter in streams in the region. However, in 2016 a second peak of 4.56 m^3/s was evident on October 18. This was likely short-lived and due to a rain event.

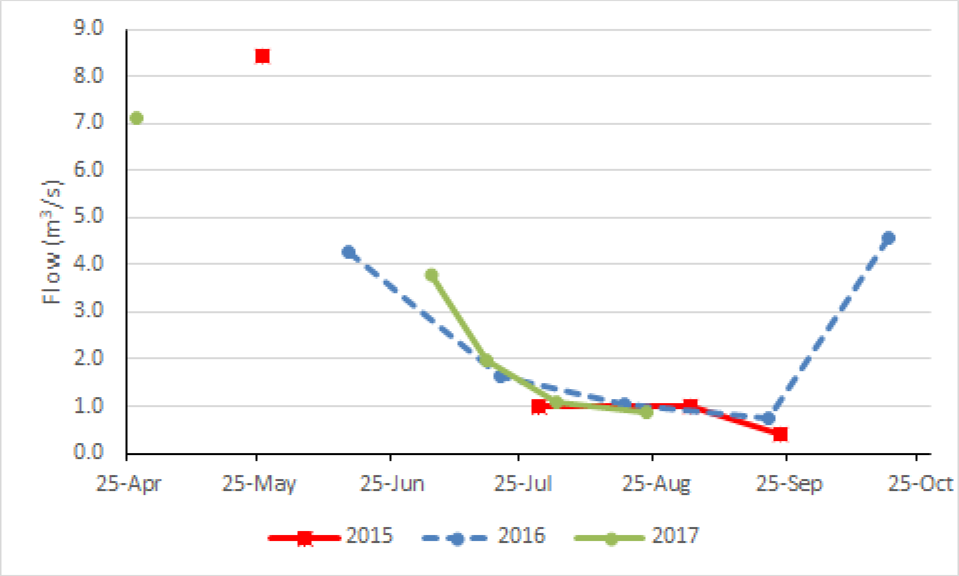

Figure 5. Streamflow in Sheep Creek (NESHP01), 2015 to 2017.

Provincial instream flow guidelines to protect aquatic ecosystems are usually set relative to natural historic flows of each stream. In order to develop these criteria, the annual hydrologic regime of the stream would need to be thoroughly described using a long-term dataset. This would be best achieved using continuous level loggers and developing water level streamflow relationships. Instantaneous streamflow measurements at one site cannot be directly related to fish habitat requirements, as water velocity will vary with channel morphology, and fish can swim to more suitable habitats within the stream. Nevertheless, the hydrometric data collected as part of this project are still important, as they can be used to evaluate changes in streamflow patterns with time.

4 Conclusions

The CABIN results indicated an improvement of the benthic invertebrate community during the study period, with a change from potentially stressed to unstressed. This was primarily evident through increases in percent EPT and Chironomidae. A cursory review of physical habitat metrics (such as velocity, and substrate), did not indicate any substantive changes between the years. Thus, the reason for the improvement is not evident; it could simply be the result of natural variation. The aquatic environment was healthy at Sheep Creek.

The CABIN model determined NESHP01 to be stressed in 2015, and potentially stressed in 2016 and 2017. These results were evident through several benthic macro-invertebrate community metrics that were outside of the range of the reference group mean. Relative to the reference group mean, at the test site total abundance was higher, proportion of EPT taxa was lower, proportion of Chironomidae was higher, and the proportion of two dominant taxa was higher. Although assessed to be stressed in 2015, the benthic macro-invertebrate community metric results were similar to the other years, and were not worse. The 2015 results appeared to only have a poorer condition based on fewer taxa being present than were expected based on the reference group mean.

The reasons for these benthic macro-invertebrate community outcomes appeared to most likely be related to habitat conditions. In 2015, average velocity and percent gravel were different than both the reference group mean and the other years sampled. The cause for the stressed and potentially stressed outcomes (amongst all years) may also be related to limitations of the reference group, as Reference Group 4 was only comprised of 12 comparable reference sites. The annual changes in invertebrate community may have also been a result of natural variability.

The chemical water quality was good at NESHP01. There was only one guideline for the protection of aquatic life not met, zinc (8.1 µg/L in September 2015). However, the exceedance may not be cause for concern, as it was only slightly higher than the long term guideline (7.5 µg/L), the guideline was met in 2016 (5.4 µg/L), and both values were considerably lower than the short term (maximum) guideline of 33 µg/L.

Monthly average water temperatures at NESHP01 did not show a notable difference amongst the years sampled. Water temperature guidelines for Bull Trout rearing, spawning, and incubating were often not met. However, it was unknown if Bull Trout utilize the temperature logger area, Based on temperatures results, they would likely seek suitable waters elsewhere in the watershed. Instantaneous streamflow data indicated a similar pattern amongst the three years sampled. These streamflow and temperature consistencies suggest Sheep Creek has a relatively stable source of year-round water.

5 Recommendations

The existing monitoring program was good for developing a baseline. Three years of monitoring provides a good picture of benthic macro-invertebrate health and water quality, assuming that the years captured were relatively representative of general conditions in the watershed and there were no changes in land-use during the years monitored. This information can be used in the future to identify if there are any water quality or invertebrate changes caused by increased disturbance. Obtaining data over a longer period, of course, would help provide a greater understanding of natural variability in the system over time. Now that baseline data have been attained, sampling should focus on locations experiencing ongoing development pressures.

There is a variety of other information, outside of the scope of this monitoring project that could be potentially collected to support a baseline understanding of a watershed. This may include, but not be limited to: 1) determining the hydrologic regime of the stream, using continuous level loggers, 2) conducting fish habitat assessments, and 3) conducting fish population assessments (e.g., composition, abundance, and use by life-history stage such as spawning). To determine the assessments required, the Salmo Watershed Streamkeepers Society should review existing data available and determine where there are information gaps needing to be filled.

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Appendix A. CABIN data

Appendix B. Water quality data

B1 – Water quality, QA/QC

B2 – Water quality, non-metals

B3 – Water quality, metals

Water quality legend:

Abbreviation/ symbol	**Description**
QA/QC table/criteria	Duplicate (or REP for replicate): review based on relative percent difference (RPD). Concern level if RPD >50% for general chemistry, if one of a set of duplicate values ≥ 5 times the RDL. Relative percent difference limit (RPD) = [(Result 2 - Result 1) / mean] x 100.
	Field Blank (BLK): recommended alert = 2X reporting limit (RDL)
	Grey highlight: exceedance of QA/QC criteria
1	Guidelines relevant to background not assessed, as they are intended to be monitored during construction/discharge activity.
AO	Aesthetic objective.
BC App	BC approved water quality guidelines (BC MoE 2018b).
BC Work	BC working water quality guidelines (BC MoE 2017).
CCME	Canadian environmental quality guidelines (CCME 2018).
HC	Health Canada drinking water guidelines (Health Canada 2017).
Red italic font	Field collected data.
Green highlight	Exceedance of guideline for the protection of aquatic life.
Blue highlight	Exceedance of drinking water guideline.