Campbell River Project Water Use Plan

Salmon River and Quinsam River Smolt and Spawner Abundance Assessments

Implementation Year 4

Reference: JHTMON-8

Year 4 Annual Monitoring Report

Study Period: March 1, 2017 to February 28, 2018

**Laich-Kwil-Tach Environmental Assessment Ltd. Partnership
and Ecofish Research Ltd.**

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JHTMON-8: Salmon River and Quinsam River Smolt and Spawner Abundance Assessments

Year 4 Annual Monitoring Report

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EXECUTIVE SUMMARY

Water Use Plans (WUPs) were developed for BC Hydro's hydroelectric facilities through a consultative process. As the Campbell River Water Use Plan process reached completion, a number of uncertainties remained with respect to the effects of BC Hydro operations on aquatic resources. The JHTMON-8 monitoring program focuses on the Salmon and Quinsam rivers, which have high fisheries values and include diversion structures that divert a portion of the total annual flow elsewhere in the Campbell River watershed for hydroelectric power generation.

The objective of JHTMON-8 is to reduce uncertainty about factors that limit fish abundance in the Salmon and Quinsam rivers. The JHTMON-8 management questions, hypotheses and current status are presented in Table i.

Table i. Status of JHTMON-8 objectives, management questions and hypotheses after Year 4.

Study Objective	Management Questions	Management Hypotheses	Year 4 (2017/2018) Status
Reduce uncertainty about factors that limit fish abundance in the Salmon and Quinsam rivers	1. What are the primary factors that limit fish abundance in the Campbell River System and how are these factors influenced by BC Hydro operations? 2. Have WUP-based operations changed the influence of these primary factors on fish abundance, allowing carrying capacity to increase? 3. If the expected gains in fish abundance have not been fully realized, what factors if any are masking the response and are they influenced by BC Hydro operations?	H_0*1: Annual population abundance does not vary with time (i.e., years) over the course of the Monitor* H_0*2: Annual population abundance is not correlated with annual habitat availability as measured by Weighted Usable Area (WUA)* H_0*3: Annual population abundance is not correlated with water quality* H_0*4: Annual population abundance is not correlated with the occurrence of flood events* H_0*5: Annual population abundance is not correlated with food availability as measured by aquatic invertebrate sampling* H_0*6: Annual smolt abundance is not correlated with the number of adult returns (Quinsam* R. *only)*	Year 4 of this ten-year study has been successfully completed. Where historical comparisons have been made, results show that H_0*1* can be rejected as population abundance varies among years. The study is on track to answer the management questions for the Quinsam River following analysis of data to be collected in future years. The Salmon River Diversion Dam was decommissioned in Year 4, which eliminated the potential for BC Hydro operations to affect fish abundance in the Salmon River in the future.

The three management questions in Table i will be addressed by testing six null hypotheses that are designed to test whether juvenile fish abundance varies among years (H_0*1*) and, if so, whether abundance is related to the following factors: habitat availability (H_0*2*), water quality (H_0*3*), floods (H_0*4*), food abundance (H_0*5*), and the abundance of returning adult fish (H_0*6*). Species of primary interest are Chinook Salmon (*Oncorhynchus tshawytscha*), Coho Salmon (*Oncorhynchus kisutch*) and steelhead (*Oncorhynchus mykiss*), although the study involves compiling adult escapement data for a wider range of anadromous salmonid species for both rivers, as well as collecting abundance data for life stages (predominantly outmigrating juveniles) of a range of species in the Quinsam River at the salmon counting fence.

Table ii below summarizes the field sampling programs scheduled to be undertaken annually as part of JHTMON-8. All sampling programs were successfully completed in Year 4 (2017).

Table ii. Summary of field sampling programs undertaken for JHTMON-8.

River	Sampling program	Lead organization[1]	Method	Timing
Salmon	Adult Steelhead survey	LKT	Snorkel surveys	March – April
	Juvenile Steelhead abundance	LKT	Closed site multi-pass electrofishing	September
	Juvenile Coho abundance	DFO/LKT	Closed site multi-pass netting	October
	Salmon escapement surveys	DFO	Various	September – November
	Water quality sampling	LKT	*In situ* and laboratory analysis	May – October
	Invertebrate sampling	LKT	Drift sampling	May – October
Quinsam	Quinsam River Hatchery juvenile downstream migration (various species)	DFO/LKT	Fish fence	March – June
	Salmon escapement surveys	DFO	Various	September – November
	Water quality sampling	LKT	*In situ* and laboratory analysis	May – November
	Invertebrate sampling	LKT	Drift sampling	May – October

[1] LKT, Laich-Kwil-Tach Environmental Assessment Ltd. Partnership; DFO, Fisheries and Oceans Canada

A milestone in 2017 was the decommissioning of the Salmon River Diversion Dam. This action was not scheduled at the outset of JHTMON-8 and therefore the initial Terms of Reference for JHTMON-8 (BC Hydro 2013) were based on the assumption that the facility would operate throughout the ten-year monitor. The removal of the Salmon River Diversion Dam now means that there is no mechanism for BC Hydro operations to affect fish abundance in the Salmon River watershed after Year 4 of JHTMON-8. Consequently, further monitoring activities on the Salmon River are no longer planned as part of JHTMON-8 following a change to the terms of reference for the study.

Fish abundance data so far support rejection of H_01 for at least some species; i.e., fish abundance measured in Year 1 to Year 4 has varied among years in cases where comparisons have been made. Key results from Year 4 were:

- Adult steelhead counts in the Salmon River were low in 2017 relative to historical counts. The total count for the primary index reach (Lower Index; 54 fish) was the sixth lowest count out of the 20 years sampled and was approximately equal to the 25th percentile of the dataset. The count for the reach that is surveyed upstream of the diversion dam (Rock Creek) was 0 fish. Year 4 was only the third year when no fish have been observed upstream of the diversion dam out of the 11 years when surveys have been undertaken. The reason for absence of adult steelhead observations upstream of the dam is uncertain; e.g., there are no obvious reasons related to sampling conditions, survey timing, or reported passage issues.
- Juvenile steelhead fry abundance in the Salmon River (12 FPU) was well below the mean for the sampling period (1998–2017; 50 FPU). This value was also lower than the 2014 (49 FPU) and 2016 (36 FPU) values, but similar to the value obtained in 2015 (11 FPU). There was a clear difference in density between sites upstream and downstream of the diversion. On average, mean observed fry density upstream of the diversion (23 FPU) was almost half of the value measured downstream of the diversion (41 FPU). Nonetheless, in contrast with adult count results described above, the presence of 0+ steelhead fry upstream of the

diversion dam means that steelhead successfully spawned upstream of the dam in Year 4, although the low abundance of juvenile fish is presumably related to low abundance of spawners. This indicates that that the steelhead fry habitat upstream of the diversion was below carrying capacity in Year 4.

- The range of juvenile Coho Salmon biomass estimated for the three sites downstream of the Salmon River Diversion (0.36 g/m^2 to 5.14 g/m^2) was comparable with Years 1 to 3. Estimated biomass values at the three sites upstream of the diversion were 0 g/m^2 to 2.3 g/m^2; values at these sites have varied considerably among years and sites.
- Salmon escapement data for 2016 (i.e., Year 3) show that Pacific Salmon escapement was generally low in the Salmon River: Chinook Salmon escapement (68) was the second lowest in 64 years and Coho Salmon escapement (276) was the sixth lowest in the 63-year record, although the low Coho Salmon count is likely to at least partly reflect that the early timing of the final inspection (September 15) Pink Salmon (6,704) and Sockeye Salmon (2) escapement in 2016 were similar to the historical medians (7,554 and 2, respectively).
- In the Quinsam River, escapement of Coho Salmon (7,397) in 2016 approximated the historical median (9,263). Chinook Salmon escapement in 2016 (6,978) was double the historical median (3,273). Pink Salmon escapement (51,032) in the Quinsam River in 2016 was slightly higher than the historical median (30,756).
- In the Quinsam River, total estimated outmigration of Pink Salmon fry in 2017 (Year 4) was 1.5 million. Outmigration of Coho Salmon in 2017 (24,920 wild smolts) was comparable with the previous 3 years of monitoring. Estimated total outmigration of wild Chinook Salmon fry and steelhead smolts in 2017 was 114,168 and 4,992 respectively; however, the accuracy of outmigration estimates for these species is expected to be relatively low because capture efficiency was based on mark-recapture experiments conducted with another species (Coho Salmon), and total counts were relatively low.

Water quality data collected at a single index site on both rivers were broadly consistent with results from previous years. Results so far show that both rivers are oligotrophic, with near-neutral pH and low turbidity during baseflow condition. Most water quality variables were in the optimum ranges for salmonid growth, although a notable exception was the occurrence in both rivers of high water temperatures during the growing season that exceed optimum ranges for several salmonid species and life stages. Also, dissolved oxygen (DO) concentrations were recorded on the Quinsam River that were below the provincial guideline for the protection of buried embryos/alevins. These measurements overlapped with reported incubation periods for resident Rainbow Trout and steelhead in May. Dissolved oxygen measured in September also indicated that the guideline was not met during the start of the Pink Salmon incubation period on the Quinsam River.

In Year 4 we also conducted evaluation of water quality data from Years 1 to 4 to examine how the data can be used to test H_03. Of the parameters measured in the water quality monitoring program, alkalinity or specific conductivity, DO, and water temperature (as mean weekly maximum temperature) may be the best candidates for use as predictor variables in statistical modelling to test $H_0$3. These parameters were selected because: they have been used previously in fish population modelling; they were outside of the ranges recommended by the BC Water Quality Guidelines for Aquatic Health (BC WQG-AL) for one or more life stages; there is inter-annual or inter-month variability in their concentrations or levels; and/or they can cause adverse effects on fish at the individual and population levels when measurements are outside of ranges recommended by the BC WQG-AL. Full analysis will be completed at the end of the ten-year monitor.

Invertebrate drift sampling was undertaken throughout the growing season at a single index site on both rivers. Invertebrate drift was sampled approximately monthly from May through October, with the exception of May when sampling was undertaken weekly. Invertebrate drift biomass declined during the growing season on both rivers; this result is generally consistent with previous years. Analysis of similarity in the invertebrate assemblages sampled to date shows consistent trends among years, with distinct communities present early in the growing season (May and June) relative to later in the growing season. Invertebrate drift biomass is generally lower in the Salmon River than the Quinsam River.

The report describes proposed analyses to be undertaken when further data are collected and additional tasks that will be conducted in Year 5. These include collating and digitizing historical data collected at the Quinsam Hatchery salmon counting fence since the 1970s, in accordance with a plan approved by BC Hydro in Year 4. This will provide an opportunity to substantially increase our ability to address the JHTMON-8 management questions for the Quinsam River by increasing the statistical power of the analysis.

TABLE OF CONTENTS

EXECUTIVE SUMMARY .... **III**

LIST OF FIGURES .... **IX**

LIST OF TABLES .... **XII**

LIST OF MAPS .... **XVI**

LIST OF APPENDICES .... **XVI**

1. INTRODUCTION **1**

1.1. BACKGROUND TO WATER USE PLANNING 1
1.2. BC HYDRO INFRASTRUCTURE, OPERATIONS AND THE MONITORING CONTEXT 1
  1.2.1. Overview *1*
  1.2.2. The Salmon River and Diversion *3*
  1.2.3. The Quinsam River and Diversion *5*
1.3. MANAGEMENT QUESTIONS AND HYPOTHESES 6
1.4. SCOPE OF THE JHTMON-8 STUDY 7
  1.4.1. Overview *7*
  1.4.2. Fish Population Assessments *8*
  1.4.3. Water Quality *9*
  1.4.4. Floods *9*
  1.4.5. Invertebrate Drift *10*

2. METHODS **11**

2.1. FISH POPULATION ASSESSMENTS 11
  2.1.1. Salmon River Adult Steelhead Survey *11*
  2.1.2. Salmon River Juvenile Steelhead Abundance *12*
  2.1.3. Salmon River Juvenile Coho Salmon Abundance *15*
  2.1.4. Salmon and Quinsam River Salmon Escapement *18*
  2.1.5. Quinsam River Hatchery Salmon Counting Fence Operations *19*
2.2. WATER QUALITY 21
  2.2.1. Water Chemistry *21*
  2.2.2. Water and Air Temperature *25*
2.3. HYDROLOGY 28
2.4. INVERTEBRATE DRIFT 30
  2.4.1. Sample Collection *30*
  2.4.2. Laboratory Processing *34*
  2.4.3. Data Analysis *34*

3. RESULTS **35**

3.1. FISH POPULATION ASSESSMENTS 35

3.1.1. Salmon River Adult Steelhead Survey 35
3.1.2. Salmon River Juvenile Steelhead Abundance 40
3.1.3. Salmon River Juvenile Coho Salmon Abundance 49
3.1.4. Salmon River and Quinsam River Salmon Escapement, 2016 53
3.1.5. Quinsam River Hatchery Salmon Counting Fence Operations 56
3.2. WATER QUALITY 59
3.2.1. Year 1 to Year 3 Water Quality Data 59
3.2.2. Water Chemistry 59
3.2.3. Water and Air Temperature Monitoring 69
3.2.4. Interim Evaluation of Potential to Incorporate Water Quality Data into Analysis.. 89
3.3. HYDROLOGY 99
3.4. INVERTEBRATE DRIFT 101
3.4.1. Salmon River Invertebrate Drift 101
3.4.2. Quinsam River Invertebrate Drift 107
3.4.3. Comparison of kick net and drift net sampling methods 113
4. DISCUSSION 115
5. ADDITIONAL TASKS FOR YEAR 5 119
REFERENCES 121
PROJECT MAPS 128
APPENDICES 131

LIST OF FIGURES

Figure 1. View at the site of the former Salmon River Diversion Dam, September 29, 2017. 4

Figure 2. Effect-pathway diagram showing the context of the six hypotheses that the JHTMON-8 monitoring program sets out to address. 7

Figure 3. Establishing stop nets at SAM-BS06 (Big Tree Creek) juvenile Coho Sampling site on September 20, 2017. 17

Figure 4. View upstream from river left towards the salmon counting fence. Reproduced from Ewart and Kerr (2014). 21

Figure 5. Looking upstream to SAM-WQ on September 13, 2017. 22

Figure 6. Looking upstream to QUN-WQ on September 13, 2017. 23

Figure 7. View upstream towards SAM-IV, July 11, 2017. 33

Figure 8. View downstream from river right towards QUN-IV, May 10, 2017. 33

Figure 9. Instantaneous discharge measured at the WSC gauge upstream of the Salmon River Diversion (Map 2) during 2017 adult steelhead surveys (triangles). Data from WSC (2017). 37

Figure 10. Salmon River adult steelhead total counts and condition, 2017. Note that counts were conducted on different dates (Table 20). 39

Figure 11. Historical and 2017 adult steelhead counts for the Lower Index reach, Salmon River. Absence of bars for some years indicates that no survey was conducted. Historical data (pre-JHTMON-8) from Pellett (2013). Dashed horizontal lines denote percentiles. 39

Figure 12. Historical and 2017 adult steelhead counts for the Upper Index reach, Salmon River. All data relate to surveys undertaken in April. Dashed horizontal lines denote percentiles...40

Figure 13. Historical and 2017 adult steelhead counts for the Rock Creek index reach, Salmon River. Absence of bars for some years indicates that no survey was conducted, unless labelled ‘0’. Pre-JHTMON-8 data from Pellett (2013). 40

Figure 14. Fork length histogram for juvenile steelhead captured in the Salmon River watershed, September 2017. 42

Figure 15. Length at age of juvenile steelhead captured in the Salmon River watershed, September 2017. 43

Figure 16. Length-weight regression for juvenile steelhead (*n* = 336) captured in the Salmon River watershed, September 2017. 44

Figure 17. Geometric mean depth-velocity-adjusted-abundance of steelhead fry (fry per unit, FPU) sampled in the Salmon River watershed in 1998–2017. 45

Figure 18. Depth-velocity-adjusted steelhead fry abundance (fish per unit area; FPU) sampled at each site in the Salmon River watershed in 2017......46

Figure 19. Geometric mean depth-velocity-adjusted juvenile steelhead (all age classes) fish per unit area (FPU) at sites upstream and downstream of the Salmon River Diversion, 1998–2017. 48

Figure 20. Geometric mean annual juvenile steelhead fish per unit (FPU) vs. adult steelhead counts in the Lower Index reach during the previous year......49

Figure 21. Fork length-frequency histogram of juvenile Coho Salmon captured in the Salmon River watershed, 2017. 51

Figure 22. Estimated biomass of juvenile Coho Salmon (Aged 0+ and 1+) at all sites sampled in 2017. 52

Figure 23. Total estimated Juvenile Coho Salmon biomass for each site during Years 1 to 4 (2014 to 2017). 53

Figure 24. Salmon escapement for the Salmon River (1953–2016; DFO 2017). 54

Figure 25. Salmon escapement for the Quinsam River (1957–2016; DFO 2017). 55

Figure 26. Total estimated outmigration of priority species on the Quinsam River during Years 1–4 (2014–2017). Coho Salmon and steelhead were captured at the smolt stage and Chinook Salmon at the fry stage......58

Figure 27. Estimated survival of out-planted salmon raised at the hatchery, based on the proportion of out-planted fish estimated to outmigrate at the salmon counting fence. Outmigrating Chinook Salmon were out-planted during spring (May) of the same year; outmigrating Coho Salmon were out-planted the previous year. No Chinook Salmon were out-planted in 2014......59

Figure 28. Water temperature in the Salmon River (SAM-WQ) between May 2014 and October 2017. The gap in the records is due to missing TidbiTs......70

Figure 29. Rate of change in hourly water temperature in the Salmon River (SAM-WQ) from 2014 to 2017. Large dots indicate rates with magnitudes exceeding ±1°C/hr. Data gap between October 2014 and May 2015 is due to missing TidbiTs. 73

Figure 30. Air temperature at the Salmon River (SAM-AT) between May 2014 and October 2017.78

Figure 31. Relationship between the daily average water and air temperatures in the Salmon River (SAM-WQ) between May 2014 and October 2017......79

Figure 32. Water temperature in the Quinsam River (QUN-WQ) between May 2014 and October 2017. 80

Figure 33. Rate of change in hourly water temperature in the Quinsam River (QUN-WQ) from 2014 to 2017. Large dots indicate rates with magnitudes exceeding ±1°C/hr. 83

Figure 34. Air temperature at the Quinsam River (QUN-AT) between May 2014 and October 2017. 88

Figure 35. Relationship between daily average water and air temperature in the Quinsam River (QUN-AT) between May 2014 and October 2017. 89

Figure 36. Nitrate concentrations measured in the Salmon River (SAM-WQ) between 2014 and 2017. 91

Figure 37. Nitrate concentrations measured in the Quinsam River (QUN-WQ) between 2014 and 2017. 92

Figure 38. Alkalinity measured in the Salmon River (SAM-WQ) between 2014 and 2017.................94

Figure 39. Alkalinity measured in the Quinsam River (QUN-WQ) between 2014 and 2017. 95

Figure 40. Specific conductivity measured in the Salmon River (SAM-WQ) between 2014 and 2017. 95

Figure 41. Specific conductivity measured in the Quinsam River (QUN-WQ) between 2014 and 2017. 96

Figure 42. Dissolved oxygen concentrations measured in the Quinsam River (QUN-WQ) between 2014 and 2017, in comparison to the BC Water Quality Guideline for the Protection of Aquatic Life. 97

Figure 43. Discharge measured on the Salmon River upstream of Memekay River (Map 2) during 2014–2016. 99

Figure 44. Discharge measured on the Quinsam River upstream of Campbell River (Map 3) during 2014–2016. 100

Figure 45. Discharge measured on the Quinsam River at Argonaut Bridge (Map 3) during 2014–2016. 100

Figure 46. Salmon River mean invertebrate drift biomass (mg/m³) ± 1 standard deviation (SD). SD was only calculated for 2014, when five drift nets were analyzed separately per site. Sampling occurred weekly during one month each year. 104

Figure 47. Salmon River cluster analysis results on the Bray-Curtis similarity matrix, by date. 106

Figure 48. Salmon River non-metric, multi-dimensional scaling ordination plot by date. 107

Figure 49. Quinsam River mean invertebrate drift biomass (mg/m³) ± 1 standard deviation (SD). SD was only calculated for 2014, when five drift nets were analyzed separately per site. Sampling occurred weekly during one month each year. 110

Figure 50. Quinsam River cluster analysis results on the Bray-Curtis similarity matrix. 112

Figure 51. Quinsam River non-metric multi-dimensional scaling ordination plot by date. 113

LIST OF TABLES

Table i. Status of JHTMON-8 objectives, management questions and hypotheses after Year 4...iii

Table ii. Summary of field sampling programs undertaken for JHTMON-8. iv

Table 1. Salmon River maximum permitted down ramping rates (BC Hydro 2012). 4

Table 2. Salmon River maximum permitted diversion flows (BC Hydro 2012). 4

Table 3. Quinsam River maximum permitted down ramping rates (BC Hydro 2012). 5

Table 4. Minimum permitted discharge in the Quinsam River (BC Hydro 2012). 5

Table 5. Summary of field sampling programs undertaken for JHTMON-8. 7

Table 6. Variables measured during snorkel surveys of adult steelhead. 12

Table 7. Details of juvenile steelhead sampling sites in the Salmon River. 13

Table 8. Juvenile Coho Salmon sampling site details and correspondence with historical site names. 17

Table 9. Methods used during 2016 salmon spawner escapement counts on the Salmon River (DFO 2017). See Table 11 for descriptions of survey types. 18

Table 10. Methods used during 2016 salmon spawner escapement counts on the Quinsam River (DFO 2017). See Table 11 for descriptions of survey types. 18

Table 11. Summary of definitions of salmon spawner escapement estimate classification types reported in Table 9 and Table 10 (DFO 2017). 19

Table 12. Water quality index site details and sampling dates in Years 1 to 4. 22

Table 13. Water quality variables measured *in situ* and meters used for measurement in 2017. 24

Table 14. Variables analyzed in the laboratory by ALS Environmental and corresponding units and method detection limit (MDL). 24

Table 15. Parameters calculated based on water and air temperature data. 27

Table 16. Water temperature guidelines for the protection of freshwater aquatic life (Oliver and Fidler 2001). 28

Table 17. Hydrometric gauges maintained by Water Survey of Canada on the two study streams. See Map 2 and Map 3 for site locations. 29

Table 18. Hydrological metrics calculated for each study stream. 30

Table 19. Invertebrate drift sample site locations, sample timing, and sampling duration during 2017. 32

Table 20. Salmon River adult steelhead survey details and conditions, 2017. 38

Table 21. Salmon River snorkel survey observations, 2017. 38

Table 22. Habitat characteristics for juvenile steelhead abundance sampling sites in the Salmon River watershed, 2017. 41

Table 23. Sampling effort and catch summaries for juvenile steelhead sites sampled in the Salmon River watershed, September 2017. 41

Table 24. Summary of fork length, weight and condition of juvenile steelhead captured during electrofishing at 10 sites in the Salmon River watershed in 2017. 44

Table 25. Steelhead fry abundance and biomass results from electrofishing sites located upstream and downstream of the Salmon River Diversion, September 2017. 47

Table 26. Salmon River watershed juvenile Coho Salmon sampling site characteristics, 2017. 50

Table 27. Salmon River watershed juvenile Coho Salmon catch results, 2017. 51

Table 28. 2016 salmon escapement data for the Salmon and Quinsam rivers (DFO 2017). 54

Table 29. Summary of downstream migration data and total migration estimates from sampling at the Quinsam River Hatchery salmon counting fence, March 11 to June 15, 2017. 57

Table 30. Salmon River (SAM-WQ) general water quality variables measured *in situ* during Year 4 (2017). 63

Table 31. Salmon River (SAM-WQ) dissolved oxygen measured *in situ* during Year 4 (2017). 63

Table 32. Salmon River (SAM-WQ) general water quality variables measured at ALS labs during Year 4 (2017). 64

Table 33. Salmon River (SAM-WQ) nutrient concentrations measured at ALS labs during Year 4 (2017). 64

Table 34. Quinsam River (QUN-WQ) general water quality variables measured *in situ* during Year 4 (2017). 67

Table 35. Quinsam River (QUN-WQ) dissolved gases measured *in situ* during Year 4 (2017). 67

Table 36. Quinsam River (QUN-WQ) general water quality variables measured at ALS labs during Year 4 (2017). 68

Table 37. Quinsam River (QUN-WQ) nutrient concentrations measured at ALS labs during Year 4 (2017). 68

Table 38. Monthly water temperature statistics in the Salmon River (SAM-WQ) from 2014 to 2017. Statistics were not generated for months with less than 3 weeks of observations

and minimum temperatures are not shaded for years with missing data during fall/winter/spring. 71

Table 39. Summary of the number of exceedances of mean daily water temperature extremes (T_{water}>18°C, T_{water}>20°C, and T_{water}<1°C) in the Salmon River (SAM-WQ) from 2014 to 2017. 72

Table 40. Statistics for the hourly rates of change in water temperature at SAM-WQ in the Salmon River from 2014 to 2017. The frequency of rates of change exceeding a magnitude of 1°C/hr is also shown. 72

Table 41. The growing season and growing degree days at SAM-WQ in the Salmon River (2014 to 2017). 74

Table 42. Mean weekly maximum temperatures (MWMxT) in the Salmon River from 2014 to 2017 compared to optimum temperature ranges for fish species present. Periodicity information is from Burt (2010). 76

Table 43. Monthly air temperature at the Salmon River (SAM-AT) from 2014 to 2017. Statistics were not generated for months with less than 3 weeks of observations. 77

Table 44. Monthly water temperature in the Quinsam River (QUN-WQ) from 2014 to 2017. Statistics were not generated for months with less than 3 weeks of observations. Minimum temperatures are not shaded for 2014 as data were not collected during January to May. 81

Table 45. Summary of the number of exceedances of mean daily water temperature extremes (T_{water}>18°C, T_{water}>20°C, and T_{water}<1°C) in the Quinsam River at QUN-WQ from 2014 to 2017. 82

Table 46. Statistics for the hourly rates of change in water temperature at QUN-WQ in the Quinsam River. The frequency of rates of change exceeding a magnitude of 1°C/hr is also shown. 82

Table 47. The growing season and growing degree days at QUN-WQ in the Quinsam River (2014 to 2017). 83

Table 48. Mean weekly maximum temperatures (MWMxT) in the Quinsam River from 2014 to 2017 compared to optimum temperature ranges for fish species present. Periodicity information is from Burt (2003). 86

Table 49. Monthly air temperature statistics at the Quinsam River (QUN-AT) from 2014 to 2017. Statistics were not generated for months with less than 3 weeks of observations. 87

Table 50. Hydrological metrics calculated for 2014–2016. See Map 2 and Map 3 for hydrometric gauge locations. 101

Table 51. Salmon River invertebrate drift mean density, biomass, Simpson’s diversity index (family level), richness and CEFI. Each drift net was analyzed separately in 2014, while nets were combined into one sample in subsequent years. 103

Table 52. Salmon River: top five families contributing to invertebrate drift biomass. 105

Table 53. Quinsam River invertebrate drift mean density, biomass, Simpson’s diversity index (family level), richness and CEFI. Each drift net was analyzed separately in 2014, while nets were combined into one sample in subsequent years. 109

Table 54. Quinsam River: top five families contributing to invertebrate drift biomass. 111

Table 55. Contribution of invertebrate taxa to total biomass by habitat type in Year 2 (2015) and Year 4 (2017) (data were not collected in 2014 and 2016). 114

Table 56. Top five families contributing to invertebrate biomass collected from a drift net and kick net in a) Salmon River, and b) Quinsam River. 115

LIST OF MAPS

Map 1. Overview of the Salmon River and Quinsam River watersheds. 2
Map 2. Overview of the Salmon River watershed. 129
Map 3 Overview of the Quinsam River 130

LIST OF APPENDICES

Appendix A. Water Quality Guidelines, Typical Parameter Values, Previous Results, and Quality Control Results Summary

1. INTRODUCTION

1.1. Background to Water Use Planning

Water use planning exemplifies sustainable work in practice at BC Hydro. The goal is to provide a balance between the competing uses of water that include fish and wildlife, recreation, and power generation. Water Use Plans (WUPs) were developed for all of BC Hydro's hydroelectric facilities through a consultative process involving local stakeholders, government agencies and First Nations. The framework for water use planning requires that a WUP be reviewed on a periodic basis and there is expected to be monitoring to address outstanding management questions in the years following the implementation of a WUP.

As the Campbell River Water Use Plan process reached completion, a number of uncertainties remained with respect to the effects of BC Hydro operations on aquatic resources. A key question throughout the WUP process was "what limits fish abundance?" For example, are fish abundance and biomass limited by available habitat, food, environmental perturbations or ecological interactions? Answering this question is an important step to better understanding how BC Hydro operations in the watershed affect fisheries, and to effectively manage water uses to protect and enhance aquatic resources. To address this uncertainty, monitoring programs were designed to assess whether fish benefits are being realized under the WUP operating regime, and to evaluate whether limits to fish production could be improved by modifying operations in the future. The *Salmon River and Quinsam River Smolt and Spawner Abundance Assessments* (JHTMON-8) is part of the wider suite of monitoring studies of the Campbell River WUP. JHTMON-8 focuses on monitoring fish populations and environmental factors that may influence fish abundance in the Salmon and Quinsam rivers.

1.2. BC Hydro Infrastructure, Operations and the Monitoring Context

1.2.1. Overview

The Salmon and Quinsam rivers are both located to the west of the city of Campbell River on the east coast of Vancouver Island, British Columbia. Both the Salmon River and the Quinsam River diversion facilities have historically diverted a portion of water from the river mainstems to generate hydroelectricity downstream at Ladore and John Hart generation stations (Map 1). Details of the diversion infrastructure and operations are summarized below based on the Campbell River System WUP (BC Hydro 2012). In 2017, the Salmon River Diversion Dam was decommissioned and it therefore no longer diverts water from the river. Prior to this, the Salmon River Diversion facility was operational during JHTMON-8. The full suite of planned monitoring activities was undertaken in both rivers in 2017. Further monitoring is not planned on the Salmon River as part of JHTMON-8 following amendments made to the JHTMON-8 terms of reference (Murphy and Duncan 2018).

Project Overview

Legend

🟥 Dam

🟦 Stream

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 2 4 6 8 10 12 km

Scale: 1:300,000

NO.	DATE	REVISION	BY
1		2/26/2015 1230_SAM_QUN_Overview_Portrait_2015Feb25	CGA
2			
3			
4			
5			

Date Saved: 2/26/2015
Coordinate System: NAD 1983 UTM Zone 10N

ECOFISH RESEARCH

Map 1

Path: M:\Projects-Active\1230_JHTMON\MXD\Overview\1230_SAM_QUN_Overview_Portrait_2015Feb25.mxd

1.2.2. The Salmon River and Diversion

The Salmon River flows from headwaters in Strathcona Provincial Park in a general northwards direction to the ocean at Sayward. Major tributaries include Grilse Creek, the Memekay River and the White River, all of which drain the western side of the Salmon River watershed. The area of the watershed is approximately 1,300 km^2 and mean annual discharge (MAD) near the mouth is 63 m^3/s (Burt 2010). The Salmon River has high fisheries values and the river supports a range of salmonid and non-salmonid fish species, including those that are both anadromous and resident (Burt 2010). The Salmon River supports all five species of Pacific salmon (*Oncorhynchus* spp.) as well as both resident and anadromous Rainbow Trout (*Oncorhynchus mykiss*), Cutthroat Trout (*Oncorhynchus clarkii*) and Dolly Varden (*Salvelinus malama*). Lamprey (*Lampetra* spp.) and Sculpin (*Cottus* spp.) species are also present.

The Salmon River Diversion infrastructure was initially constructed in 1958. The diversion dam is a 69 m long rock-filled timber crib dam that diverts water into the Campbell River watershed. Water is diverted from the mainstem of the Salmon River via an intake channel, through a radial gate and into a concrete-lined canal that conveys water to Brewster Lake, which is upstream of Lower Campbell Lake Reservoir. Non-diverted water is returned to the mainstem downstream, either via the main spillway, an undersluice, a trimming weir, or the fishway.

Blasting was undertaken in 1975 and 1976 to remove a rock obstruction in a canyon at river km 38 that formed both a velocity and vertical obstruction to fish migrating upstream (Ptolemy *et al.* 1977 cited in Burt 2010). Subsequent surveys showed that juvenile steelhead were present upstream of the canyon where they were previously absent.

A fish (smolt) screen was installed in 1986 to prevent out-migrating smolts from being diverted into the Campbell River watershed. The fishway was installed in 1992 to aid upstream passage of fish past the diversion dam. Historically, there have been issues with the performance of both the fish screen and the fish way (Burt 2010). In summer 2017, BC Hydro decommissioned the diversion dam (Figure 1) and flow conditions in the river were unimpeded by the diversion infrastructure from September 10 onwards (Jay, pers. comm. 2018).

Prior to this, the Salmon River Diversion was operational in Year 1 to Year 3 of JHTMON-8. A total of 493.39 million m^3 was licensed to be diverted annually, and the 7.8 km diversion canal had a maximum design discharge capacity of 45 m^3/s. The Campbell River System WUP stipulates maximum down ramping rates for the Salmon River and the Diversion Canal (Table 1), maximum diversion flows to enhance fish screen efficiency (Table 2), and minimum flows that must be maintained in the Salmon River downstream of the diversion dam when sufficient flows are naturally available (4.0 m^3/s).

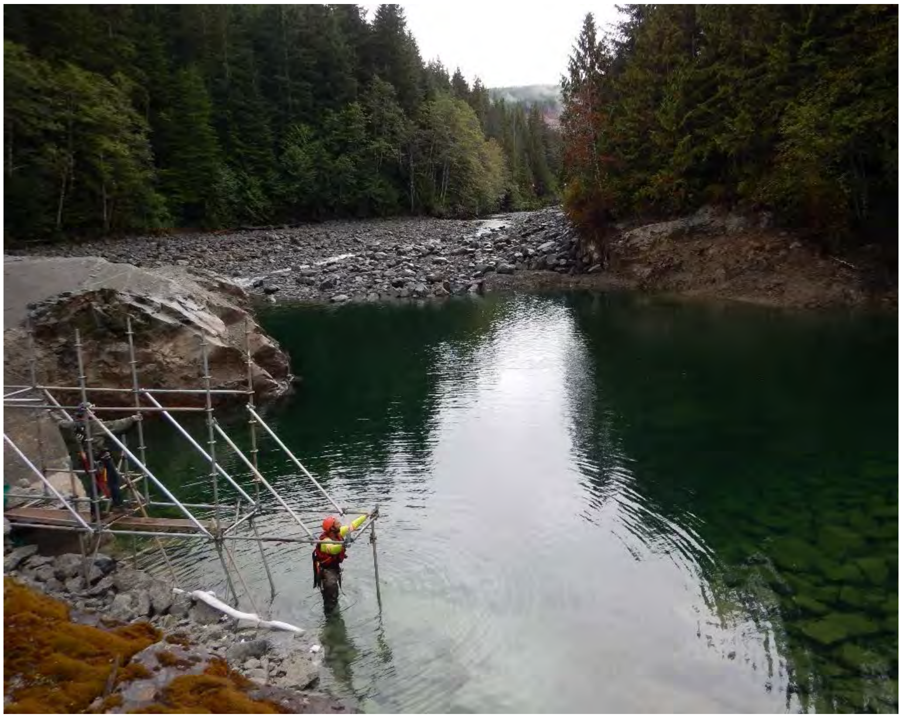
Table 1. Salmon River maximum permitted down ramping rates (BC Hydro 2012).

Stream	Salmon River discharge (m^3/s)	Salmon River maximum down ramping rate ($m^3/s/h$)
Salmon River	< 8.0	1.0
	8.0 to 10.0	2.0
	>10.0	10.0
Salmon River Diversion	0 to 43.0	10.0

Table 2. Salmon River maximum permitted diversion flows (BC Hydro 2012).

Date	Maximum diversion (m^3/s)	Fish screen operation
Jan 1 to Mar 31	43	N/A
Apr 1 to Dec 31	15	On

Figure 1. View at the site of the former Salmon River Diversion Dam, September 29, 2017.



1.2.3. The Quinsam River and Diversion

The Quinsam River is the only major tributary of the lower Campbell River, entering the Campbell River approximately 3.5 km upstream of the mouth. The Quinsam flows through a series of lakes and has a mainstem length of 45 km (excluding lakes), a watershed area of 283 km^2, and a mean annual discharge near the mouth of 8.5 m^3/s. The river has high fisheries values, supporting the same assemblage of native salmonid species that is found in the Salmon River (Burt 2003). The Quinsam River Hatchery was constructed in 1957 and is located 3.3 km upstream from the confluence with the Campbell River. The hatchery has been active in the watershed, augmenting populations of Chinook Salmon, Pink Salmon, Coho Salmon and Cutthroat Trout since 2014 (Year 1), with Chum Salmon and steelhead also released in previous years (DFO 2016). Smolt and fry life stages that are ready for downstream migration to the ocean are released from the hatchery during the spring. In addition, juvenile Coho Salmon, steelhead and (less frequently) Chinook Salmon have been outplanted to the upper watershed since 1978 to promote adult returns upstream of the hatchery (Burt 2003).

The Quinsam River Diversion comprises a small concrete gravity storage dam, a concrete gravity diversion dam, a concrete flume and the natural waterways that convey water to Lower Campbell Lake Reservoir. Non-diverted water is conveyed to the Quinsam River via an undersluice gate or the free crest weir. The dams were both constructed in 1957.

A total of 100 million m^3 is licensed to be diverted annually and the design capacity of the Quinsam River Diversion is 8.50 m^3/s. The WUP stipulates maximum down ramping rates (Table 3) and minimum flows (when naturally available) in the Quinsam River downstream of the diversion dam (Table 4).

Table 3. Quinsam River maximum permitted down ramping rates (BC Hydro 2012).

Stream	Discharge (m^3/s)	Maximum down ramping rate (m^3/s/h)
Quinsam River	> 4.0	8.5
	≤ 4.0	1.0
Quinsam Diversion	> 2.0	N/A
	≤ 2.0	1.0

Table 4. Minimum permitted discharge in the Quinsam River (BC Hydro 2012).

Date	Minimum discharge in Quinsam River (m^3/s)
Jan 1 to Apr 30	2.0
May 1 to Oct 31	1.0
Nov 1 to Dec 31	0.6

1.3. Management Questions and Hypotheses

The JHTMON-8 monitoring program aims to address the following three management questions:

1. What are the primary factors that limit fish abundance in the Campbell River System and how are these factors influenced by BC Hydro operations?
2. Have WUP-based operations changed the influence of these primary factors on fish abundance, allowing carrying capacity to increase?
3. If the expected gains in fish abundance have not been fully realized, what factors if any are masking the response and are they influenced by BC Hydro operations?

In addressing the questions, the monitoring program is designed to test the following five null hypotheses:

$H_0$1: Annual population abundance does not vary with time (i.e., years) over the course of the Monitor.

$H_0$2: Annual population abundance is not correlated with annual habitat availability as measured by Weighted Usable Area (WUA).

$H_0$3: Annual population abundance is not correlated with water quality.

$H_0$4: Annual population abundance is not correlated with the occurrence of flood events.

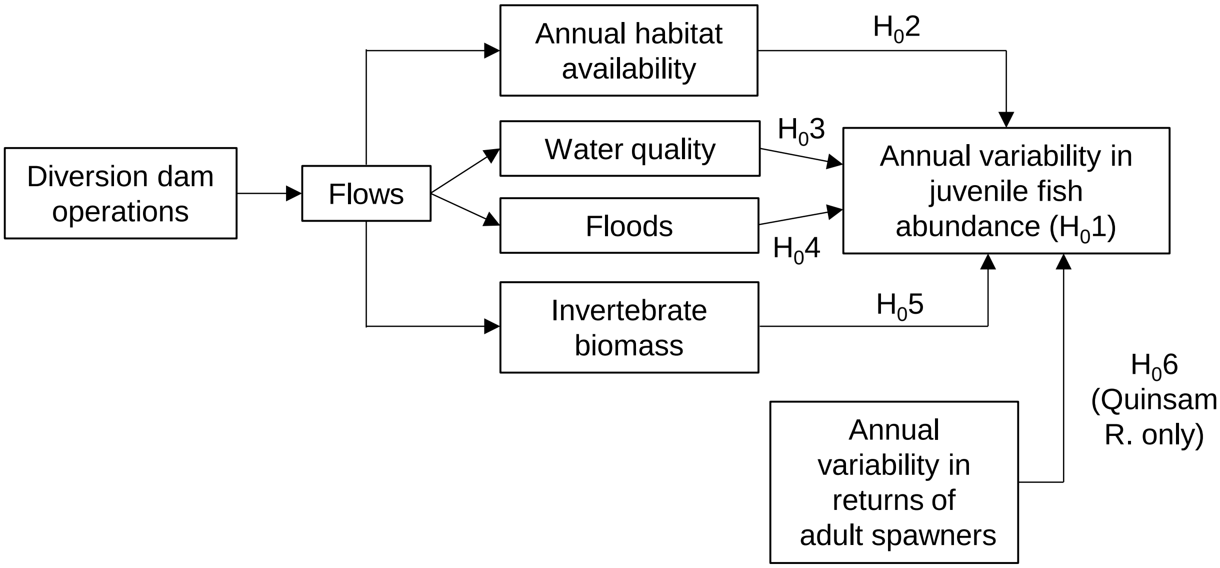
$H_0$5: Annual population abundance is not correlated with food availability as measured by aquatic invertebrate sampling.

There is one additional null hypothesis to be tested for the Quinsam River System where adult escapement and smolt abundance data are collected separately for a wide range of species:

- $H_0$6: Annual smolt abundance is not correlated with the number of adult returns.

The basis of JHTMON-8 is outlined conceptually in Figure 2. The monitoring program is designed to first establish whether there is among-year variability in fish abundance ($H_0$1). The program is then designed to collect data to examine whether inter-annual variability in fish abundance is related to important environmental factors that could be influenced by BC Hydro operations, specifically: Weighted Usable Area of habitat ($H_0$2); water quality ($H_0$3); an accumulated flood risk index during the spawning and incubation periods ($H_0$4), or; invertebrate abundance (food availability; $H_0$5). The study will also investigate whether annual variability in juvenile fish abundance is affected by annual variability in salmon spawner escapement ($H_0$6) – a factor that is influenced by marine survival and not by diversion dam operations.

Figure 2. **Effect-pathway diagram showing the context of the six hypotheses that the JHTMON-8 monitoring program sets out to address.**



1.4. Scope of the JHTMON-8 Study

1.4.1. Overview

The JHTMON-8 study has been designed to build upon monitoring that is already occurring in the Quinsam and Salmon watersheds. This allows the study to integrate established work programs and provides an opportunity to incorporate historical data into the analyses. Table 5 summarizes the field sampling programs that were undertaken during Year 4 of JHTMON-8.

Table 5. **Summary of field sampling programs undertaken for JHTMON-8.**

River	Sampling program	Lead organization[1]	Method	Timing
Salmon	Adult Steelhead survey	LKT	Snorkel surveys	March – April
	Juvenile Steelhead abundance	LKT	Closed site multi-pass electrofishing	September
	Juvenile Coho abundance	DFO/LKT	Closed site multi-pass netting	October
	Salmon escapement surveys	DFO	Various	September – November
	Water quality sampling	LKT	*In situ* and laboratory analysis	May – October
	Invertebrate sampling	LKT	Drift sampling	May – October
Quinsam	Quinsam River Hatchery juvenile downstream migration (various species)	DFO/LKT	Fish fence	March – June
	Salmon escapement surveys	DFO	Various	September – November
	Water quality sampling	LKT	*In situ* and laboratory analysis	May – November
	Invertebrate sampling	LKT	Drift sampling	May – October

[1] LKT, Laich-Kwil-Tach Environmental Assessment Ltd. Partnership; DFO, Fisheries and Oceans Canada

The species of primary interest on the Salmon River are anadromous Rainbow Trout (steelhead) and Coho Salmon; surveys to enumerate juvenile Coho Salmon and both juvenile and adult steelhead provide the majority of the fisheries data for the Salmon River for JHTMON-8. Species of primary interest in the Quinsam River include Chinook Salmon, Coho Salmon and steelhead, although Pink Salmon is also of interest. Fisheries data for the Quinsam River are primarily obtained via operation of a salmon counting fence at Quinsam River Hatchery to enumerate downstream juvenile migration of a range of species. In addition to these juvenile abundance datasets, adult escapement data obtained by Fisheries and Oceans Canada (DFO) for a range of Pacific salmon species during routine monitoring are also considered for both rivers as part of JHTMON-8.

Further information about the scope and objectives of specific sampling programs is provided below.

1.4.2. Fish Population Assessments

The JHTMON-8 juvenile fish sampling program was designed to ensure that the error associated with fish sampling methods is sufficiently small to assess between-year variability in fish abundance. The fish abundance data will first be used to test $H_0$1: '*annual population abundance does not vary with time (i.e., years) over the course of the Monitor*' (Section 1.3). Interim analysis to examine whether there are statistically significant variations in fish abundance between years will be undertaken during Year 5, with final analysis undertaken during Year 10. This analysis will focus on the Quinsam River.

The program was designed to enumerate both adult and juvenile life stages to allow relationships between the numbers of adult spawning fish and juvenile recruitment to be examined. This enables testing of $H_0$6: *'annual smolt abundance is not correlated with the number of adult returns'*, which will help to tease apart the extent to which any variations in abundance reflect either variations in adult returns (dependent on marine conditions and harvest) or variations in juvenile survival (dependent on freshwater conditions). Testing this hypothesis will therefore indicate whether the watershed is fully 'seeded' for each species. This hypothesis was proposed to only be tested for the Quinsam River, where the salmon counting fence is monitored to provide estimates of total juvenile fish out-migration. Work is scheduled for Year 5 to collate historical data collected at the Quinsam Hatchery salmon counting fence since the 1970s, thus increasing the extent of data available for analysis. Testing $H_0$6 will involve comparing the productivity of naturally-spawned Coho and Chinook salmon with the productivity of colonization programs that out-plant juvenile fish to areas in the upper Quinsam River watershed, e.g., Lower Quinsam Lake. This comparison will further help to examine whether spawning areas are fully seeded. This will need to consider the potential for lower fitness of hatchery-reared fish compared with wild fish, as has been observed during previous field studies in the watershed (Burt, pers. comm. 2016).

We anticipate that significant variability in annual population abundance will be detected (i.e., the null hypothesis will be rejected) for at least some of the species and life stages that are monitored. It will therefore be necessary to use these data to test four of the five remaining hypotheses to determine whether there are any relationships between the observed variability in fish abundance, and variations in key environmental factors, namely: habitat ($H_0$2), water quality ($H_0$3), floods ($H_0$4) and food availability ($H_0$5).

Juvenile steelhead and Coho Salmon sampling on the Salmon River are undertaken during the low flow period in late summer to maximize capture efficiency and minimize the potential for results to be confounded by variability in discharge (and therefore habitat use by fish). Sampling is intended to provide an index of juvenile fish abundance that is representative of each age class for a specific year; data are not expected to reflect the potential effects of water management operations on the day of sampling. Prior to the decommissioning, the Salmon River Diversion was not generally operated during juvenile fish sampling because discharge in the mainstem is typically less than the minimum flow requirement of 4.0 m^3/s (Section 1.2.2) during late summer. For example, mainstem discharge in the upper watershed during juvenile steelhead sampling in Year 4 was <1.0 m^3/s (Section 3.1.2), which is representative of the flow conditions that are targeted for this work. Therefore, we do not expect that decommissioning of the diversion undermined the value of the juvenile fish abundance data collected in Year 4.

1.4.3. Water Quality

Healthy fish populations require water quality variables to be within confined ranges. This range of suitable conditions varies depending on the individual variable, fish species and life stage. The objective of the JHTMON-8 water quality monitoring is to measure biologically important water quality variables to provide data to test $H_0$3: '*annual population abundance is not correlated with water quality*' (Section 1.3). An evaluation of how to incorporate the water quality data into final analysis is provided in this report. Complete analysis will be done at the end of the ten-year monitor to examine whether there is a relationship between fish abundance and water quality. If a relationship is detected (i.e., the null hypothesis is rejected), then we will evaluate whether BC Hydro operations are likely to have adversely affected water quality. This will be done as part of this study to help address Management Question 1 and 2. If required, we expect this analysis to be predominantly qualitative and it will involve considering the pathways of effect by which BC Hydro operations may affect water quality.

Thus, a key objective of this aspect of the study is that water quality data are collected that suitably reflect variability of water quality in time and space, and are representative of the conditions experienced by fish communities. A single mainstem index site was selected on each river that was assumed to be representative of water quality in the wider watershed.

1.4.4. Floods

High flows have potential to adversely affect fish populations due to a variety of mechanisms; these include: redd scour, delayed redd construction, redd desiccation due to spawning occurring along channel margins during high flows, sediment intrusion, physical shock, or reduced holding opportunities shortly after emergence (reviewed in Gibbins *et al.* 2008). Discharge data are collected at numerous sites on both study streams by the Water Survey of Canada. These data will be used to quantify the occurrence of high flow events during individual years to test $H_0$4: '*annual population abundance is not correlated with the occurrence of flood events*' (Section 1.3).

During Year 3, we evaluated suitable hydrological metrics to quantify key flow characteristics that have potential to influence fish productivity. Based on this, we quantified the maximum daily mean discharge each year that occurs during the spawning and incubation periods of key species on both study streams. In future years, we will consider calculating additional metrics (e.g., based on the duration of high flows), which can be easily calculated by modifying the code that we prepared this year. Analysis will be later undertaken to determine whether variability in these values explains variability in fish abundance, providing a test of $H_0$4. The proposed analysis will focus on the spawning and incubation life stages because these life stages have been shown to be particularly sensitive to the effects of high flows (e.g., Cattanéo *et al.* 2002). We recognize that there is a range of mechanisms by which high flows can affect these life stages (see list above); therefore, if $H_0$4 is rejected, it may be necessary to undertake further analysis to characterize the most sensitive periods and threshold flows at which high flow events adversely affect juvenile fish abundance. We also recognize that, although $H_0$4 specifically focuses on floods, other aspects of hydrological variability could affect juvenile fish productivity. For example, the occurrence of low flows during summer can potentially limit the abundance of juvenile fish species that rear in freshwater throughout the summer, e.g., Coho Salmon (Matthews and Olson 1980). Accordingly, we propose to calculate a range of annual minimum flow metrics for each stream so that this analysis can be extended to evaluate whether low flows affect juvenile fish abundance. Further details are provided in Section 2.3.

1.4.5. Invertebrate Drift

Invertebrates typically form the bulk of the diet of both juvenile and resident adult salmonids in rivers (Quinn 2005). Invertebrate populations can vary due to a range of factors and therefore variability in the abundance and biomass of invertebrates can be an important factor that limits the growth of salmonids in rivers. The objective of the JHTMON-8 invertebrate sampling is to provide data to test $H_0$5: "*annual population abundance is not correlated with food availability as measured by aquatic invertebrate sampling*" (Section 1.3). Analysis will later be undertaken towards the end of the ten-year monitor to examine whether there are any relationships between fish abundance and food availability, as inferred from invertebrate sampling. If a relationship is detected (i.e., the null hypothesis is rejected), then we will evaluate whether BC Hydro operations are likely to have adversely affected invertebrate drift biomass. This will be done as part of this study to help address Management Question 1 and 2. If required, we expect this analysis to be predominantly qualitative and it will involve considering the pathways of effect by which BC Hydro operations may affect invertebrate drift.

A key objective is therefore to collect invertebrate data that reflect variability of watershed invertebrate communities in time and space, and are thus representative of the food available to fish communities. Invertebrate drift includes: dislodged benthic invertebrates, terrestrial invertebrates entrained in the stream, and invertebrates originating from riparian areas. A single mainstem index site was selected on each river that was assumed to be representative of the invertebrate communities present in the wider watershed. Invertebrate drift biomass is measured as a proxy for food availability, although invertebrate community composition is also examined to provide information on food quality. Drift sampling is undertaken during the growing season when rearing juvenile salmonid are actively feeding. In addition, a single kick net sample is collected from each river in September. Kick sampling targets benthic invertebrates, and is therefore less representative of the total abundance of food available to fish. However, kick sampling based on the CABIN protocol (Environment Canada 2012) has been used more widely to characterize stream invertebrate communities throughout Canada. Data collected using this method can be used to evaluate the wider ecological integrity of the streams, based on comparisons with the Environment Canada database of Georgia Basin reference sites (e.g., see Strachan *et al.,* 2009).

2. METHODS

2.1. Fish Population Assessments

2.1.1. Salmon River Adult Steelhead Survey

Annual spring snorkel surveys have been conducted as part of adult steelhead stock production monitoring on the Salmon River since 1998. These have historically been undertaken by British Columbia Conservation Foundation (BCCF) and Ministry of Environment (MoE) staff. Since 2014, this work has been led by LKT, with BCCF (K. Pellett) providing supervision until Year 2 to ensure ongoing consistency of methods. Surveys of an index reach ('Lower Index') are the primary stock assessment method, with surveys typically undertaken during the second week of March. Surveys of two additional index reaches ('Rock Creek' and 'Upper Index') have also been undertaken in April during most of the years since 2000. These reaches are upstream of the Lower Index reach: the Rock Creek reach extends upstream of the diversion dam and the Upper Index reach extends downstream of the dam (Map 2).

These surveys provide valuable information to inform the JHTMON-8 study as they indicate whether any variability in juvenile steelhead abundance (see Section 2.1.2) is influenced by the abundance of returning adult fish. A caveat to this is that the adult snorkel surveys provide estimates of maximum density for select reaches rather than absolute escapement estimates for the watershed, although it is assumed that the two metrics are correlated.

All three reaches were successfully surveyed in 2017, with survey timings consistent with historical surveys. The Lower Index was surveyed on March 21, Rock Creek on April 17, and the Upper Index reach was surveyed on April 27. Each reach was snorkelled during a single day by two experienced technicians. Surveys were conducted in a downstream direction, with particularly steep and potentially dangerous sections bypassed on foot. Surveyors recorded the number, length and condition of adult steelhead, in addition to associated variables (Table 6). Incidental observations of other salmonids were recorded, although fish with fork length < 250 mm were not recorded.

Table 6. Variables measured during snorkel surveys of adult steelhead.

Variable	Unit/Classification
Weather	Observation
Air/water temperature	°C
Effective visibility	Measured or estimated (m)
Fish size class	fry/parr/adults; 150–250 mm, 251–350 mm, 351–450 mm, and > 450 mm
Fish species	Steelhead (ST)/Cutthroat Trout (CT)/resident Rainbow Trout (RB)
Fish condition	Bright/moderately coloured/mid-spawn/post-spawn/undetermined
Redd observations	Number

2.1.2. Salmon River Juvenile Steelhead Abundance

2.1.2.1. Field Methods

Juvenile steelhead[1] populations were sampled with multipass removal electrofishing at five sites upstream and five sites downstream of the Salmon River Diversion (Table 7; Map 2). Site locations were based on those historically sampled by BCCF during 1998–2013, with minor adjustments made to the positions of stop nets to account for changes in stream morphology. Sites were historically selected to specifically target fry (not parr) habitat. The main criteria used to select sampling locations were:

- Water depth (maximum 1.0 m, average 0.1 to 0.4 m);
- Water velocity (maximum 1.0 m/s, average 0.1 to 0.5 m/s);
- Cover and substrate (non-embedded boulder, cobble, and/or gravel);
- Area of site (target 100 m^2); and
- Proximity to previous sampling location (as close as possible).

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[1] For consistency with the historical sampling program, we use the term 'juvenile steelhead' to refer to juvenile (fry and parr) Rainbow Trout. We acknowledge that this may include resident and anadromous individuals.

Table 7. Details of juvenile steelhead sampling sites in the Salmon River.

Location	Site	Historic Site #	Historic Site Name/Description	River km	Sampling Date	Mesohabitat	UTM		
							Zone	Easting	Northing
Downstream of Diversion	SAM-EF01	1	Pallans (23.94 KM)	23.94	7-Sep-17	Riffle	10U	297922	5570705
	SAM-EF02	2	WSC Station (Kay Creek)	35.44	7-Sep-17	Riffle	10U	304030	5564241
	SAM-EF03	3	Memekay Mainline Bridge	52.60	6-Sep-17	Riffle	10U	309310	5556475
	SAM-EF04	4	Smolt Screen	58.02	6-Sep-17	Riffle	10U	309036	5552478
	SAM-EF07	7	Memekay River (lower bridge)	27.93	7-Sep-17	Riffle	10U	302056	5566097
Upstream of Diversion	SAM-EF05	5	Washout, old bridge 5km u/s/ diversion	67.73	6-Sep-17	Riffle	10U	304267	5548471
	SAM-EF06	6	Washout 500 m u/s of Grilse confluence	69.25	6-Sep-17	Riffle	10U	301417	5546997
	SAM-EF08	8	Grilse Ck. (100 m u/s of lower bridge)	70.77	5-Sep-17	Riffle	10U	300741	5547323
	SAM-EF09	9	Grilse Ck. (300 m d/s of upper bridge)	74.27	5-Sep-17	Riffle	10U	297133	5546961
	SAM-EF10	10	Grilse Ck. (500 m d/s of upper bridge)	75.91	5-Sep-17	Riffle	10U	296773	5546524

Fish were captured using closed-site multipass removal electrofishing methods in accordance with guidelines (Lewis *et al.* 2004; Hatfield *et al.* 2007). Sites were enclosed using stop nets (15.2 m long × 1.2 m deep, mesh size = 3.2 mm). Each pass consisted of two full circuits of the enclosure, and two to three passes were conducted at each site. Data collected included:

- Sampling effort (seconds) expended during each pass;
- The number, species, length (+/- 1 mm) and weight (+/- 0.01 g) of each fish caught per pass;
- Scales samples from a sub-sample of fish that were close to size/age class boundaries;
- Wetted width (three or four measurements) and site length; and
- Physical stream characteristics (cover types, substrate size, habitat type, stream gradient, compaction, sand in substrate, and roughness).

After electrofishing was complete, hydraulic habitat variables were measured along transects placed across the width of the sampling site. A minimum of ten wetted stations spaced a minimum of 0.25 m apart were placed along each transect. The following variables were measured at each station: distance from wetted edge, water depth, water velocity, available cover, and net locations. If a single transect was not long enough to accommodate 10 wetted stations then an additional transect was completed at the site. Water temperature and conductivity were measured using *in situ* meters calibrated prior to sampling. Photographs from standardized locations were also taken at each sampling site.

2.1.2.2. Data Analysis

Individual Fish Data

For juvenile steelhead, we defined age class structure, described length-weight relationships, Fulton's condition factor (K), and length at age. Fulton's condition factor (K) was calculated for all captured fish as:

$$K = \text{weight} \times \text{length}^{-3} \times 100{,}000$$

Where weight was recorded in g and length in mm. Scale samples were examined under a dissecting microscope to age individual fish: representative scales were photographed and apparent annuli were noted on a digital image. Fish age was determined by two independent observers using a double-blind methodology. The data produced by each observer were then compared to identify any discrepancies. Where discrepancies occurred, they were discussed and final age determination was based on professional judgement of the senior biologist.

Fish were separated into age classes for fish abundance and biomass analysis. To define discrete age class size bins (size classes), the length-frequency histograms for fish captured during electrofishing were reviewed along with all of the length at age data from the scale analysis. Based on these data, discrete fork length ranges were defined for each of the following age classes: fry (0+), parr (1+), parr (2+) and adult (≥3+), although no 2+ parr or adult fish were captured during sampling in 2017. These discrete fork length ranges allow all fish to be assigned to an age class based on fork length for population analysis. Fork length ranges may differ from year to year and are therefore determined annually. Summary statistics of fish length, weight, and Fulton's condition factor were summarized by age class for both the upstream and downstream reaches.

Population Analysis

Total abundance and biomass were calculated for steelhead fry (0+) using removal depletion equations in MicroFish V3.0 (Van Deventer 2006). Fish abundance and biomass by age class at individual sites were then standardized to fish per 100 m^2.

Abundance and biomass estimates were also adjusted to account for differences in habitat suitability of each sampling site. The habitat suitability of each electrofishing site was determined based on depth and velocity measured at each transect data, and habitat suitability indices for steelhead fry (0+) developed for BC Water Use Planning projects (curves dated February 2001 provided by R. Ptolemy, MoE). Habitat suitability is expressed as a usability percentage, which is calculated by computing the weighted usable width of each transect within the sampling enclosures, and dividing by the wetted width of the transect. The transect usability at each site was then used to adjust the fish density estimates. Results are expressed in terms of fish per unit area (FPU; fish/100 m^2), and are reported as both non-adjusted (FPU_{obs}) and usability-adjusted estimates (FPU_{adj}), and as non-adjusted and adjusted biomass per unit area (BPU_{obs} and BPU_{adj}; g/100 m^2). Abundance and biomass densities are presented for individual sites and as averages for upstream and downstream of the diversion reaches.

Results were compared with historical data collected at the same sites by BCCF from 1998 to 2013, and by LKT and Ecofish in 2014 to 2016.

2.1.3. Salmon River Juvenile Coho Salmon Abundance

2.1.3.1. Field

The abundance of juvenile Coho Salmon has been measured in the Salmon River during the fall since 2008, with the work undertaken by DFO prior to JHTMON-8. This work has been integrated into the JHTMON-8 study to continue collection of abundance data for a species of primary interest in the study. Continuation of this established monitoring program means that historical data collected between 2008 and 2013 can be combined with data collected during JHTMON-8 to increase the length of the dataset.

The program involves sampling at six sites, with three sites upstream of the diversion dam and three sites downstream (Map 2). Sites are representative of the juvenile Coho Salmon habitat generally present. Sites were typically ~ 20 m long and comprised pools. As part of LKT's standardized approach to data collection and quality assurance, new site names were assigned to the sampling sites for data recording purposes in 2015. Correspondence between these and existing site names is shown in Table 8, although note that precise sampling areas have varied within stream reaches between years in response to differences in water levels and channel morphology. In 2016, it was necessary to slightly reposition sites SAM-BS03 and SAM-BS06 as fallen trees were present in the middle of the sites, which prohibited sampling with a beach seine net. These sites were repositioned by approximately 25 m and 55 m respectively, with the new sites named SAM-BS03B and SAM-BS06B. Data collected at these new sites are considered comparable with historic data as the sites were located in the same tributaries and consisted of comparable habitat (pools). In 2017, SAM-BS06 was clear again and crews were able to sample in the original location. Sampling at SAM-BS03 was still prohibited by fallen trees and the water level on the 2017 sampling date was too low at SAM-BS03B for the site to be representative of available juvenile Coho Salmon habitat. For this reason, crews established a new site in 2017, SAM-BS03C, which was approximately 50 m from SAM-BS03B.

Sampling was conducted on September 19 and 20, 2017. Sites were isolated using barrier nets placed at the upstream and downstream ends to form full enclosures that included the full width of the channel (Figure 3). Multi-pass beach and/or pole seine netting, depending on the site conditions, were then used to remove fish at five sites. In 2017, the water level at SAM-BS01 was too low for effective beach seining so crews used a backpack electrofisher (settings: 400 volts, 60 Hz frequency, 36% duty cycle) to sample that site. Two to four passes were undertaken with the objective of observing declining catches, which permitted estimation of capture efficiency and subsequent estimation of total fish abundance.

All captured fish were retained until sampling was complete. Fork lengths of all juvenile Coho Salmon were tallied using 1 mm size bins. Weight (g) of individual fish in each size bin was recorded, with a maximum of three measurements recorded per size bin for each pass. Scales were retained for a subsample of fish (*n* = up to 8 for each size class). These were analyzed at Ecofish's laboratory in Campbell River to establish fork length categories that corresponded to age classes.

The length of each site was measured and three width measurements were recorded at all six sites. Both wetted width and width of the channel with water depth > 10 cm were measured. The latter width measurements were used to calculate the area of each site when estimating fish density as they are more representative of the habitats used by juvenile Coho Salmon.

2.1.3.2. Data Analysis

The weighted mean mass (g/fish, $\hat{m}_j$) was calculated for each age class (0+, 1+ and 2+) at each site as:

$$\hat{m}_j = \frac{\sum_{i_{min}}^{i_{max}}(n_{i,j} \cdot \bar{m}_{i,j})}{N_j}$$

where i_{max} is the maximum fork length (±1 mm) measured at a site, i_{min} is the minimum fork length (±1 mm) measured at a site, n_i is the number of fish recorded in size bin i for age class j, $\bar{m}_i$ is mean mass of fish in size bin i for age class j and N_j is the total number of fish caught at a site in age class j.

A total weighted mean mass (g/fish, $\hat{M}$) at each site was calculated as:

$$\hat{M} = \frac{\sum_{0+}^{2+}(\hat{m}_j \cdot N_j)}{N}$$

where N is the total number of fish caught at a site.

Total juvenile Coho Salmon abundance ($\widehat{N}$) was estimated at each site using DFO's standard capture efficiency model for analyzing multiple pass removal data. Total biomass at each site (g/m^2) was subsequently estimated as:

$$Biomass = \frac{\widehat{N} \cdot \widehat{M}}{Area_{>0.1\,m}}$$

where $Area_{>0.1\,m}$ is the area (m^2) of the site with depth > 0.1 m.

Table 8. Juvenile Coho Salmon sampling site details and correspondence with historical site names.

Location Relative to Diversion	Site	Historic Name	Stream	Coordinates (NAD 83)		
				Zone	E (m)	N (m)
Upstream	SAM-BS01	Crowned	Crowned Creek	10U	301818	5543950
Upstream	SAM-BS02	G02	Grilse Creek	10U	300117	5547376
Upstream	SAM-BS03C	Gmain	Grilse Creek	10U	300110	5547281
Downstream	SAM-BS04	Pater	Paterson Creek	10U	309986	5552605
Downstream	SAM-BS05	Mari	Marilou Creek	10U	307472	5557836
Downstream	SAM-BS06	BTCKFlCh	Big Tree Creek	10U	303387	5566520

Figure 3. Establishing stop nets at SAM-BS06 (Big Tree Creek) juvenile Coho Sampling site on September 20, 2017.

2.1.4. Salmon and Quinsam River Salmon Escapement

Annual salmon spawner escapement counts have been undertaken on the Salmon and Quinsam rivers since the 1950s by DFO and its predecessors. Although these data are collected as part of wider salmon stock assessment work, they provide an important source of data to support the JHTMON-8 study. The results of summer and fall 2016 surveys were finalized during Year 4. These were obtained from DFO's New Salmon Escapement Database (nuSEDS) and are reported here to provide data to support analysis scheduled for later during JHTMON-8 to examine relationships between abundance of adult spawning fish and corresponding counts of juvenile fish in successive years.

Methods used in the 2016 surveys are summarized in Table 9 and Table 10 for the Salmon and Quinsam rivers respectively, based on information provided in the nuSEDS database (DFO 2017). Surveys of individual species conducted by DFO conform to one of six estimate classification types, ranging from Type-1 (most rigorous, almost every fish counted individually) to Type-6 (least rigorous, determination of presence/absence only). The estimate classification types are reported in the two tables of methods, with further general details about survey types provided in Table 11.

Table 9. Methods used during 2016 salmon spawner escapement counts on the Salmon River (DFO 2017). See Table 11 for descriptions of survey types.

	Salmon species				
	Chinook	**Chum**	**Coho**	**Pink**	**Sockeye**
Estimate classification	4	5	4	4	5
Number of surveys	7	Unknown	8	8	Unknown
Date of first inspection	Jul-08	Unknown	Jul-08	Jul-08	Unknown
Date of last inspection	Sep-15	Unknown	Sep-15	Sep-15	Unknown
Estimation method	Area under the curve	N/A (none observed)	Area under the curve	Area under the curve	Peak live and dead

Table 10. Methods used during 2016 salmon spawner escapement counts on the Quinsam River (DFO 2017). See Table 11 for descriptions of survey types.

	Salmon species				
	Chinook	**Chum**	**Coho**	**Pink**	**Sockeye**
Estimate classification	2	3	2	2	3
Number of surveys	Unknown	Unknown	Unknown	Unknown	Unknown
Date of first inspection	Aug-08	Sep-01	Aug-30	Jul-17	Aug-02
Date of last inspection	Nov-30	Dec-15	Dec-15	Oct-30	Dec-15
Estimation method	Mark and recap. (Petersen)	Fixed site census	Fixed site census	Fixed site census	Fixed site census

Table 11. Summary of definitions of salmon spawner escapement estimate classification types reported in Table 9 and Table 10 (DFO 2017).

Estimate Classification Type	Abundance Estimate Type	Resolution	Analytical methods	Reliability (within stock comparisons)	Units	Accuracy	Precision
1	True	High resolution survey method(s): total, seasonal counts through fence or fishway with virtually no bypass	Simple	Reliable resolution of between year differences >10% (in absolute units)	Absolute abundance	Actual or assigned estimate; high	± 0%
2	True	High resolution survey method(s): high effort (5 or more trips), standard methods (e.g. equal effort surveys executed by walk, swim, overflight, etc.)	Simple to complex multi-step, but always rigorous	Reliable resolution of between year differences >25% (in absolute units)	Absolute abundance	Actual or assigned estimate; high	Actual estimate; high to moderate
3	Relative	Medium resolution survey method(s): high effort (5 or more trips), standard methods (e.g. mark-recapture, serial counts for area under curve, etc.)	Simple to complex multi-step, but always rigorous	Reliable resolution of between year differences >25% (in absolute units)	Relative abundance linked to method	Assigned range; medium to high	Assigned estimate; medium to high
4	Relative	Medium resolution survey method(s): low to moderate effort (1-4 trips), known survey method	Simple analysis by known methods	Reliable resolution of between year differences >200% (in relative units)	Relative abundance linked to method	Unknown; assumed fairly constant	Unknown; assumed fairly constant
5	Relative	Low resolution survey method(s): low effort (e.g. 1 trip), use of vaguely defined, inconsistent or poorly executed methods.	Unknown to ill defined inconsistent or poorly executed	Uncertain numeric comparisons, but high reliability for presence or absence	Relative abundance, but vague or no i.d. on method	Unknown; assumed highly variable	Unknown; assumed highly variable
6	Presence or absence	Any of above	N/A	Moderate to high reliability for presence/absence	Present or absent	Medium to high	Unknown

2.1.5. Quinsam River Hatchery Salmon Counting Fence Operations

Technical staff provided by LKT worked under the instruction of DFO hatchery staff to enumerate fish at the Quinsam River Hatchery salmon counting fence in spring, 2017. Methods were based on those described in Ewart and Kerr (2014); specific details about 2017 operations are based on information provided by the hatchery Enhancement Technician (Kerr, pers. comm. 2017). Data were collated and quality assured by Quinsam River Hatchery.

Fish were caught using inclined plane traps (Wolf traps) that capture a proportion of the fish that migrate downstream through the fence, with the aim to capture salmonid fry and smolts as they out-migrate to the ocean (Figure 4). Sampling was undertaken from March 11 to June 15, 2017, with traps deployed continuously during this period. The proportion of the river that was 'fished' varied depending on fish abundance, with a smaller number of traps (three) used during March and April when Pink Salmon fry were out-migrating and highly abundant. Specifically, three traps were installed from March 11 to April 26, with two additional traps then added for the remainder of the period (10 trap panels were open from May 17 to May 21 as the traps were overflowing on May 16). Pink Salmon fry typically migrate at night and therefore traps were set overnight from approximately 15:00 to 09:00 during sampling in March 11 to April 19. For the remainder of the sampling period, traps were set constantly during the times when fish were not being processed. Target species during this time were: steelhead (kelts and smolts), Coho Salmon (smolts), Chinook Salmon (fry), Chum Salmon (fry), Sockeye Salmon (fry), Cutthroat Trout (kelts and smolts) and Dolly Varden (smolts).

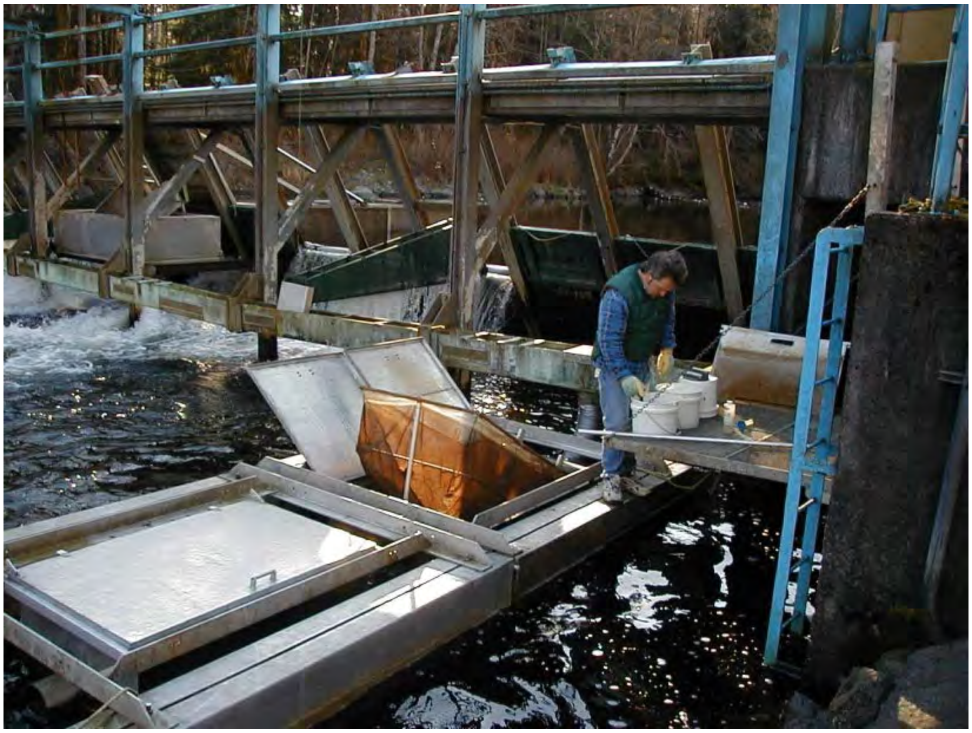
Total downstream migration estimates for individual species and life stages were calculated by multiplying fish capture numbers by capture efficiency coefficients. The capture efficiency coefficients were derived from mark-recapture studies in the system. For Pink Salmon fry, capture efficiency was estimated based on the results releases of wild fish marked with Bismarck brown dye. The fish were captured in the trap, marked with the dye, and released approximately 350 m upstream of the fence. A total of five releases were undertaken on March 30, April 5, April 11, April 19, and April 25; a total of 21,259 fish were released. The resulting capture efficiency coefficients were used to estimate the abundance of Pink Salmon fry and also to estimate the abundance of other species captured during the Pink Salmon fry trapping period (i.e., steelhead, Cutthroat Trout, and Chum Salmon). Capture efficiency was calculated as k/K (where k is the number of marked fish recaptured and K is the total number of fish marked in the study).

Separate catch efficiency estimates were derived for Coho Salmon smolts based on two releases of wild Coho Salmon smolts marked with pelvic fin clips (alternating between right and left between experiments). Again, smolts were captured in the traps and released upstream of the traps. Releases were undertaken on May 17 and May 23; a total of 899 fish were released. The capture efficiency estimates were also used to estimate abundance of other salmonid species caught after April 23 (i.e., steelhead, Cutthroat Trout, Chinook Salmon, Sockeye Salmon, and Chum Salmon). Further details about the mark recapture methods are provided in Ewart and Kerr (2014).

For Coho Salmon and Chinook Salmon, separate counts were recorded for wild and 'colonized' smolts. Colonized refers to fish that were incubated at the hatchery and transplanted to the upper Quinsam River watershed as fry. As per hatchery protocols, 20% of transplanted fish are marked with an adipose fin clip. The abundance of colonized Coho Salmon was therefore estimated by multiplying the number of marked fish captured in the traps by five. Wild and colonized fry/smolts were further distinguished by size class (colonized juveniles are generally larger than wild juveniles), with size breaks generated from the length data for adipose-clipped fish. Size class calculations were not used to distinguish wild from colonized Chinook Salmon; there is, therefore, uncertainty in their relative numbers.

In 2016, 146,547 Coho Salmon fry were released into the upper Quinsam River watershed by hatchery staff between May 30 and June 1. In 2015 (Year 2), hatchery-incubated Chinook Salmon were released in the watershed for the first time in approximately 10 years and further releases were undertaken in 2016. Chinook Salmon fry were again released into lower Quinsam Lake in 2017, with 207,319 fry released on May 9 and May 10. The date of the second release in 2017 was not recorded by field crews.

Figure 4. **View upstream from river left towards the salmon counting fence. Reproduced from Ewart and Kerr (2014).**



2.2. Water Quality

2.2.1. Water Chemistry

2.2.1.1. Salmon River and Quinsam River Water Chemistry Monitoring

One water quality site was established in the Salmon River (SAM-WQ; Map 2) and one in the Quinsam River (QUN-WQ; Map 3) in 2014. Both sites were selected based on the guidelines of the British Columbia Field Sampling Manual (Clarke 2013) and the Ambient Fresh Water and Effluent Sampling Manual (RISC 2003).

The Salmon River site (SAM-WQ; Figure 5) was located downstream of the Salmon River Diversion, in a run immediately downstream of a braided section of the river with sandy banks. The Quinsam River site (QUN-WQ; Figure 6) is located ~950 m downstream of the confluence with the Iron River, and downstream of the Quinsam Coal Mine and the salmon carcass nutrient enhancement site. Coordinates, site elevation, and sampling dates (*in situ* and laboratory samples) for both sites are provided in Table 12.

Table 12. Water quality index site details and sampling dates in Years 1 to 4.

Waterbody	Site Name	UTM Coordinates (Zone 10)		Elevation (m)	Sampling Dates
		Easting	Northing		
Salmon River	SAM-WQ	309308	5556385	172	21-May-14; 17-Jun-14; 23-Jul-14; 18-Aug-14; 23-Sep-14; 03-Nov-14; 13-May-15; 16-Jun-15; 22-Jul-15; 12-Aug-15; 17-Sep-15; 15-Oct-15; 17-May-16; 14-Jun-16; 12-Jul-16; 16-Aug-16; 13-Sep-16; 11-Oct-16; 9-May-17; 13-Jun-17; 11-Jul-17; 8-Aug-17; 12-Sep-17; 10-Oct-17
Quinsam River	QUN-WQ	327433	5534757	193	23-May-14; 18-Jun-14; 22-Jul-14; 19-Aug-14; 24-Sep-14; 04-Nov-14; 12-May-15; 17-Jun-15; 23-Jul-15; 13-Aug-15; 16-Sep-15; 14-Oct-15; 18-May-16, 15-Jun-16, 13-Jul-16; 17-Aug-16, 14-Sep-16; 12-Oct-16; 10-May-17; 14-Jun-17; 12-Jul-17; 9-Aug-17; 13-Sept-17; 11-Oct-17

Figure 5. Looking upstream to SAM-WQ on September 13, 2017.

Figure 6. Looking upstream to QUN-WQ on September 13, 2017.

Consistent with previous years, water quality was monitored six times at each site on a monthly basis during May through October, 2017. Standard methods were employed to collect samples and measure water quality; methods were consistent with previous years. Sample collection and analyses were completed according to procedures set out in the Guidelines for Designing and Implementing a Water Quality Monitoring Program in British Columbia (RISC 1997a). Water chemistry variables were chosen based on provincial standards (Lewis *et al.* 2004). The variables in Year 4 are presented in Table 13 (*in situ*) and Table 14 (laboratory). Total gas pressure (TGP) was not sampled in Year 3 or Year 4 based on a recommendation following Year 1 (Abell *et al.* 2015b). Laboratory method detection limits (MDL) occasionally differ (Table 14) due to matrix effects in the sample, or variations in laboratory analytical instruments.

Table 13. Water quality variables measured *in situ* and meters used for measurement in 2017.

Parameter	Unit	Meter
Water temperature	°C	YSI Pro Plus
pH	pH units	YSI Pro Plus
Salinity	ppt	YSI Pro Plus
Conductivity	µS/cm	YSI Pro Plus
Specific conductivity	µS/cm	YSI Pro Plus
Oxidation reduction potential	mV	YSI Pro Plus
Dissolved oxygen	mg/L	YSI Pro Plus
Dissolved oxygen	% Saturation	YSI Pro Plus

Table 14. Variables analyzed in the laboratory by ALS Environmental and corresponding units and method detection limit (MDL).

Parameter	Unit	MDL
General Water Quality		
Specific conductivity	µS/cm	2
pH	pH	0.1
Total suspended solids	mg/L	1
Total dissolved solids	mg/L	10 to 20
Turbidity	NTU	0.1
Alkalinity, Total (as $CaCO_3$)	mg/L	1 to 2
Nutrients		
Ammonia (as N)	µg/L	5
Nitrate (as N)	µg/L	5
Nitrite (as N)	µg/L	1
Total phosphorus	µg/L	2
Orthophosphate	µg/L	1

2.2.1.1. Quality Assurance/Quality Control

In situ water quality meters were maintained and operated following manufacturer recommendations. Maintenance included calibration, cleaning, periodic replacement of components, and proper storage. Triplicate *in situ* readings were recorded from each meter at each site on each sampling date.

For samples collected for laboratory analysis, sampling procedures and assignment of detection limits were determined following the guidelines of the BC Field Sampling Manual (Clarke 2013) and the Ambient Fresh Water and Effluent Sampling Manual (RISC 2003). Duplicate samples were collected on each sampling date at each site.

No field or trip blanks were collected in 2017. In Years 1 and 2 (2014 and 2015), field and trip blanks were collected during each sampling event. In Year 3 (2016), a field blank and travel blank were also collected during the May 17-18 field trip, resulting in >50% of Year 3 samples being quality assurance/quality control (QA/QC) samples, which include trip blanks, field blanks or duplicate samples. Overall for the sampling program, the total number of QA/QC samples collected over four years (64 out of 72 samples, or 75%) exceeds recommendations; the BC field sampling manual recommends that 20% to 30% of samples consist of QA/QC samples (Clark 2013), while the RISC (1997a) manual recommends a minimum of 10% of samples.

Samples for laboratory analysis were collected in clean 500 mL plastic bottles provided by a certified laboratory. Samples were packaged in clean coolers that were filled with ice packs and couriered to ALS Environmental in Burnaby within 24 to 48 hours of collection. Standard Chain of Custody procedure was strictly followed. ALS Environmental performed in-house quality control checks including analysis of replicate aliquots, measurement of standard reference materials, and method blanks. A summary of the quality assurance/quality control (QA/QC) laboratory results is provided in Appendix A.

It is a common occurrence in Vancouver Island streams to have concentrations of a number of variables (notably nutrients) that are less than, or near to, the MDL. When this occurs, there are a number of different possible methods that can be used to analyze these values. In this report, any values that were less than the MDL were assigned the actual MDL values and averaged with the results of the other replicates. In these cases, the 'real' average is less than the average reported.

2.2.1.2. Comparison with Guidelines for the Protection of Aquatic Life

Water quality guidelines for the protection of aquatic life (WQG-AL) and typical ranges of water quality variables in BC waters that were considered for this report are provided in Appendix A. Any results for water chemistry variables that approximated or exceeded WQG-AL, or ranges typical for BC, are noted in Section 3.2.2.

For most water quality variables measured in this study, there are provincial WQG-AL. For total phosphorus, there are no provincial WQG-AL; however, there are federal guidelines (CCME 2004). For the remaining variables without provincial WQG-AL (i.e., orthophosphate, alkalinity, and specific conductivity) there are no federal guidelines either.

2.2.2. Water and Air Temperature

2.2.2.1. Salmon River and Quinsam River Temperature Monitoring

Water and air temperature monitoring was successfully completed in Year 4. Water temperature data have now been collected at the water quality index sites on both rivers for the period May 2014 to October 2017, although there is a gap in the Salmon River dataset from October 2014 to May 2015 due to lost temperature loggers. Air temperature has also been measured near-continuously throughout this period; these measurements provide data that could be used to model water temperatures elsewhere in the watershed if later required.

Water temperature was recorded at intervals of 15 minutes using self-contained TidbiT v2 loggers (Onset, MA, USA). These TidbiT loggers had an operating range of -20°C to +70°C with an accuracy of ±0.2°C and have a resolution of 0.02°C. For most of the record duration, water temperature at each of the monitoring stations was logged using duplicate TidbiT loggers installed on separate anchors. This redundancy is intended to prevent gaps in the data if one of the loggers malfunctions or is lost; however, both TidbiT loggers were lost at SAM-WQ during high flows in late October 2014, and monitoring did not resume until May 2015.

Air temperature was measured using one HOBO Air Temperature U23 Data Logger (range of -40°C to 70°C, accuracy of ±0.21°C) at each water quality index site. The temperature loggers recorded air temperature at a regular interval of 15 minutes. The loggers were placed on trees that were close (< 100 m) to each site. Temperature measurements were made near-continuously at each site between May 2014 and October 2017.

2.2.2.2. Data Analysis

Water temperature data were analyzed as follows. First, erroneous data were identified and removed. Sources of erroneous data include occasional drops in water level which can expose the sensors to the atmosphere, and high flows which can move sediment and bury the sensors. Second, the records from duplicate loggers (when available) were averaged and records from different download dates were combined into a single time-series for each monitoring station. The time series for all stations were then interpolated to a regular interval of 15 minutes, starting at the full hour.

Time series of water and air temperature data were plotted at 15-minute intervals; the hourly rates of change in water temperature were also plotted. Analysis of the water temperature data involved computing a range of summary statistics (Table 15) that were chosen based on the provincial WQG-AL (Oliver and Fidler 2001; Table 16). The following statistics were computed: mean, minimum, and maximum water temperatures for each month of the record; hourly rate of change of temperature; days with mean daily temperature >18°C, >20°C, and <1°C; the length of the growing season, and; the accumulated thermal units in the growing season. The number of degree days in the growing season was not calculated for the Salmon River due to a lack of temperature data for the start and end dates of the growing season (data were downloaded in October) as well as due to gap in records (as mentioned above). Statistics were based on the data collected at, or interpolated to, intervals of 15 min.

Mean weekly maximum temperatures (MWMxT) were calculated for both datasets and compared to optimum temperature ranges for different fish species and their life stages as outlined in the provincial WQG-AL (Oliver and Fidler 2001).

Table 15. Parameters calculated based on water and air temperature data.

Parameter	Description	Method of Calculation
Monthly water- and air- temperature statistics	Average, minimum, and maximum temperatures on a monthly basis	Calculated from temperatures observed at or interpolated to 15-min intervals.
Rate of water temperature change	Hourly rate of change in water temperature	Calculated from temperatures observed at or interpolated to 15-min intervals. The hourly rate of cahange was set to the difference between temperature data points that are separated by one hour and was assigned to the avarage time for these data points.
Degree days in growing season	The beginning of the growing season is defined as the beginning of the first week that average stream temperatures exceed and remain above 5°C; the end of the growing season is defined as the last day of the first week that average stream temperature dropped below 4°C (as per Coleman and Fausch 2007).	Daily average water temperatures were summed over this period (i.e., from the first day of the first week when weekly average temperatures reached and remained above 5°C until the last day of the first week when weekly average temperature dropped below 4°C)
Number of days with extreme daily-mean temperature	>18°C , >20°C , and <1°C	Total number of days with daily-mean water temperature >18°C , >20°C , and <1°C
MWMxT	Mean Weekly Maximum Temperature	A 1-week moving-average filter is applied to the record of daily-maximum water temperatures inferred from hourly data; e.g., if MWMxT = 15°C on August 1, 2008, this is the average of the daily-maximum water temperatures for the 7 days from July 29 to August 4. MWMxT is calculated for every day of the year.

Table 16. Water temperature guidelines for the protection of freshwater aquatic life (Oliver and Fidler 2001).

Category	Guideline
All Streams	the rate of temperature change in natural water bodies not to exceed 1°C/hr
Streams with Known Fish Presence	temperature metrics to be described by the mean weekly maximum temperature (MWMT)
	mean weekly maximum water temperatures should not exceed ±1°C beyond the optimum temperature range for each life history phase of the most sensitive salmonid species present
Streams with Bull Trout or Dolly Varden	maximum daily temperatures should not exceed 15°C
	maximum spawning temperature should not exceed 10°C
	preferred incubation temperatures should range from 2°C to 6°C
	±1°C change from natural condition[1]
Streams with Unknown Fish Presence	salmonid rearing temperatures not to exceed MWMT of 18°C
	maximum daily temperature not to exceed 19°C
	maximum temperature for salmonid incubation from June until August not to exceed 12°C

[1] provided natural conditions are within these guidelines, if they are not, natural conditions should not be altered (Deniseger, pers. comm. 2009).

2.3. Hydrology

The Water Survey of Canada measures discharge at multiple gauges on both study streams (Table 17). Available discharge data collected since the start of the study were plotted to evaluate flow conditions at the following sites downstream of the diversion facilities: 'Salmon R. above Memekay R.', 'Quinsam R. near Campbell R.' and 'Quinsam R. at Argonaut Bridge' sites (Table 17). To provide historical context, discharge was plotted alongside summary statistics (10th, 50th and 90th percentiles) for the periods of record. At the time of reporting, quality assured historical data were only available until the end of 2016 (Year 3).

In addition, several annual hydrological metrics were calculated for each study stream to quantify key flow characteristics that have potential to influence fish productivity (Table 18). The metrics quantify the occurrence of high flows during biologically sensitive periods of the year to support analysis to test $H_0$4, which relates to floods (Section 1.4.4). For Pacific Salmon species (fall spawners), the maximum discharge during the incubation period was calculated based on the discharge measured between the start of incubation in fall the previous year, and the end of incubation during spring of the current year. Low flow metrics were also calculated for each stream to support analysis to test whether low summer flows affect the abundance of juvenile salmonids that rear in freshwater through the summer (Coho Salmon and steelhead). All metrics are based on a subset (Group 2) of the Indicators of Hydrologic Alteration (Richter *et al.* 1996) that were developed to quantify the magnitude and duration of hydrological extremes. Metrics were either calculated based on annual records of mean daily discharge (m^3/s), or using records for the spawning and incubation periods of specific fish species, based on fish periodicity information reported by Burt (2010; Salmon River) and Burt (2003; Quinsam River). Metrics were calculated using the Indicators of Hydrologic Alteration package developed for R (R Core Team 2016) by The Nature Conservancy. For the Salmon River, metrics were calculated based on discharge data collected at the gauge above Memekay River (08HD007); for the Quinsam River, metrics were calculated based on discharge data collected at the gauges at Argonaut Bridge (08HD021) and near the confluence with the Campbell River (08HD005).

Table 17. Hydrometric gauges maintained by Water Survey of Canada on the two study streams. See Map 2 and Map 3 for site locations.

Stream	Site Name	Site Code	Period of Record		Position Relative to Diversion
			Start	End	
Salmon River	Salmon R. above Campbell Lake Diversion	08HD015	1981	Ongoing	Upstream
	Salmon R. below Campbell Lake Diversion	08HD032	1981	Ongoing	Downstream
	Salmon R. above Memekay R.	08HD007	1960	Ongoing	Downstream
	Salmon R. near Sayward	08HD006	1965	Ongoing	Downstream
Quinsam River	Quinsam R. at Argonaut Bridge	08HD021	1993	Ongoing	Downstream
	Quinsam R. below Lower Quinsam Lake	08HD027	1997	Ongoing	Downstream
	Quinsam R. near Campbell R.	08HD005	1957	Ongoing	Downstream

Table 18. **Hydrological metrics calculated for each study stream.**

Stream	Hydrological Metric	Data Period
Salmon River	Max. discharge during Coho Salmon incubation	Oct 1–April 15
	Max. discharge during steelhead incubation	March 1–June 30
	1-day minimum discharge	Calendar year
	7-day minimum discharge	Calendar year
	30-day minimum discharge	Calendar year
Quinsam River	Max. discharge during Chinook Salmon incubation	Oct 15–April 30
	Max. discharge during Coho Salmon incubation	Oct 15–April 22
	Max. discharge during steelhead incubation	Feb 15–June 15
	Max. discharge during Pink Salmon incubation	Sep 15–April 8
	1-day minimum discharge	Calendar year
	7-day minimum discharge	Calendar year
	30-day minimum discharge	Calendar year

2.4. Invertebrate Drift

2.4.1. Sample Collection

One invertebrate drift sampling site was established on the Salmon River (Map 2, Figure 7) and one on the Quinsam River (Map 3, Figure 8), both located close (<150 m) to the water quality index sites. Site locations matched those for previous years. Sites were located in riffle or run habitats, upstream of any obvious source of debris that could clog the nets or areas that receive frequent sediment disturbance. Invertebrate sampling was conducted on a monthly basis from May to October, with weekly sampling conducted during August in Year 4 – the month that is sampled weekly is rotated between study years to quantify the variance associated with monthly data. In total, sampling occurred on nine dates on each river. Table 19 presents details of the sampling dates and times.

Invertebrate drift sampling followed methods recommended in Hatfield *et al.* (2007) and Lewis *et al.* (2013). Upon arrival at site, local areas with velocities of approximately 0.2 to 0.4 m/s were identified with a model 2100 Swoffer meter with a 7.5 cm propeller and a 1.4 m top-set rod. This range of velocities is ideal for sampling invertebrate drift as velocities are slow enough to prevent clogging of the nets. Due to flow conditions at the time of sampling, it was not always possible to deploy the nets in areas with velocities of 0.2 m/s to 0.4 m/s (as per Hatfield *et al.* 2007), and nets sampled higher or lower water velocities at times.

Five drift nets were deployed simultaneously across the channel. The mouth of each drift net was positioned perpendicular to the direction of stream flow, and nets were spaced apart to ensure that each individual net did not obstruct flow into an adjacent net. The drift net mouth dimensions were 0.3 × 0.3 m and the nets (250 µm mesh) extended 1 m behind the mouth. Nets were anchored such that there was no sediment disturbance upstream of the net before and during deployment. All nets were deployed so that the top edge of the net was above the water surface so that both invertebrate drift in the water column and on the water surface could be sampled.

At the start of sampling, measurements were made of water depth in each net and the water velocity at the midpoint of the water column that was being sampled by each net. These measurements were repeated hourly to permit calculation of the volume of water sampled with each net. Any large debris (e.g., leaves) that had entered the nets was periodically removed from the nets (after it had been washed of any invertebrates which were returned to the nets). Nets were deployed for approximately four hours on each sample date (Table 19). Once the nets were removed, the contents of all five nets were transferred into sample jars (500 mL plastic jars with screw top lids) for processing as a single sample. This is a method change from Year 1 (2014), when contents of each net were processed separately. Samples were preserved in the field with a 10% solution of formalin (formalin = 37-40% formaldehyde).

Additional invertebrate samples were collected using kick net sampling on September 12, 2017 at SAM-IV and September 13, 2017 at QUN-IV. At both sites, the CABIN standardized sampling method was followed (MoE 2009), with a single drift net (described above) used as a kick net. This required one crew member to hold the net flush with the stream bed immediately downstream of a second crew member undertaking the sampling. Sampling proceeded in upstream direction for a timed period of 3 minutes, covering a horizontal distance of approximately 10 m. During sampling, the sampler kicked the substrate to disturb it to a depth of 5–10 cm, while turning over any large cobbles or boulders in order to dislodge invertebrates. Once sampling was complete, the contents were sieved (250 µm mesh), transferred into a sample jar, and preserved in the same manner as drift net samples.

Table 19. Invertebrate drift sample site locations, sample timing, and sampling duration during 2017.

Stream	Site	Sample Date	UTM Coordinate (Zone 10)		Start	Finish	Sampling
			Easting	Northing	Time[1]	Time[2]	Duration[3,4]
Quinsam	QUN-IV	10-May-2017	309,304	5,556,468	06:37	10:37	4:00
		14-Jun-2017	309,304	5,556,468	06:33	10:34	4:01
		12-Jul-2017	309,304	5,556,468	06:42	10:43	4:01
		09-Aug-2017	309,304	5,556,468	07:00	11:00	4:00
		16-Aug-2017	309,304	5,556,468	07:00	11:00	4:00
		23-Aug-2017	309,304	5,556,468	07:20	11:20	4:00
		31-Aug-2017	309,304	5,556,468	07:30	11:30	4:00
		13-Sep-2017	309,304	5,556,468	07:56	11:56	4:00
		11-Oct-2017	309,304	5,556,468	08:35	12:35	4:00
Salmon	SAM-IV	09-May-2017	327,361	5,534,796	06:33	10:33	4:00
		13-Jun-2017	327,361	5,534,796	06:21	10:22	4:01
		11-Jul-2017	327,361	5,534,796	06:39	10:44	4:05
		08-Aug-2017	327,361	5,534,796	07:15	11:15	4:00
		15-Aug-2017	327,361	5,534,796	07:04	11:04	4:00
		22-Aug-2017	327,361	5,534,796	07:20	11:20	4:00
		30-Aug-2017	327,361	5,534,796	07:30	11:30	4:00
		12-Sep-2017	327,361	5,534,796	07:55	11:55	4:00
		10-Oct-2017	327,361	5,534,796	08:35	12:35	4:00

[1] When the first net was set

[2] When the last net was removed

[3] The duration between retrieving the first and last net

[4] For data analysis, start and finish times for individual nets were used to calculate the volume of water filtered for each net

Figure 7. View upstream towards SAM-IV, July 11, 2017.

Figure 8. View downstream from river right towards QUN-IV, May 10, 2017.

2.4.2. Laboratory Processing

Samples were sent to Ms. Dolecki of Invertebrates Unlimited in Vancouver, BC for processing. Ms. Dolecki is a taxonomist with Level II (genus) certification for Group 2 (Ephemeroptera, Plecoptera, and Trichoptera (EPT)) and for Chironomidae from the North American Benthological Society.

The drift and kick net samples were first processed by removing the formalin (pouring it through a 250 μm sieve), followed by immediate picking of the very large and rare taxa. Samples were split into subsamples if the number of invertebrates was over 1,000. The invertebrates were enumerated using a Leica stereo-microscope with 6 to 8 × magnification, with additional examination of crucial body parts undertaken at higher magnifications (up to 400 ×) using an Olympus inverted microscope where necessary. Individuals from all samples were identified to the highest taxonomic resolution possible and it was noted whether a taxon was aquatic, semi-aquatic, or terrestrial. Life stages were also recorded.

Digitizing software (Zoobbiom v. 1.3; Hopcroft 1991) was used to measure the length and biomass (mg dry weight) of a sub-sample of individuals, with the average biomass of individuals in each taxon calculated. For abundant taxa, up to 25 randomly chosen individuals per taxon were digitized to address the variability in size structure of the group. For the rare taxa, all individuals in the taxon were measured. The damaged or partial specimens were excluded from the measurements. For pupae and emerging Chironomidae, up to 50 individuals were measured.

To provide QA/QC, all the samples were re-picked a second time to calculate the accuracy of picking. This assured that > 90% accuracy was attained, and the accuracy of the methods employed is expected to be over 95%.

2.4.3. Data Analysis

Variables were chosen and calculated as per Lewis *et al.* (2013), and all taxa (aquatic, semi-aquatic, and terrestrial) were considered. Density (# of individuals) and biomass (mg dry weight) of each sample were expressed as units per m^3 of water, where volume is the amount of water that was filtered through a single net during a set. Volume filtered by each net was calculated based on the duration that the nets were deployed and the average discharge measured at each net.

Family richness (i.e., the number of families present) was calculated for each sample. Simpson's diversity (1-λ, Simpson 1949) was calculated from family level density data to provide a measure that reflects both richness and the relative distribution or 'evenness' of invertebrate communities. The Canadian Ecological Flow Index (CEFI) was calculated using family level data for aquatic taxa following Armanini *et al.* (2011). Taxa present in <5% of the samples were not excluded from the CEFI calculation (Armanini, pers. comm. 2013). Relative abundances of taxa at each site were calculated considering only aquatic taxa, and only aquatic taxa used to develop the CEFI were considered when calculating the index. The top five families contributing to biomass at each site on each date were also identified.

PRIMER (Plymouth Routines in Multivariate Ecological Research) v. 6 software was used to generate a Bray-Curtis similarity matrix for samples collected from each study stream. The similarity matrix was generated from square-root-transformed density data for aquatic, semi-aquatic, and terrestrial taxa at the highest taxonomic resolution available for each taxon. The square root transformation down-weights the effect of the most abundant taxa, allowing for a better representation of the invertebrate community as a whole, rather than having similarity measures dominated by only the most abundant taxa. The similarity matrix was generated by calculating a similarity coefficient for all possible pairs of sample dates with respect to the taxonomic composition and abundance of different taxa on both sample dates.

The resulting Bray-Curtis similarity matrices were then examined using cluster analysis dendrograms in PRIMER to detect similarities among samples. The clustering method used is a hierarchical clustering with group-average linking. The method takes a Bray-Curtis similarity matrix as a starting point and successively fuses the samples into groups, and the groups into larger clusters. The method starts with the highest mutual similarities, and then gradually lowers the similarity level at which groups are formed. The significance level for clustering was set at 5% using the SIMPROF tool in PRIMER (1000 permutations were used to calculate the mean similarity profile and 999 to generate the null distribution of the departure statistic). Further discussion of the cluster analysis can be found in Clarke and Warwick (2001) and Clarke and Gorley (2006).

The Bray-Curtis similarity matrices were also examined using non-metric, multi-dimensional scaling (MDS) ordination plots in PRIMER to detect trends in similarity among samples. MDS uses an algorithm that successively refines the positions of the points (samples) until they satisfy, as closely as possible, the dissimilarity between samples (Clarke and Warwick 2001). This algorithm was repeated 1,000 times for each similarity matrix (i.e., with density from each site on each date as samples). The result is a two-dimensional ordination plot in which points that are close together represent samples that are very similar in community composition with respect to the taxa present and their abundances. Conversely, points that are far apart represent samples with a very different community composition. Further discussion of the MDS analysis can be found in Clarke and Warwick (2001) and Clarke and Gorley (2006).

3. RESULTS

3.1. Fish Population Assessments

3.1.1. Salmon River Adult Steelhead Survey

All three reaches were successfully surveyed in 2017, with survey timings consistent with historical surveys. Surveys were conducted during near-baseflow conditions (Figure 9); estimated visibility was 6–7 m and water temperatures were 3.0–5.5°C (Table 20).

Survey observations are presented in Table 21; 2017 adult steelhead counts are summarized in Figure 10. Adult steelhead density was highest in the lower and upper section of the Lower Index reach (5.3 fish/km and 4.3 fish/km respectively; Table 21). Adult steelhead density was the same in both the upper and lower sections of the Upper Index reach (1.4 fish/km; Table 21). No steelhead were observed in the Rock Creek reach, which was the only survey reach upstream of the diversion dam. Low numbers of steelhead redds were observed, with only 6 redds observed in the upper section of the Upper Index reach (latest survey date; Table 21). Adult steelhead were predominantly moderately coloured or in mid-spawn condition. No fish were determined to be in the bright condition in both of the Upper Index reaches in (Figure 10). A total of 15 fish (28%) were determined to be in bright condition in the Lower Index in 2017, compared with 26% in Year 1 (2014), 50% in Year 2 (2015), and 8% in Year 3 (2016). Low numbers of trout were incidentally recorded in all reaches (a total of 20 Cutthroat Trout and one Rainbow Trout), although this partly reflects that crews did not record fish with fork length < 250 mm due to time constraints[2].

Adult steelhead abundance was low relative to historical counts (Figure 11 to Figure 13). The total count for the Lower Index reach (54) was the sixth lowest count out of the 19 years sampled and was approximately equal to the 25th percentile of the dataset. This count was higher than the count for Year 1 (39) and Year 3 (50) but lower than the count for Year 2 (72). The total count for the Upper Index reach (16) was the lowest of the ten years that have been sampled. Similarly, Year 4 was only the third year when no fish have been observed in the Rock Creek reach (upstream of the diversion dam) out of the 11 years when surveys have been undertaken (historical range of counts: 0–70). Survey conditions (i.e., visibility and flow; Table 20) were comparable with previous years and fish condition observations (Figure 10) indicate that the surveys were appropriately scheduled to sample adult fish abundance, i.e., fish condition indicated that surveys were undertaken approximately during the middle of the spawning period. Thus, results show that adult steelhead abundance was low overall in 2017, both upstream and downstream of the diversion dam.

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[2] E.g., 44 Cutthroat Trout were recorded in the lower section of the Lower Index reach in 2015 when crews recorded all trout that were observed.

Figure 9. Instantaneous discharge measured at the WSC gauge upstream of the Salmon River Diversion (Map 2) during 2017 adult steelhead surveys (triangles). Data from WSC (2017).

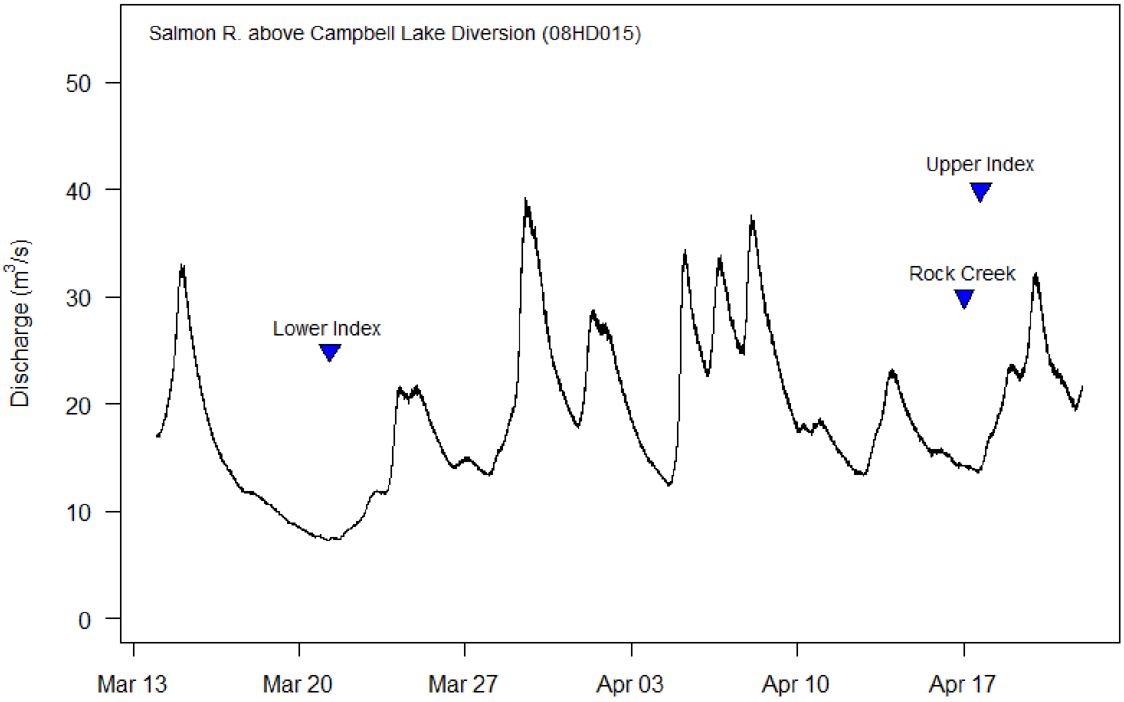


Table 20. Salmon River adult steelhead survey details and conditions, 2017.

Date	Survey reach	Section	Upstream limit	Downstream limit	Distance (km)	Time in	Time out	# Swimmers	Total Effort (hh:mm)	Temperature		Visibility (m)
										Air	Water	
17-Apr-2017	Rock Creek	N/A	Rock Creek Mainline Bridge	Diversion Dam	6.2	13:35:00	16:20:00	2	5:30	10.0	4.8	7
27-Apr-2017	Upper Index	Upper	Diversion Dam	Memekay Mainline Bridge	5.6	11:30:00	13:20:00	2*	3:50	12.0	5.5	7
		Lower	Memekay Mainline Bridge	Norberg Creek Confluence	5.9	12:05:00	14:10:00	2	4:10	12.0	5.5	7
21-Mar-2017	Lower Index	Upper	Cable Crossing to Kay Creek	Big Tree Creek Confluence	7.2	10:50:21	13:55:38	2	6:10	4.5	3.0	6
		Lower	Big Tree Creek confluence	Pallans	4.3	11:35:37	13:55:50	2	4:40	4.5	3.0	6

[*] For the Upper Section of the Upper Index Survey reach, a side channel was surveyed by a single swimmer totalling 10 minutes of effort. This was added to the section total effort.

Table 21. Salmon River snorkel survey observations, 2017.

Date	Reach	Section	Species[1]	Total observed	Density (#/km)	Adult fork length (mm)[2]						Marked Fish (#)	Redd count	Sex (ST only)		
						Fry	Parr	151–250	251–350	351–450	450+			M	F	UNK
17-Apr-17	Rock Creek	N/A	NFO	0	0.0	0	0	0	0	0	0	0	0	0	0	0
27-Apr-17	Upper Index	Upper	ST	8	1.4	0	0	0	0	0	8	0	6	6	2	0
		Lower	ST	8	1.4	0	0	0	0	0	8	0	0	3	3	2
21-Mar-17	Lower Index	Upper	RB	1	0.1	0	0	0	0	1	0	0	0	N/A	N/A	N/A
			ST	31	4.3	0	0	0	0	0	31	0	0	6	2	23
		Lower	CT	20	4.7	0	0	0	12	8	0	0	0	N/A	N/A	N/A
			ST	23	5.3	0	0	0	0	0	23	0	0	4	14	5

[1] ST, steelhead; RB, resident Rainbow Trout; CT, Cutthroat Trout

[2] Additional trout were observed; only trout > 250 mm were recorded.

Figure 10. Salmon River adult steelhead total counts and condition, 2017. Note that counts were conducted on different dates (Table 20).

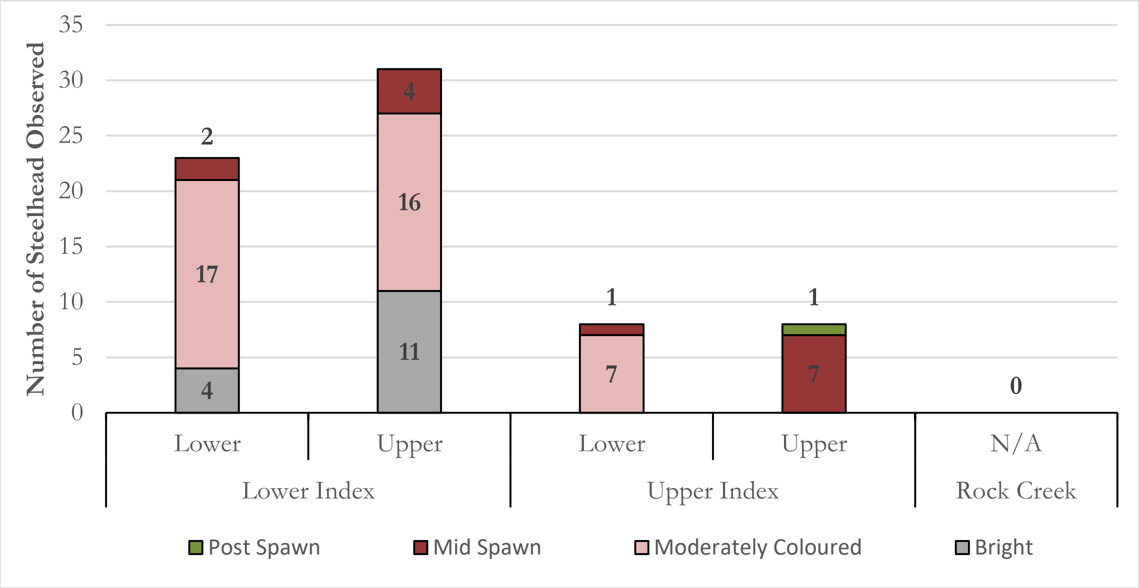


Figure 11. Historical and 2017 adult steelhead counts for the Lower Index reach, Salmon River. Absence of bars for some years indicates that no survey was conducted. Historical data (pre-JHTMON-8) from Pellett (2013). Dashed horizontal lines denote percentiles.

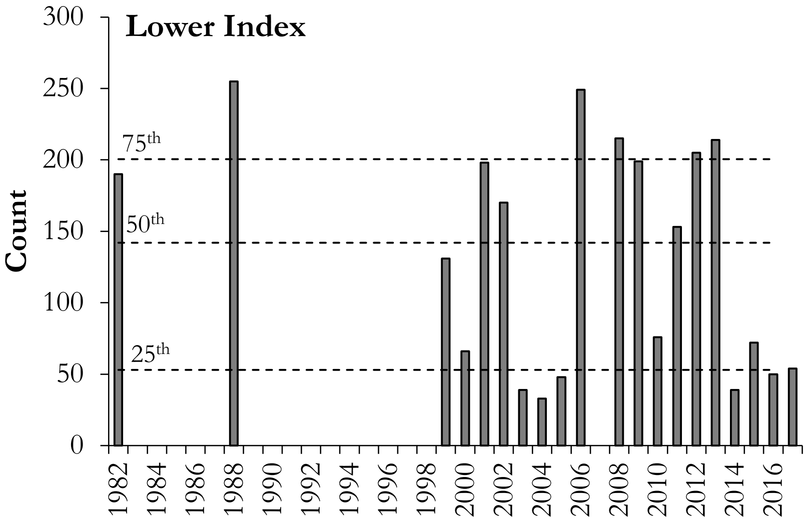


Figure 12. **Historical and 2017 adult steelhead counts for the Upper Index reach, Salmon River. All data relate to surveys undertaken in April. Dashed horizontal lines denote percentiles.**

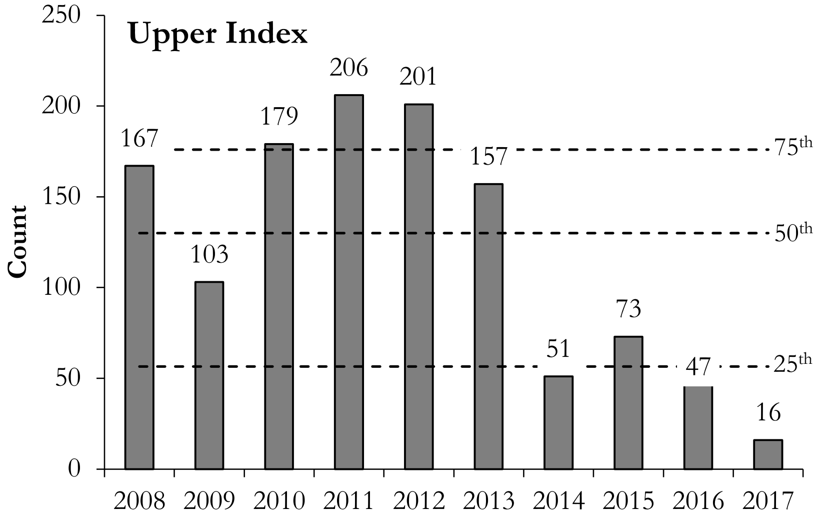
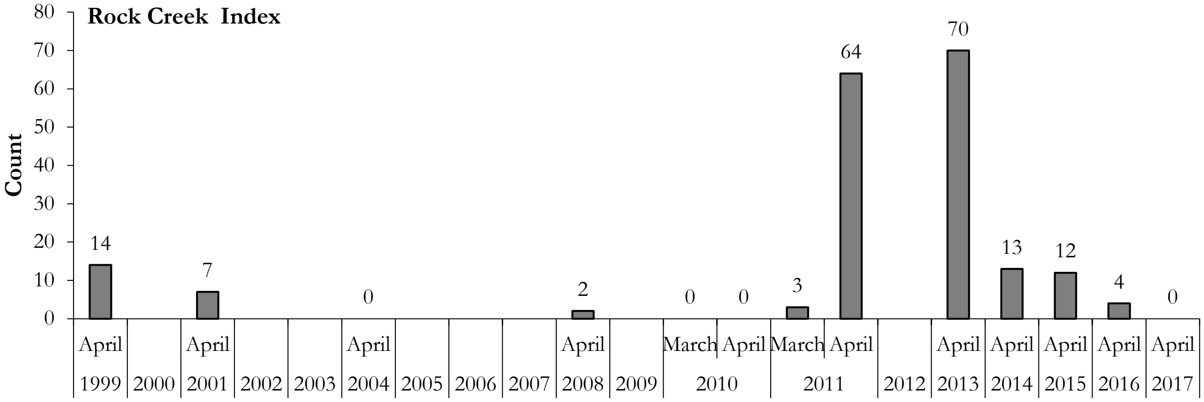


Figure 13. **Historical and 2017 adult steelhead counts for the Rock Creek index reach, Salmon River. Absence of bars for some years indicates that no survey was conducted, unless labelled '0'. Pre-JHTMON-8 data from Pellett (2013).**



3.1.2. Salmon River Juvenile Steelhead Abundance

3.1.2.1. Flow and Habitat

Electrofishing was undertaken on September 5–7, 2017, consistent with the timing of historical sampling. Flow conditions were appropriate for effective sampling; discharge measured upstream of the diversion dam (WSC gauge 08HD015) was 0.78–0.90 m^3/s and discharge measured downstream of the diversion dam (above Memekay River WSC gauge 08HD007) was 0.70 m^3/s to 0.87 m^3/s.

Habitat characteristics of the ten sites sampled for juvenile steelhead in 2017 are shown in Table 22. All sites were located in riffle mesohabitat; site areas ranged from 88.9 m^2 to 141.2 m^2. Gradient varied between 1.0% and 2.0%; water temperature during sampling varied between 15.4°C and 20.0°C (Table 22). Boulder or cobble were the dominant cover and substrate type.

Table 22. Habitat characteristics for juvenile steelhead abundance sampling sites in the Salmon River watershed, 2017.

Location	Site	Meso-habitat	Site Length	Site Width (m)	Site Area (m^2)	Gradient (%)	Water Temp.	Cover Type[1]		Substrate Composition (%)[2]					
								D	SD	BR	BO	CO	LG	SG	F
Below Diversion	SAM-EF01	Riffle	17.7	8.0	141.2	1.0	15.4	CO	n/a	0	0	10	60	30	0
	SAM-EF02	Riffle	13.9	8.3	115.0	1.7	18.8	CO	BO	0	20	55	20	3	2
	SAM-EF03	Riffle	13.9	7.1	98.9	1.5	19.0	BO	CO	0	60	30	5	3	2
	SAM-EF04	Riffle	14.1	6.8	95.3	1.0	n/c	BO	CO	0	55	35	5	3	2
	SAM-EF07	Riffle	16.7	6.3	105.9	1.0	16.0	BO	CO	0	60	32	6	2	0
Above Diversion	SAM-EF05	Riffle	14.8	7.1	105.5	1.5	15.8	CO	BO	0	20	65	10	5	0
	SAM-EF06	Riffle	10.0	8.9	88.9	1.0	17.3	BO	CO	0	25	55	15	3	2
	SAM-EF08	Riffle	11.3	8.3	93.9	2.0	20.0	CO	BO	0	30	55	7	5	3
	SAM-EF09	Riffle	13.7	9.4	129.1	2.0	19.5	BO	LWD, CO	0	50	35	7	8	0
	SAM-EF10	Riffle	12.4	7.3	90.2	2.0	15.8	CO	BO	0	35	55	8	2	0

[1] D = Dominant, SD = Sub-Dominant, LWD = Large Woody Debris, B = Boulders, CO =Cobble, UC = Undercut Banks, OV = Overhanging Vegetation, n/a = None

[2] BR = Bedrock, BO = Boulder, CO = Cobble , LG = Large Gravel, SG = Small Gravel, F = Fines

3.1.2.2. Catch Summary

Electrofishing effort varied from 2,145 seconds to 2,865 seconds among sites, with three passes completed at eight sites, and two passes completed at two sites (Table 23). In total, 341 juvenile steelhead were captured; 263 fish were captured in sites downstream of the diversion and 78 fish were captured upstream of the diversion. The average catch per site was 53 fish downstream of the diversion and 16 fish upstream of the diversion.

Table 23. Sampling effort and catch summaries for juvenile steelhead sites sampled in the Salmon River watershed, September 2017.

Location	Site	Date	Total Electrofishing Effort (sec)[1]				Electrofishing Catch (# of RB)[1]			
			Pass 1	Pass 2	Pass 3	Total	Pass 1	Pass 2	Pass 3	Total
Below Diversion	SAM-EF01	7-Sep-17	1,133	892	840	2,865	109	25	10	144
	SAM-EF02	7-Sep-17	1,160	890	n/a	2,050	24	2	n/a	26
	SAM-EF03	6-Sep-17	1,165	819	612	2,596	28	11	2	41
	SAM-EF04	6-Sep-17	1,250	932	655	2,837	34	11	2	47
	SAM-EF07	7-Sep-17	1,203	1,015	647	2,865	3	2	0	5
		Below Diversion Total				**13,213**				**263**
		Below Diversion Average				**2,643**				**53**
Above Diversion	SAM-EF05	6-Sep-17	902	830	613	2,345	5	2	0	7
	SAM-EF06	6-Sep-17	960	762	590	2,312	5	5	0	10
	SAM-EF08	5-Sep-17	1,024	827	626	2,477	12	1	0	13
	SAM-EF09	5-Sep-17	1,275	870	n/a	2,145	21	6	n/a	27
	SAM-EF10	5-Sep-17	1,014	815	409	2,238	16	3	2	21
		Above Diversion Total				**11,517**				**78**
		Above Diversion Average				**2,303**				**16**
	Combined Total					**24,730**				**341**
	Combined Average					**2,473**				**34**

[1] "n/a" indicates that an electrofishing pass was not completed.

3.1.2.3. Juvenile Steelhead Length-Weight Relationships

Juvenile steelhead fork length ranged from 34 mm to 134 mm below the diversion, and 39 mm to 139 mm above the diversion (Figure 14). Below the diversion, the distribution shows a clear peak between 35 mm and 70 mm. Above the diversion, the distribution was relatively even among the age classes (low kurtosis), although it was bimodal with a small peak between 35 mm and 70 mm, and a slightly larger peak between 80 mm and 100 mm. The overall low frequency of larger fish greater than 80 mm reflects the focus on sampling age 0+ fry.

Scale samples were analyzed to determine age for 18 juvenile fish at the Ecofish laboratory in Campbell River, BC. Based on review of these results (Figure 15) and the fork length histograms (Figure 14), discrete fork length ranges were defined for each age class and year, with ranges applied consistently to all fish sampled upstream and downstream of the diversion. Fish with fork length ≤ 76 mm were classed as fry (0+) and those measuring between 77 mm and 128 mm were classed as aged 1+. Fish with fork length ≥129 mm were classified as 2+ fish.

Figure 14. **Fork length histogram for juvenile steelhead captured in the Salmon River watershed, September 2017.**

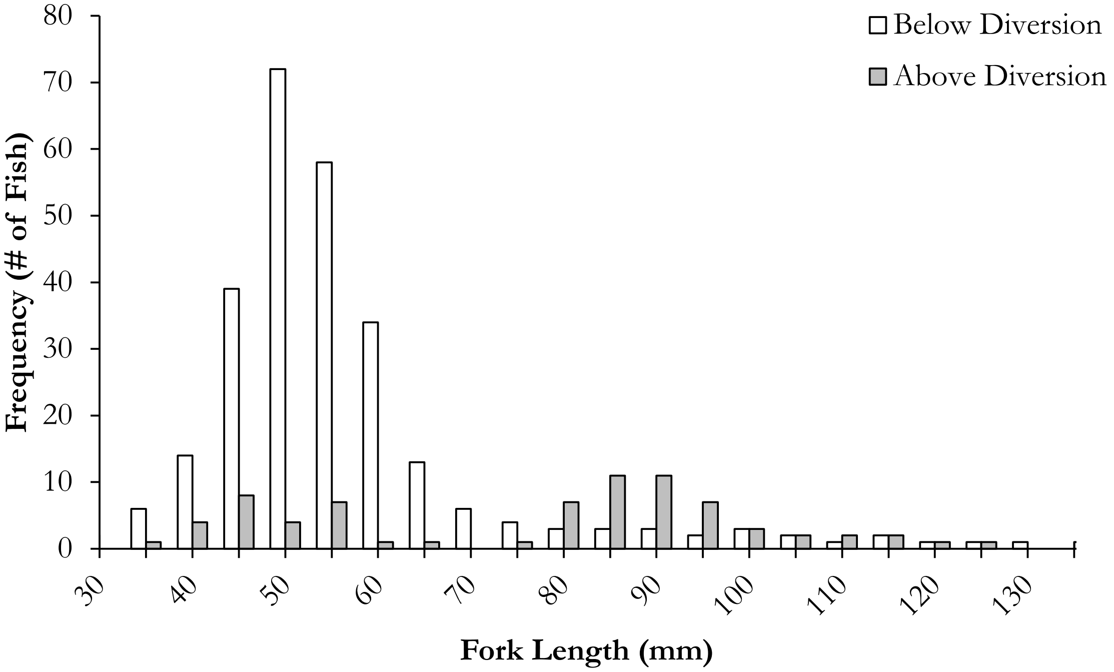
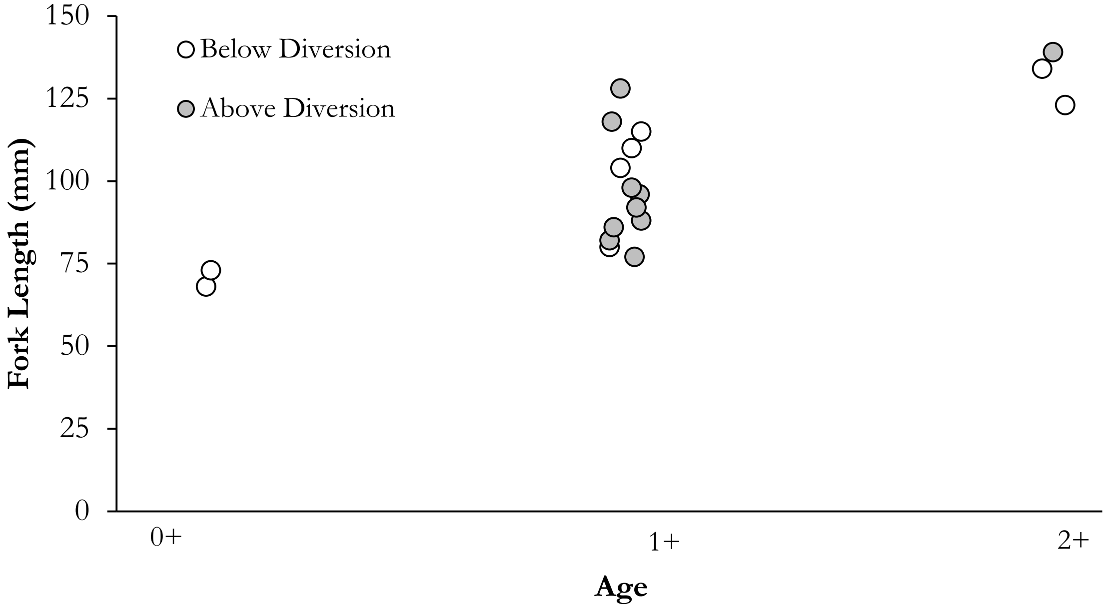


Figure 15. **Length at age of juvenile steelhead captured in the Salmon River watershed, September 2017.**



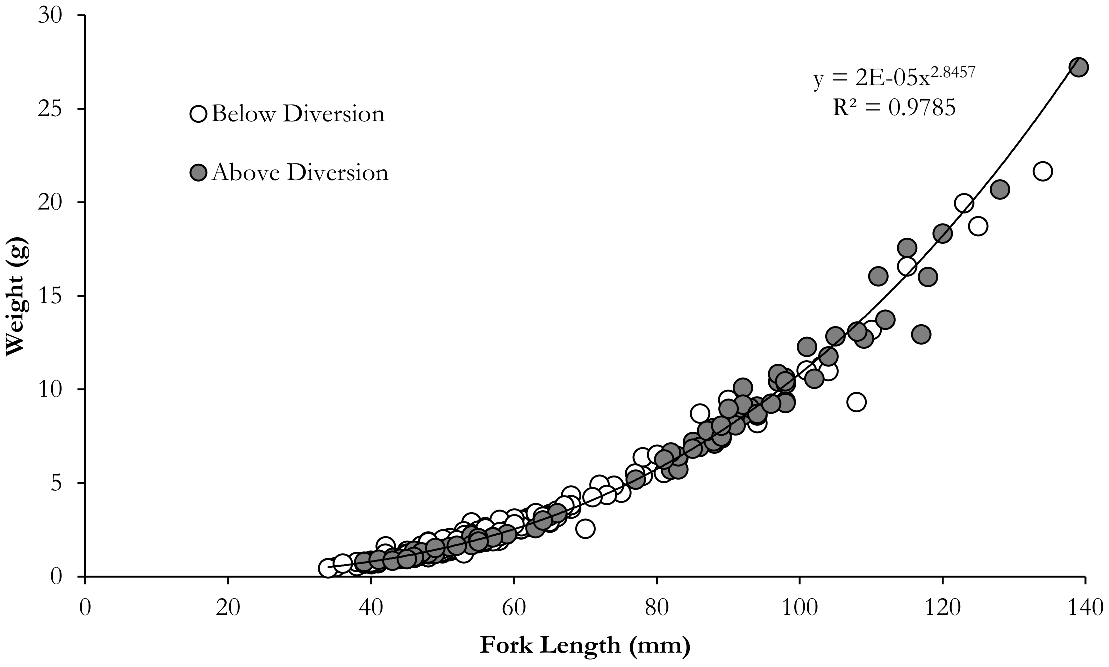
Fork length was measured for all 345 juvenile steelhead captured in 2017, and weight was also measured for 336 fish (Table 24). Length-weight relationships for the 336 fish are shown in Figure 16. These relationships are well-described by a power function, which indicates that fork length accounts for 98% of the variance in juvenile steelhead weight.

Table 24 shows the fork length, weight and condition of juvenile steelhead. Overall, the average condition was similar among age classes, and averaged 1.09 above the diversion and 1.17 below the diversion. These values approximate the nominal condition factor of 1.10 that the BC Ministry of Environment deems representative of well-conditioned juvenile Rainbow Trout/steelhead (Ptolemy, pers. comm. 2016). On average, 0+ fry sampled below the diversion had higher fork length (54 mm compared with 51 mm) and greater weight (1.9 g compared with 1.6 g) than 0+ fry sampled above the diversion.

Table 24. Summary of fork length, weight and condition of juvenile steelhead captured during electrofishing at 10 sites in the Salmon River watershed in 2017.

Location	Age Class	Fork Length (mm)				Weight (g)				Condition Factor (K)			
		n	Average	Min	Max	n	Average	Min	Max	n	Average	Min	Max
Below Diversion	0+	243	54	34	75	234	1.9	0.4	4.9	234	1.18	0.73	2.02
	1+	19	96	77	125	19	9.9	5.3	19.9	19	1.09	0.74	1.35
	2+	1	134	134	134	1	21.6	21.6	21.6	1	0.90	0.90	0.90
Combined Total		263	57	34	134	254	2.6	0.4	21.6	254	1.17	0.73	2.02
Above Diversion	0+	28	51	39	66	28	1.6	0.7	3.3	28	1.11	0.99	1.34
	1+	53	95	77	128	53	9.6	5.1	20.6	53	1.09	0.81	1.28
	2+	1	139	139	139	1	27.1	27.1	27.1	1	1.01	1.01	1.01
Combined Total		82	81	39	139	82	7.1	0.7	27.1	82	1.09	0.81	1.34

Figure 16. Length-weight regression for juvenile steelhead (*n* = 336) captured in the Salmon River watershed, September 2017.

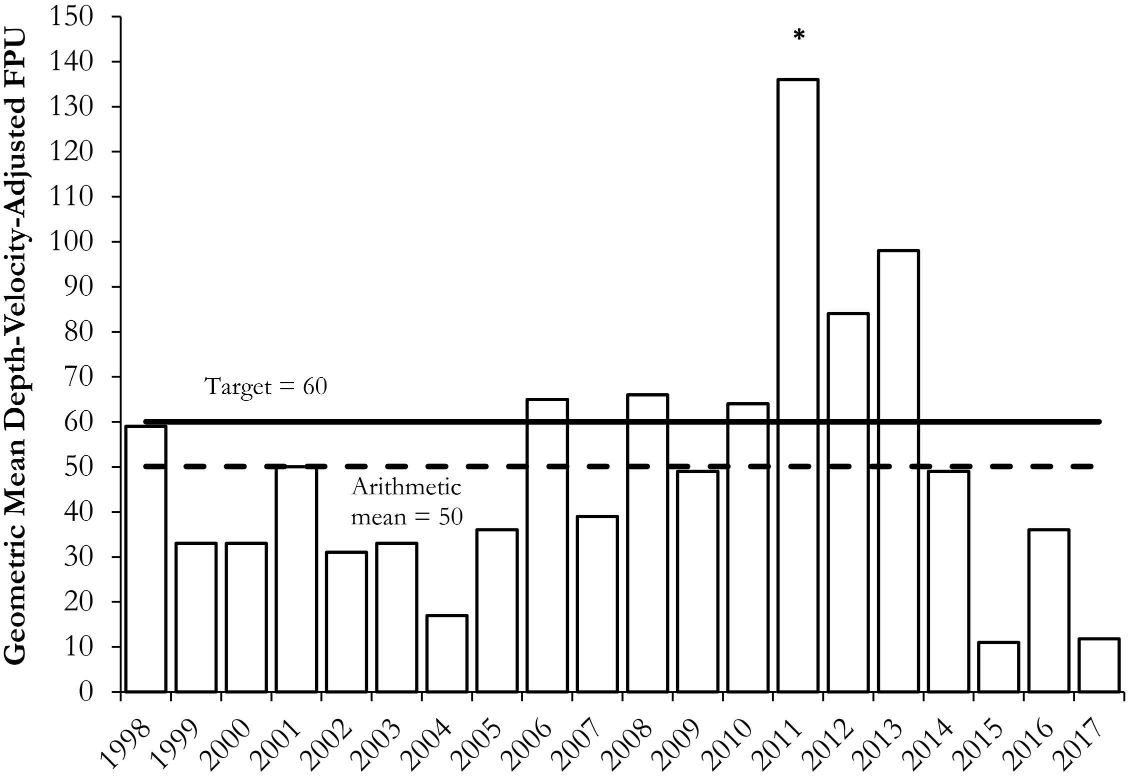


3.1.2.4. Fish Abundance

The geometric mean depth-velocity-adjusted-abundance in 2017 was 12 fry per 100 m^2 (fry per unit/FPU), which is below the precautionary target of 60 FPU set for the watershed by provincial biologists (Figure 17). The target of 60 FPU was based on a predicted juvenile Rainbow Trout/steelhead capacity of 162 g/100 m^2 (Lill 2002) and assumes a mean fry weight of 2.7 g (Pellett 2014). The mean FPU was below the arithmetic mean for the sampling period (1998–2017; 50 FPU).

The value obtained in 2017 was similar to 2015 (11 FPU) but significantly lower than values obtained in 2014 (49 FPU) and 2016 (36 FPU) during the JHTMON-8 program.

Figure 17. **Geometric mean depth-velocity-adjusted-abundance of steelhead fry (fry per unit, FPU) sampled in the Salmon River watershed in 1998–2017.**



* Only sites upstream of the diversion dam were sampled in 2011 (Pellet 2011b)

The density of steelhead fry in the Salmon River and tributaries was variable among sites in 2017 (Figure 18), with a coefficient of variation of 152%. Variability among sites was greatest downstream of the diversion dam, although densities were generally greatest at those sites. The highest density of fish was observed at SAM-EF01 (195 FPU), and the lowest density at sites SAM-EF05, 06, 07 and 08 (2 FPU). Mean observed density below the diversion was 41 FPU compared to 23 FPU upstream of the diversion. Adjusted densities showed a greater variance below and above the diversion with values of 66.0 FPU compared to 8.1 FPU, respectively. Average habitat usability at the sites upstream and downstream of the diversion was the same at 67%. Mean depth-velocity adjusted biomass at sites upstream of the diversion (13.1 g/100m^2) was almost nine times lower than at sites downstream of the diversion (126.2 g/100m^2), reflecting lower adjusted fry density and lower mean weight at sites upstream of the diversion.

Figure 18. Depth-velocity-adjusted steelhead fry abundance (fish per unit area; FPU) sampled at each site in the Salmon River watershed in 2017.

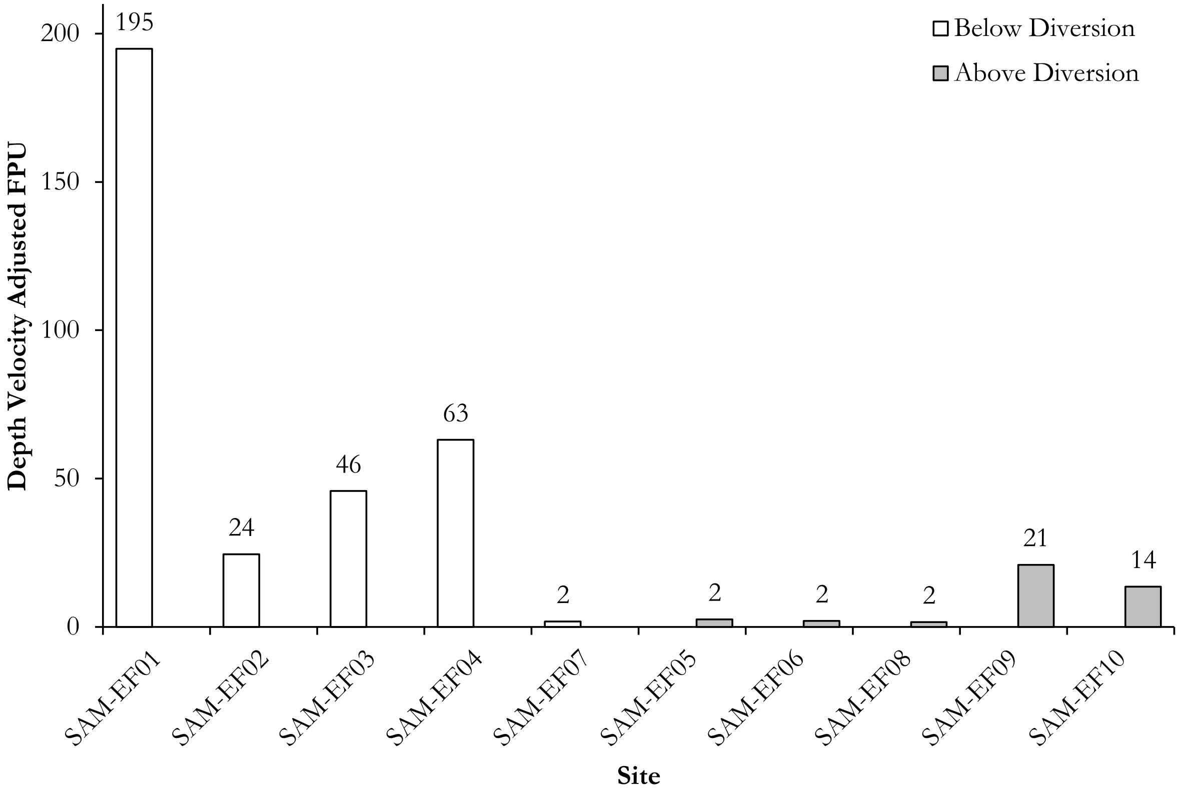


Table 25. Steelhead fry abundance and biomass results from electrofishing sites located upstream and downstream of the Salmon River Diversion, September 2017.

Location	Site	Usability (%)	Observed Densities[1,2]		Adjusted Densities[3,4]		Maximum Densities[5,6]	
			FPU_{obs} (#/100 m^2)	BPU_{obs} (g/100 m^2)	FPU_{adj} (#/100 m^2)	BPU_{adj} (g/100 m^2)	FPU_{max} (#/100 m^2)	BPU_{max} (g/100 m^2)
Below Diversion	SAM-EF01	53%	103.4	208.7	194.9	393.4	111	224.9
	SAM-EF02	85%	20.9	66.2	24.5	77.7	71	224.9
	SAM-EF03	79%	36.4	39.6	45.8	49.9	207	224.9
	SAM-EF04	65%	40.9	66.7	63.1	102.7	138	224.9
	SAM-EF07	54%	0.9	4.1	1.8	7.6	52	224.9
	Mean	**67%**	**40.5**	**77.1**	**66.0**	**126.2**	**115.9**	**224.9**
Above Diversion	SAM-EF05	76%	1.9	4.5	2.5	5.9	96	224.9
	SAM-EF06	57%	1.1	3.7	2.0	6.5	68	224.9
	SAM-EF08	68%	1.1	2.0	1.6	3.0	118	224.9
	SAM-EF09	70%	14.7	21.8	20.9	31.0	152	224.9
	SAM-EF10	65%	8.9	12.4	13.6	19.0	161	224.9
	Mean	**67%**	**5.5**	**8.9**	**8.1**	**13.1**	**119.0**	**224.9**
All Sites Combined	**Mean**	**67%**	**23.0**	**43.0**	**37.1**	**69.6**	**117.4**	**224.9**

[1] FPU_{obs} = Observed fish per unit (100 m^2) based on population estimates computed using MicroFish V3.0

[2] BPU_{obs} = Biomass of fish per unit (100 m^2) based on population estimates computed using MicroFish V3.0

[3] FPU_{adj} = FPU_{obs}/Usability (%)

[4] BPU_{adj} = BPU_{obs}/Usability (%)

[5] FPU_{max} = Theoretical maximum biomass/mean weight (g) of the age class (by site)

[6] BPU_{max} = Theoretical maximum biomass based on mean growing season alkalinity measured at SAM-WQ in Year 1 and 2 (19.7 mg/L as $CaCO_3$) and a model provided by R. Ptolemy (Rivers Biologist, Ministry of Environment) ((alkalinity^0.62)×36). Note that this is extremely similar to the value that has been historically reported (224.5 g/100 m^2) based on an older, slightly different model and historic alkalinity measurements (e.g., see BCCF 2013).

Figure 19 shows the geometric mean depth-velocity adjusted fish density for sites above and below the diversion since 1998. The geometric mean density was lower for sites upstream of the diversion (5 FPU) compared with sites downstream of the diversion (30 FPU). This trend was also evident when comparing arithmetic mean values (Table 25). Below the diversion, results were comparable with previous years but generally lower than values obtained between 1998 and 2013. Above the diversion, results were the lowest on record (5 FPU), although they were only slightly lower than results for 2015 (second lowest on record). In relative terms, the difference between adjusted fish densities measured at sites upstream and downstream of the diversion in 2017 was the second greatest of all study years; the density measured upstream of the diversion was only 16% of the density measured downstream. On average for 1998–2017, the density measured upstream of the diversion was 83% of the density measured downstream (range of values: 7–200%). Geometric mean values are used here to compare results among years because these values are less sensitive to the influence of particularly low or high values than the arithmetic mean.

Figure 20 shows geometric mean adjusted densities of steelhead fry compared with the peak adult steelhead count from the 11.5 km Lower Index reach on the Salmon River (Kay Creek to Pallans). The general positive relationship between the two variables indicates that spawning and rearing habitats are not at carrying capacity, i.e., increased peak adult density is correlated with increased fry density the following years, indicating that habitats are not fully seeded. The 2017 datum indicates that, although steelhead fry and adult density were low overall, the relationship between fry and adult density was consistent with historical data, i.e., the data point lies close (although slightly below) the regression line. This suggests that early juvenile survival in 2017 was approximately average, or slightly below average, relative to previous years.

Figure 19. Geometric mean depth-velocity-adjusted juvenile steelhead (all age classes) fish per unit area (FPU) at sites upstream and downstream of the Salmon River Diversion, 1998–2017.

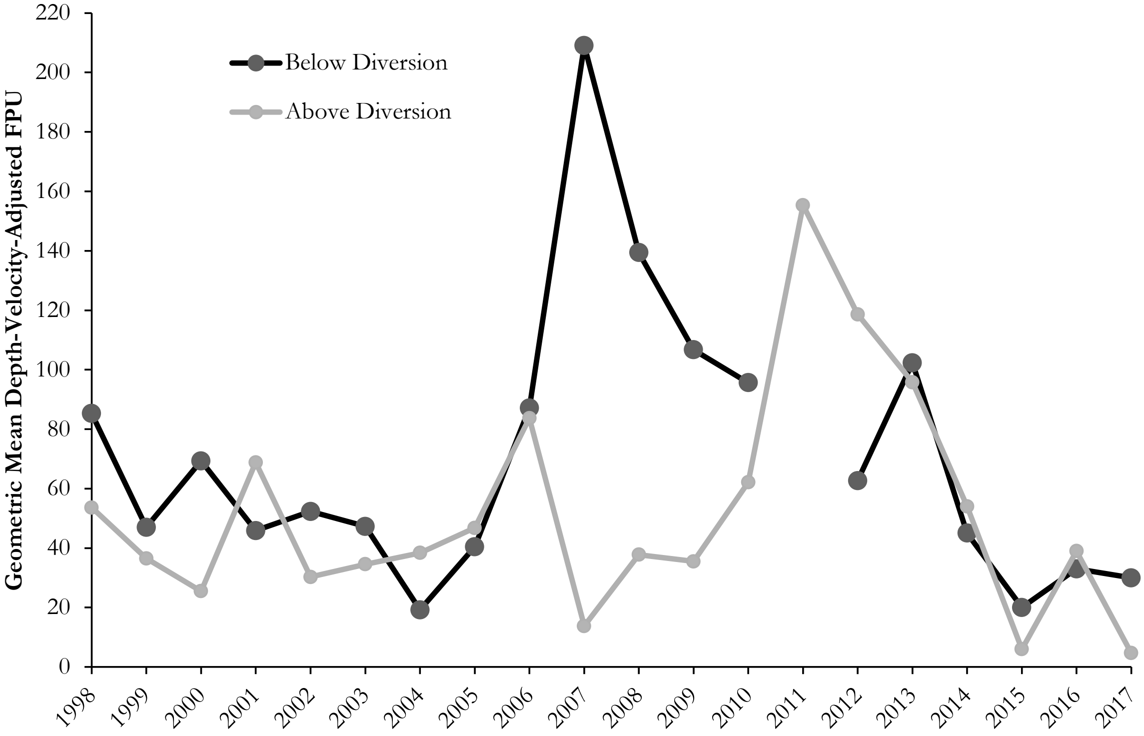
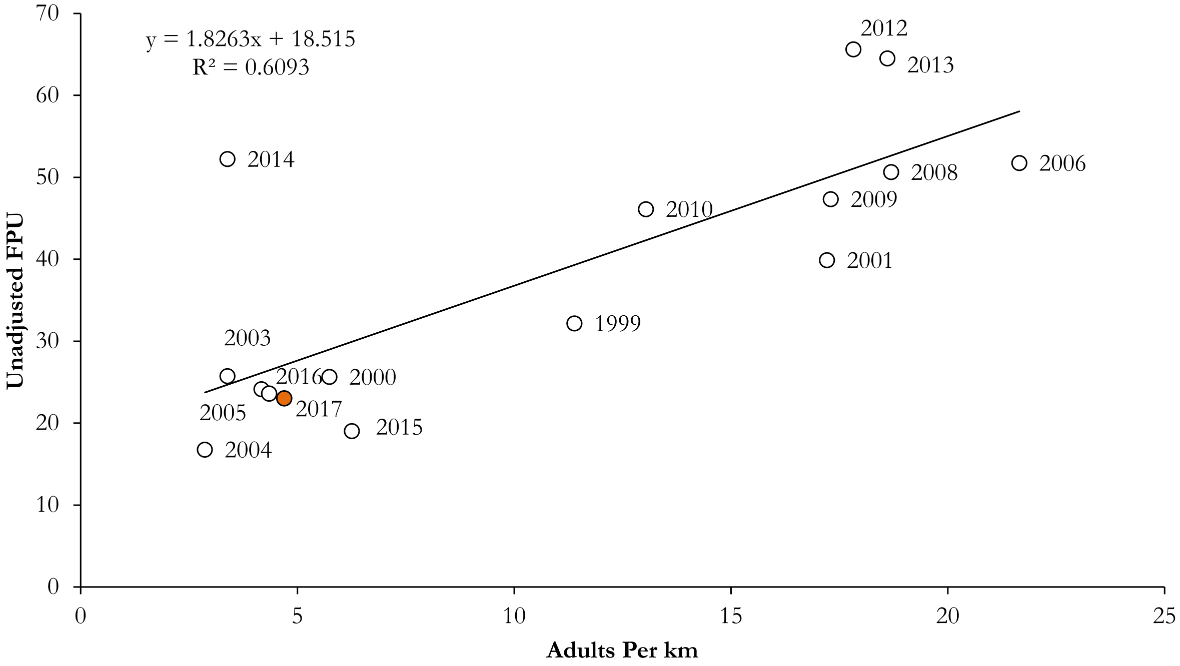


Figure 20. **Geometric mean annual juvenile steelhead fish per unit (FPU) vs. adult steelhead counts in the Lower Index reach during the previous year.**



3.1.3. Salmon River Juvenile Coho Salmon Abundance

3.1.3.1. Flow and habitat

Juvenile Coho Salmon sampling site characteristics are summarized in Table 26. In Year 4, sampling was conducted on September 19 and 20, 2017, consistent with previous years. Flows during 2017 sampling (1.71–2.19 m^3/s as measured at Salmon River above the Campbell Lake Diversion) were suitable for effective sampling.

At each site, the total sampling area ranged from 83 m^2 to 174 m^2, with 70% to 100% of the area containing water >0.1 m deep. Water temperatures ranged from 8.9°C to 11.8°C. The warmest temperatures were measured at Grilse Creek (SAM-BS02 and SAM-BS03C), which is upstream of the diversion (Map 2). The coldest temperature was recorded upstream of the diversion at Crowned Creek (SAM-BS01). The water depth was sufficiently low at all sites to permit effective sampling of the entire site (maximum depths 0.2 m to 1.5 m).

Table 26. Salmon River watershed juvenile Coho Salmon sampling site characteristics, 2017.

Location	Site	Sampling Date	Total Area (m^2)	Area >0.1 m Deep (m^2)	Water Temp (°C)	Habitat Type	Max Depth (m)	Discharge at Salmon R. Above Campbell Lake Diversion[1]	Discharge at Salmon R. Above Memekay River[2]
Upstream of Diversion	SAM-BS01	19-Sep-17	174	174	8.9	Riffle	0.2	1.71	1.43
	SAM-BS02	19-Sep-17	133	120	11.8	Pool	1.0	1.74	1.51
	SAM-BS03C	19-Sep-17	108	105	11.3	Pool	1.3	1.75	1.51
Downstream of Diversion	SAM-BS04	20-Sep-17	83	69	9.1	Pool	0.5	2.19	1.81
	SAM-BS05	20-Sep-17	101	70	9.9	Pool	0.7	2.15	2.00
	SAM-BS06	20-Sep-17	134	129	9.8	Pool	1.5	2.12	1.95

[1] Discharge data from Wateroffice Canada (2017); Gauge #08HD015, at time of sampling, m^3/s

[2] Discharge data from Wateroffice Canada (2017); Gauge #08HD007, at time of sampling, m^3/s

3.1.3.2. Catch Results

Catch results for individual sites are summarized in Table 27. In 2017, no juvenile Coho Salmon were caught at SAM-BS01 (consistent with all previous years), located upstream of the diversion in Crowned Creek. A total of 3 to 75 juvenile Coho Salmon were caught in 2 to 5 passes at each of the remaining sites; estimated density ranged from 0.03 fish/m^2 to 2.15 fish/m^2 at these sites. The total number of juvenile Coho Salmon caught in 2017 was 238.

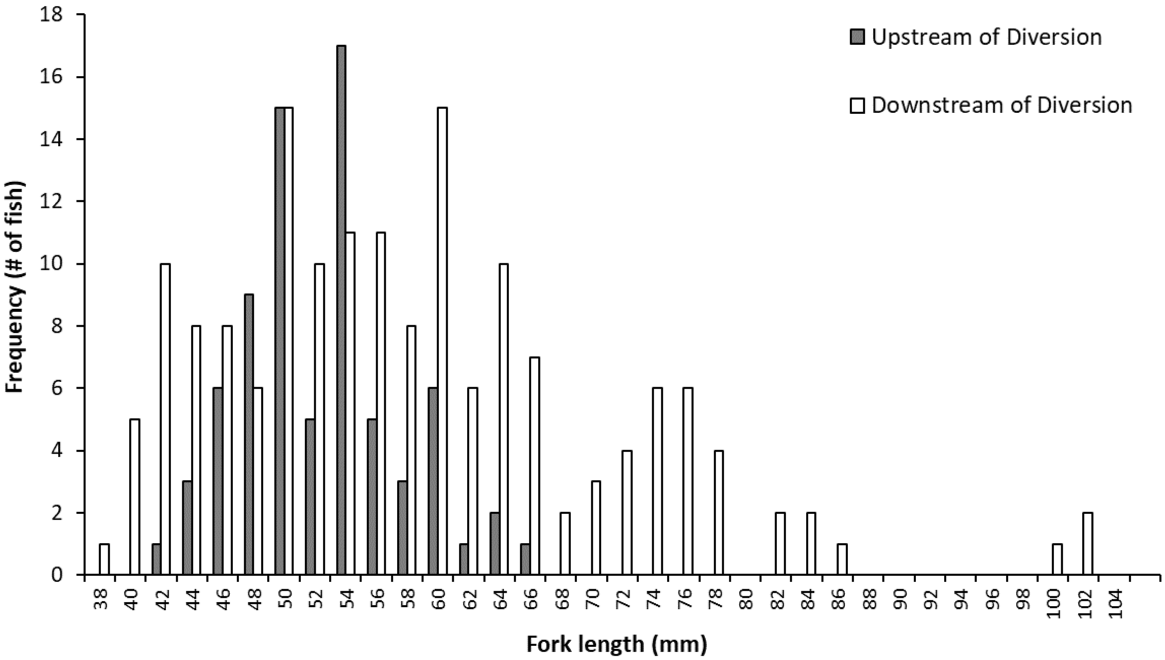
Fork length-frequency data for sites upstream and downstream of the Salmon River Diversion are summarized in Figure 21. Juvenile Coho Salmon ranged from 32 mm to 102 mm in length. The fish upstream of the diversion were generally smaller than those downstream of the diversion. Upstream of the diversion, the modal fork-length category was 48–54 mm (62% of fish), whereas the modal fork length category was 50–60 mm downstream of the diversion (43% of fish). The data for downstream sites exhibit a bi-modal distribution, although the data are skewed to the right, i.e., there were more fish caught in the smaller size classes. All fish >67 mm fork length were caught in the downstream sites.

Based on the results of scale analysis, all of the juvenile Coho Salmon caught in 2017 were aged 0+ except for the three largest fish that were aged 1+. In 2016, all captured fish were aged 0+. In 2015, only three fish aged 1+ were caught, with one fish caught at each of the three sites downstream of the diversion. In 2014, 1+ Coho Salmon comprised 6–28% of captures at each of the five sites where fish were caught. No 2+ aged Coho Salmon were caught in any year.

Table 27. Salmon River watershed juvenile Coho Salmon catch results, 2017.

Location	Site	# of Passes	Area (m^2)	Catch Results (# of Fish)			Mean Weight (g)	Estimated Abundance (# of Fish)	Estimated Density (# of Fish/m^2)
				Total	0+	1+			
Upstream of Diversion	SAM-BS01	2	174	0	0	0	0.0	0	0.00
	SAM-BS02	5	120	71	71	0	1.8	150	1.25
	SAM-BS03C	2	105	3	3	0	1.5	3	0.03
Downstream of Diversion	SAM-BS04	2	69	75	75	0	2.4	149	2.15
	SAM-BS05	3	70	63	63	0	1.6	69	0.98
	SAM-BS06	3	129	26	23	3	5.8	27	0.21

Figure 21. Fork length-frequency histogram of juvenile Coho Salmon captured in the Salmon River watershed, 2017.



3.1.3.3. Biomass Estimates

Estimated total biomass for 0+ and 1+ Coho Salmon is presented in Figure 22. Biomass for 0+ fish ranged from 0.00 g/m^2 in SAM-BS01 upstream of the diversion to 5.14 g/m^2 in SAM-BS04 downstream of the diversion. The estimated total biomass values for 0+ fish at the other four sites ranged from 0.04 g/m^2 to 2.30 g/m^2. The estimated total biomass for 1+ Coho Salmon was 0.36 g/m^2 at site SAM-BS06, the only site where 1+ fish were captured.

Comparison of estimated total biomass of juvenile Coho Salmon among the four years of the JHTMON-8 program shows that among-year variability is highest for the sites upstream of the diversion (Figure 23), with the exception of SAM-BS01, where no fish have been caught. With the exception of SAM-BS03(C), total biomass estimated during Year 4 was either higher or the same as during Year 3.

Figure 22. **Estimated biomass of juvenile Coho Salmon (Aged 0+ and 1+) at all sites sampled in 2017.**

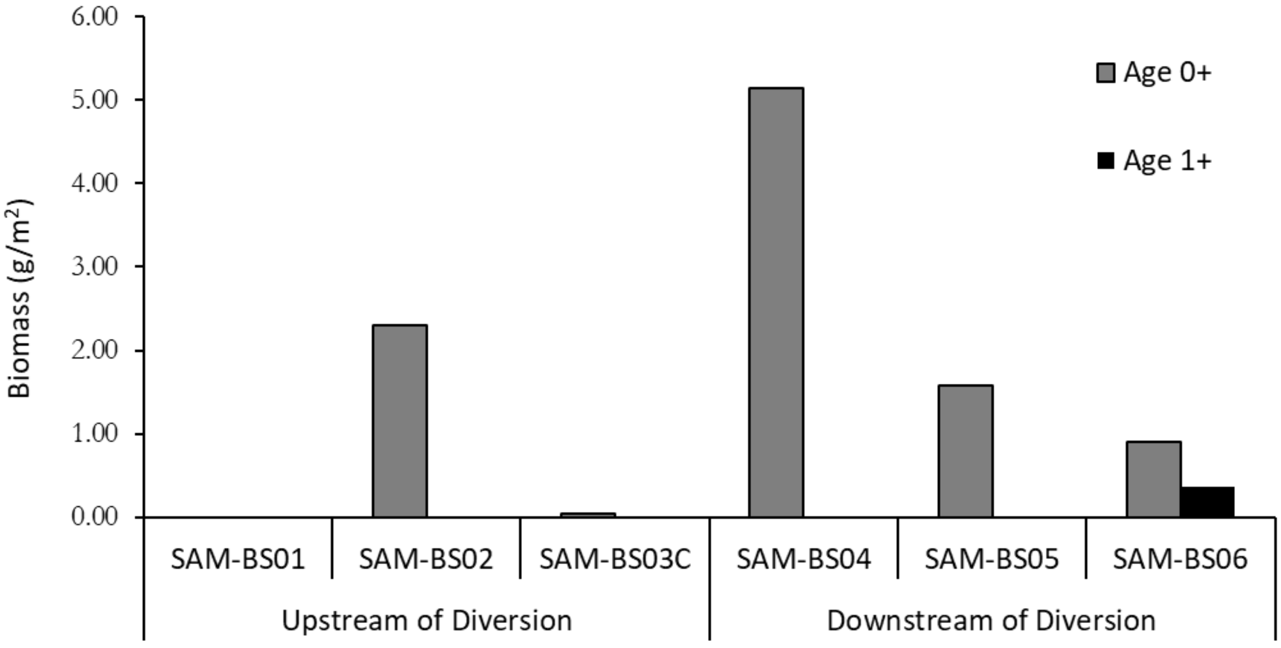
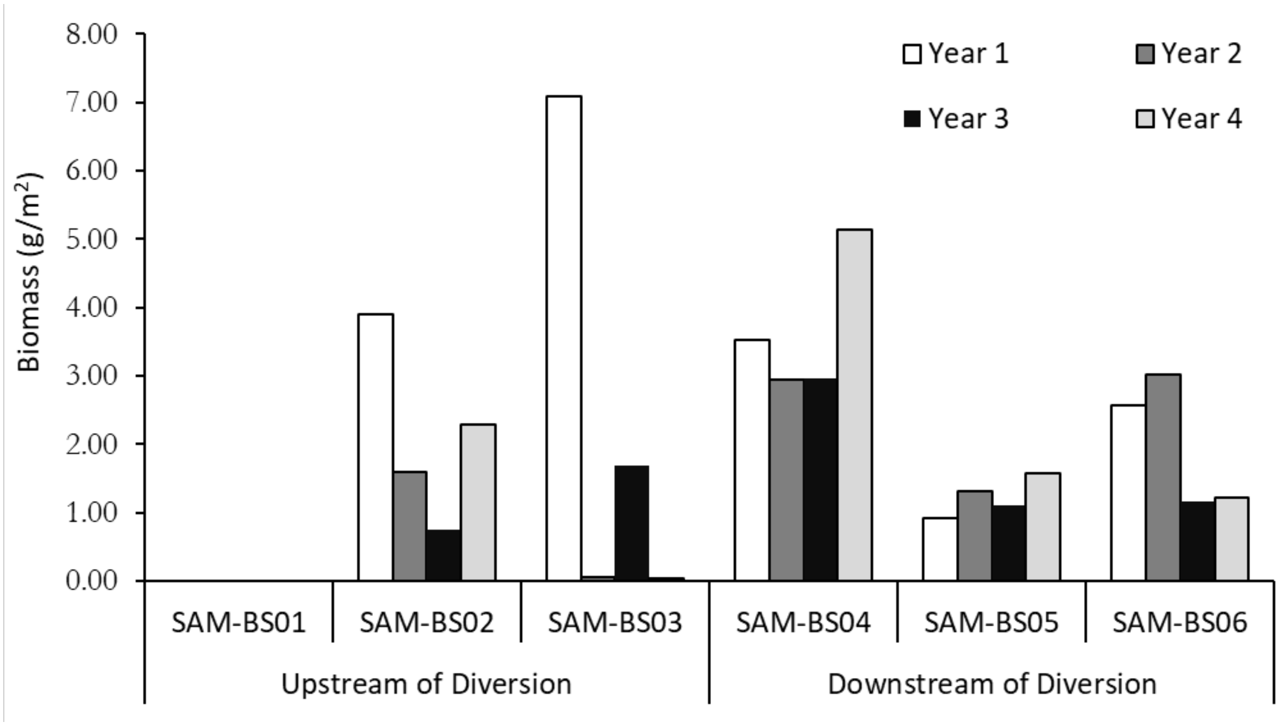


Figure 23. Total estimated Juvenile Coho Salmon biomass for each site during Years 1 to 4 (2014 to 2017).



3.1.4. Salmon River and Quinsam River Salmon Escapement, 2016

Salmon escapement data for 2016 (Year 3) for the Salmon and Quinsam rivers are presented in Table 28. Summary statistics for the period of record are also provided in this table to provide points of reference. Figure 24 and Figure 25 present salmon escapement data for the periods of record for the Salmon River and Quinsam River respectively.

Table 28. 2016 salmon escapement data for the Salmon and Quinsam rivers (DFO 2017).

River	Statistic	Salmon species				
		Chinook[1]	Chum	Coho[1]	Pink	Sockeye
Salmon	2016 count	68	0	275	6,704	2
	Mean (1953-2016)	844	937	3,265	30,708	31
	Median (1953-2016)	650	400	2,000	7,554	2
	10th percentile (1953-2016)	92	0	285	1,350	0
	90th percentile (1953-2016)	1,500	3,300	7,500	85,651	100
	Percent of years sampled (1953-2016)[2]	100	94	98	100	55
Quinsam	2016 count	6,978	208	7,397	51,032	9
	Mean (1953-2016)	4,117	495	12,308	130,620	54
	Median(1953-2016)	3,273	300	9,263	30,756	25
	10th percentile (1953-2016)	25	82	1,500	1,500	7
	90th percentile (1953-2016)	9,683	1,500	33,038	438,469	135
	Percent of years sampled (1953-2016)[2]	80	95	98	98	75

[1] Priority species for JHTMON-8.

[2] 'Percent of years sampled' is approximate; uncertainty in data recording means that a count of zero is not always distinguished from a record of 'not measured'.

Figure 24. Salmon escapement for the Salmon River (1953–2016; DFO 2017).

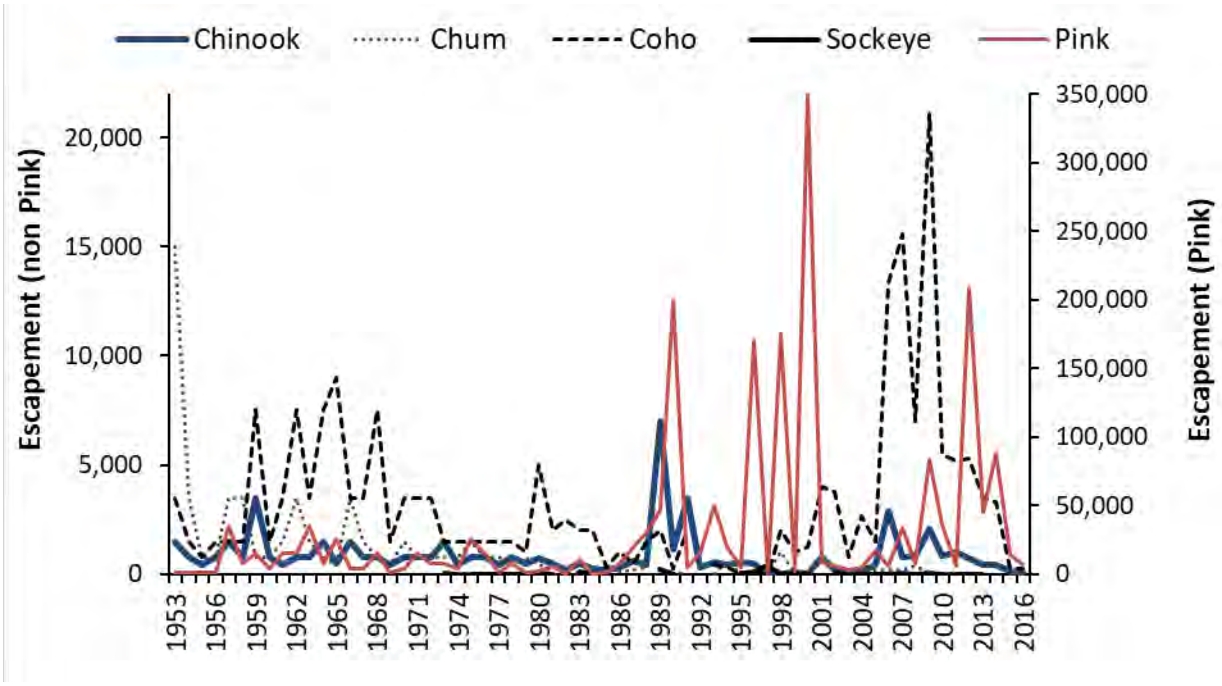
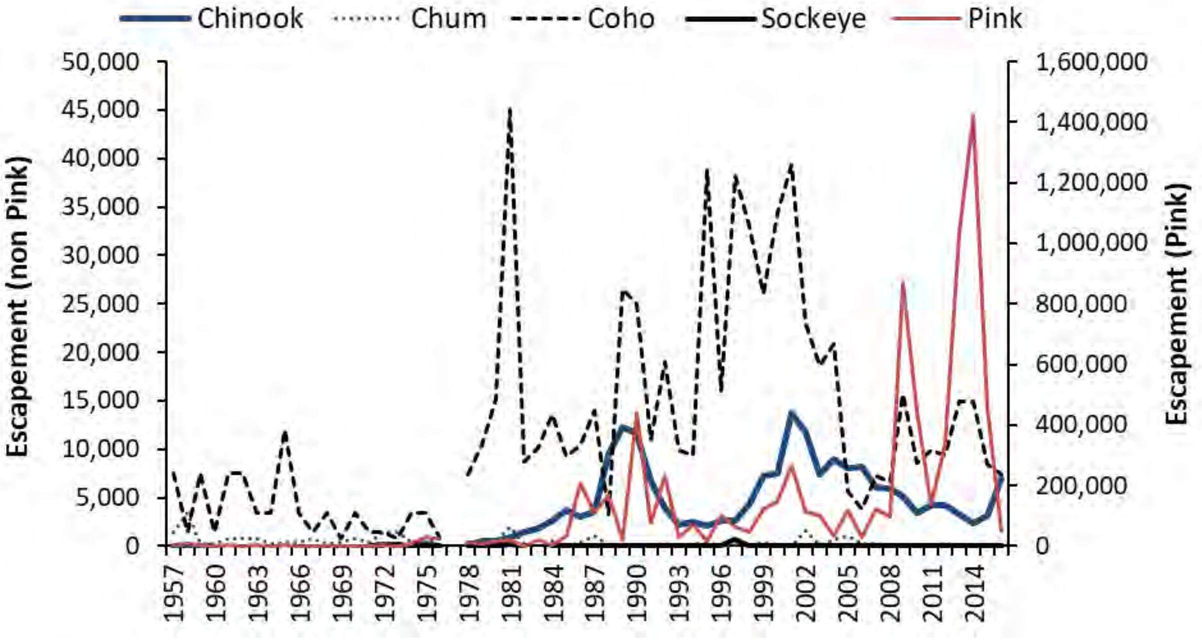


Figure 25. Salmon escapement for the Quinsam River (1957–2016; DFO 2017).



Pink, Coho and Chinook salmon were the dominant returning species in 2016, with escapement of each of these three species highest in the Quinsam River (Table 28). Salmon escapement was generally poor for the Salmon River: Chinook Salmon escapement (68) was the 5th lowest in 63 years and Coho Salmon escapement (275) was the 5th lowest in the 62-year record. Pink Salmon escapement on the Salmon River (6,704) was similar to the historical median (7,554) but well below the 10-year median (2007-2016, 34,906 fish). Chum Salmon escapement on the Salmon River was recorded as "none observed". For both Chum Salmon and Coho Salmon, the low counts may at least partly reflect the survey timing as the final inspection date recorded in the DFO data (September 15; Table 9) was before the start of the reported spawning periods for both species (October 1–December 15; Burt 2010). This means that fish migrating into the river later in the period were not counted. For context, the final Coho Salmon inspection date in 2013 was November 14 and October 7 in both 2014 and 2015. The sampling date bias is also expected to affect Chinook Salmon escapement estimates as the final survey date was at the start of the reported peak spawning period (14–30 September; Burt 2010).

On the Quinsam River, escapement of Chinook Salmon (6,978) was higher than the historical median (1953-2016; 4,117 fish) and was the highest escapement since 2006. This is most likely due to the resumption of a juvenile Chinook Salmon supplementation program in 2014 for the first time in ~10 years. Coho Salmon (7,397) escapement in 2016 was only slightly lower than 2015 (8,484) and the 10-year median (2007-2016, 8,980 fish). Pink Salmon escapement (51,032) in the Quinsam River in 2016 was higher than the 59-year median (1957-2016, 30,756 fish) but was only about 8% of the 10-year median (2007-2016, 391,535 fish). Pink Salmon escapement has generally increased in the Quinsam River since 2008 (records of >1 million fish in 2013 and 2014) and the broodline that spawns in even-numbered years is typically dominant. It is unclear why the Pink Salmon outmigration in 2017 was low, considering record Pink Salmon escapement was estimated in 2014.

3.1.5. Quinsam River Hatchery Salmon Counting Fence Operations

Data collected at the salmon counting fence are summarized in Table 29. The traps were monitored continuously from March 11 to June 15 and fish were sampled from the traps each day, with the exception of March 12 when the fish in the trap were not collected and May 16 when the number of captured fish exceeded the capacity of the trough and only a subsample of the total fish that passed through the trap were sampled. The March 11 start date for monitoring the traps was earlier than the start dates in previous years (March 19 in 2014, March 13 in 2015, and March 26 in 2016) and most likely covered the entire Pink Salmon fry migration in 2017.

Total estimated migration of Pink Salmon fry has been variable in the four years of the monitoring program and was 1.46 million in 2017 (Year 4) (Table 29). This is a decrease of 84% over the Year 3 abundance (9.2 million), 47% less than the abundance in Year 2 (2.7 million), and 93% less than Year 1 (22 million).

Total migration estimates for the three JHTMON-8 priority species in the Quinsam River (Coho Salmon, steelhead, and Chinook Salmon) are presented in Figure 26 as well asFigure 27. Total smolt abundance for Year 4 (54,279 Coho Salmon, 4,992 steelhead, 14,168 wild Chinook Salmon, and 153,570 colonized Chinook Salmon) was comparable to previous years in the study.

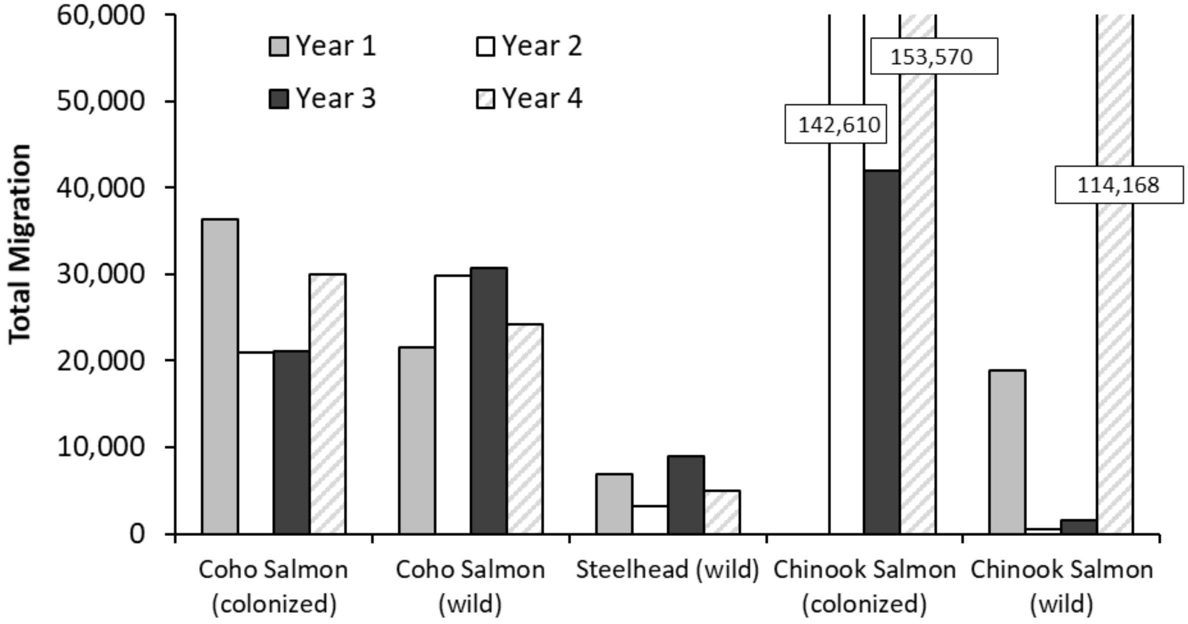
Table 29. Summary of downstream migration data and total migration estimates from sampling at the Quinsam River Hatchery salmon counting fence, March 11 to June 15, 2017.

Species	Life Stage	Total Counts	Total Estimated Migration[1]	Peak Migration	Migration Period	Comments
Coho Salmon (colonized)	Smolt	2,469	29,920	May 24	Apr 30 - Jun 5	
Coho Salmon (wild)	Smolt	1,902	24,239	May 17	Mar 28 - Jun 12	
Coho Salmon (2-year)	Smolt	12	120	May 21	Apr 28 - May 21	
Coho Salmon	Fry	1,798	42,362	Apr 21	Mar 14 - Jun 12	
Steelhead	Smolt	404	4,992	May 25	Apr 12 - Jun 8	
Steelhead	Fingerling	977	11,569	May 24	Mar 16 - Jun 12	
Steelhead	Kelts	1	31	Apr 22	Apr 22	
Cutthroat Trout	Fingerling	55	653	May 27	3 Apr - 11 Jun	
Cutthroat Trout	Smolt	29	356	Jun 03	13 Apr - Jun 15	Still migrating on Jun 15th
Cutthroat Trout	Kelts	2	39	n/a	Mar 21 - May 22	
Trout species	Fry	19	551	Mar 31	Mar 31	
Chinook Salmon	Fry	7,191	114,168	May 06	Mar 15 - June 15	Still migrating on Jun 15th
Chinook Salmon (colonized)	Fry	12,920	153,570	May 25	Mar 15 - June 15	Still migrating on Jun 15th
Chum Salmon	Fry	3,714	111,167	Apr 02	Start-June 5	
Sockeye Salmon	Fry	8	189	Apr 13	Apr 21 - Apr 22	
Pink Salmon	Fry	47,283	1,458,225	Apr 14	Start - May 21	
Dolly Varden	Smolt	0	0	n/a	n/a	
Lamprey (2 species)	all	230	3,466	May 17	Apr 6 - Jun 14	
Sculpin	all	184	3,153	May 17	Mar 14 - Jun 6	

[1] Based on capture efficiency measured for Pink Salmon and Coho Salmon.

"n/a" indicates no peak or migration period identified

Figure 26. **Total estimated outmigration of priority species on the Quinsam River during Years 1–4 (2014–2017). Coho Salmon and steelhead were captured at the smolt stage and Chinook Salmon at the fry stage.**



The survival of out-planted juvenile salmon was estimated by expressing the estimated outmigration of juvenile colonized salmon as a percentage of the total number of fish that were out-planted (Figure 27). Estimated survival of colonized juvenile Chinook Salmon in Year 4 was 74%; this was higher than Year 3 (28%) and Year 2 (66%). Note that colonized Chinook Salmon were still outmigrating in low numbers on June 15 when the sampling finished, indicating that the survival estimate may be biased low[3]. Estimated survival of colonized juvenile Coho Salmon in Year 4 was 20%; this was higher than Years 3 and 2 (13% survival both years), and similar to survival in Year 1 (21%). Note that the estimates for Coho Salmon assume that fish outmigrate aged 1+, although a small number of 2+ smolts were recorded at the fence[4].

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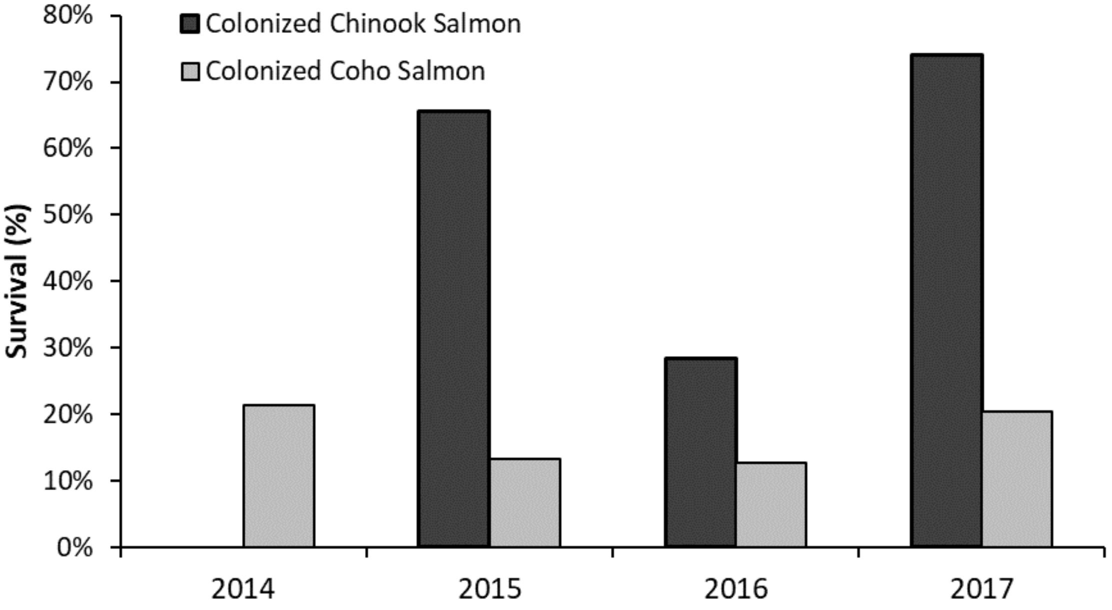
[3] Outmigration of juvenile Chinook Salmon in the Quinsam River is recorded to extend until the third week of July (Burt 2003).

[4] Estimated outmigration of 2+ Coho Salmon was 120 fish. Burt (2003) suggests that 2+ smolts represent fish that were trapped in off-channel habitats, preventing them from out-migrating the previous year.

Figure 27. **Estimated survival of out-planted salmon raised at the hatchery, based on the proportion of out-planted fish estimated to outmigrate at the salmon counting fence. Outmigrating Chinook Salmon were out-planted during spring (May) of the same year; outmigrating Coho Salmon were out-planted the previous year. No Chinook Salmon were out-planted in 2014.**



3.2. Water Quality

3.2.1. Year 1 to Year 3 Water Quality Data

Results from Years 1 to 3 (2014 to 2016) water quality monitoring are presented in Appendix A. Year 4 (2017) results are described below in Section 3.2.2; this includes discussion of any notable differences between results in Year 4 and previous years.

3.2.2. Water Chemistry

3.2.2.1. QA/QC Results

With the exception of pH, all laboratory analyses were conducted within the recommended hold times in 2017 (Appendix A). For pH, all samples for all sites and sample dates exceeded the recommended hold time of 0.25 hours. Both laboratory and field data for pH are presented in the following sections.

Clark (2013) and RISC (2003) recommend that results for duplicate samples should have relative percent difference (RPD) or relative standard error (RSE) values of 20% or less (provided that the concentrations are greater than five times higher than the MDL), otherwise it can indicate a potential issue with the sample. Contamination is suspected when the relative variability between duplicates exceeds 50% (Clark 2013).

In 2017, considering parameters with concentrations five times higher than the MDL, there was only a single sample and single parameter for which the duplicate values exhibited > 20% relative variability (total dissolved solids, sampled on May 10, 2017 at the QUN-WQ site, with an RSE of 39%). Variability between all other duplicate samples for all other parameters at both sites was below 20%. It is unlikely that the high variability in the total dissolved solids measurements for these duplicates is due to contamination of the sample, since values for other parameters measured in the same samples do not show high variability. It is possible that the variability in the duplicates is a result of sample heterogeneity associated with collecting two samples within a span of a few minutes. The concentrations of total dissolved solids in these duplicate samples are within the range measured at the QUN-WQ site in Years 1 through 4.

Although field and trip blanks were not collected in 2017, examination of the data collected between 2014 and 2016 shows that, for the majority of samples (96.2%), concentrations measured in field and trip blanks were below the MDL. The exception is for total ammonia, for which the trip blank (but not the field blank) results were above the MDL in 15 out of 18 samples. Since the trip blank was provided by the laboratory in a pre-filled bottle and was not opened in the field, and the field blank results were below the MDL, it is likely that there was contamination of the sample at the laboratory.

3.2.2.2. Salmon River

The *in situ* and lab water chemistry results for the Salmon River at SAM-WQ are summarized in Table 30 (general variables measured *in situ*), Table 31 (DO), Table 32 (general variables measured at ALS labs), and Table 33 (low level nutrients measured at ALS labs).

Ranges for individual water quality variables that were measured during the Year 4 sampling in the Salmon River are described below. Instances where values exceed the provincial or federal WQG-AL, or are not within the normal ranges of BC streams, are discussed in additional detail (see Appendix A for applicable WQG-AL and typical ranges).

Alkalinity

Alkalinity (as $CaCO_3$) measured at ALS labs in 2017 was similar to previous years. Alkalinity ranged from 12.4 mg/L (May) to 25.4 mg/L (September; Table 32). Alkalinity concentrations less than 10 mg/L in streams indicate sensitivity to acidic inputs, or poor buffering capacity. Alkalinity in the range of 10 mg/L to 20 mg/L indicates that the watercourse is moderately sensitive to acidic inputs, whereas values greater than 20 mg/L suggest a low sensitivity (RISC 1997b). Thus, the Salmon River is moderately sensitive to acidic inputs during the majority of the growing season.

Specific Conductivity and Total Dissolved Solids

Specific conductivity (i.e., conductivity normalized to 25°C) measured *in situ* in 2017 was similar to previous years. Values ranged from 23.7 μS/cm (June) to 55.4 μS/cm (September) (Table 30). Similarly, lab values for conductivity ranged from 27.9 μS/cm to 57.3 μS/cm, with the lowest value occurring in June and the highest in October (Table 32). Coastal BC streams generally have a specific conductivity of ~100 µS/cm (RISC 1997b). Thus, results show that the Salmon River has a relatively low concentration of dissolved ions.

Total dissolved solids measured in the lab for the Salmon River ranged from 18 mg/L to 47 mg/L, similar to 2016 (Table 32).

pH

pH values measured in the laboratory ranged from 7.31 (October) to 7.68 (September), whereas *in situ* pH ranged from 6.10 to 7.37 (Table 32 and Table 30, respectively). Between July and October 2017, the pH values measured *in situ* were below of the range recommended by the BC WQG-AL (6.5 to 9.0), similar to the pH values measured between May and July in 2016. All other values were similar to previous years and were within the range recommended by the BC WQG-AL.

Natural fresh waters have a pH range from 4 to 10; BC lakes tend to have a pH ≥ 7.0, and coastal streams commonly have pH values of 5.5 to 6.5 (RISC 1997b). The pH values measured *in situ* are within the range expected for coastal streams and may represent more reliable measurements of the stream pH than the laboratory pH values, given that the pH measured in the laboratory samples exceeded the recommended hold time.

Turbidity and Total Suspended Solids (TSS)

Turbidity in the Salmon River at SAM-WQ was low in 2017, similar to previous years, indicating high water clarity (values ranged from 0.17 NTU to 0.36 NTU; Table 32). Similarly, low TSS concentrations were measured throughout the sampling period, with concentrations that were predominantly non-detectable (<1.0 mg/L to 3.1 mg/L; Table 32).

Dissolved Oxygen

Dissolved oxygen concentrations in the Salmon River were moderate to high over the course of all four years of monitoring. In BC, surface waters generally exhibit DO concentrations greater than 10 mg/L, and are close to equilibrium with the atmosphere (i.e., ~100% saturated; RISC 1997b). Dissolved oxygen concentrations measured in 2017 ranged from 9.04 mg/L to 12.82 mg/L, with three of the six average measurements < 10.0 mg/L (Table 31). This is generally consistent with growing season measurements from 2014 to 2016 (range: 8.27 mg/L to 11.68 mg/L). All measurements in 2017 exceeded (i.e., complied with) instantaneous minimum WQG-AL (BC MOE 1997).

Total Gas Pressure

Monitoring of total gas pressure (TGP) was discontinued in Year 2 following evaluation of results in Year 1, and the limited potential of the Salmon River diversion to have caused elevated TGP concentrations.

Nitrogen

Total ammonia (including the ammonium ion) concentrations in the Salmon River at SAM-WQ were less than the MDL of 5.0 µg N/L, except for one of the duplicate samples on August 8, 2017 for which the ammonia (as N) concentration was 12.9 µg/L (Table 33). Ammonia is usually present at low concentrations (<100 µg N/L) in waters not affected by wastewater discharges (Nordin and Pommen 1986).

Nitrite concentrations were below the MDL of 1.0 µg N/L for all the monthly sampling dates (Table 33) in 2017, which is the same result as previous years. Nitrite is an unstable intermediate ion that serves as an indicator of recent contamination from sewage and/or agricultural runoff; concentrations are typically <1.0 µg N/L (RISC 1997b).

Nitrate concentrations ranged from 10 µg N/L to 133.0 µg N/L during the 2017 monitoring (Table 33), with the highest concentrations measured in September. These concentrations are similar to previous years and are typical of oligotrophic streams, which generally have nitrate concentrations lower than 100 µg N/L (Nordin and Pommen 1986). The maximum concentration was the highest concentration measured at SAM-WQ to date (the second-highest concentration was 97.3 µg N/L, measured in 2015; Appendix A). This measurement coincided with a small increase in flow during the summer low-flow period (see Section 3.2.2.3) and likely reflects mobilization of nitrogen from riparian sources that had accumulated over a prolonged dry period.

Phosphorus

Orthophosphate concentrations were below the detection limit of 1.0 µg P/L during the 2017 monitoring (Table 33), similar to previous years. Very low orthophosphate concentrations are typical of coastal BC streams, which generally have orthophosphate concentrations <1.0 µg P/L (Slaney and Ward 1993; Ashley and Slaney 1997).

Total phosphorus concentrations during the Year 4 (2017) sampling period were similar to previous years, ranging from <2.0 µg/L to 3.1 µg/L (Table 33). Low phosphorus concentrations limit productivity in the Salmon River watershed (Pellett 2011a).

Table 30. Salmon River (SAM-WQ) general water quality variables measured *in situ* during Year 4 (2017).

Year	Date	Air Temperature °C				Conductivity µS/cm				Specific Conductivity µS/cm				Temperature °C				pH pH units			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2017	09-May	5	5	5	0	17.8	17.8	17.8	0.0	28.0	27.9	28.0	0.1	5.9	5.9	5.9	0.0	7.37	7.37	7.37	0.00
	13-Jun	11	11	11	0	16.6	16.6	16.7	0.1	23.7	23.7	23.7	0.0	10.1	10.1	10.1	0.0	7.26	7.26	7.26	0.00
	11-Jul	13	13	13	0	28.5	28.5	28.5	0.0	37.1	37.1	37.1	0.0	13.4	13.4	13.4	0.0	6.38	6.30	6.44	0.07
	08-Aug	12	12	12	0	39.2	39.2	39.2	0.0	48.0	48.0	48.0	0.0	15.8	15.8	15.8	0.0	6.43	6.42	6.45	0.02
	12-Sep	12	12	12	0	43.0	43.0	43.0	0.0	55.4	55.4	55.4	0.0	13.8	13.8	13.8	0.0	6.13	6.10	6.17	0.04
	10-Oct	7	7	7	0	35.6	35.5	35.6	0.1	53.5	53.4	53.5	0.1	8.3	8.3	8.3	0.0	6.23	6.23	6.24	0.01

[1] Average of three replicates (n=3) on each date.

Parameters that have a concentration below the detection limit are assumed to have a concentration equal to the detection limit for calculation purposes.

Blue shading indicates that the pH was outside the range (6.5 to 9.0) provided in the provincial water quality guideline for the protection of aquatic life.

Table 31. Salmon River (SAM-WQ) dissolved oxygen measured *in situ* during Year 4 (2017).

Year	Date	Oxygen Dissolved (In Situ) %				Oxygen Dissolved (In Situ) mg/L			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2017	09-May	102.7	102.7	102.8	0.1	12.81	12.80	12.82	0.01
	13-Jun	98.5	98.3	98.7	0.2	11.10	11.07	11.15	0.04
	11-Jul	92.9	92.9	93.0	0.1	9.72	9.69	9.79	0.06
	08-Aug	93.6	93.5	93.7	0.1	9.29	9.25	9.31	0.03
	12-Sep	87.1	86.8	87.4	0.3	9.05	9.04	9.05	0.01
	10-Oct	98.1	97.9	98.5	0.3	11.56	11.52	11.64	0.07

[1] Average of three replicates (n=3) on each date.

Table 32. Salmon River (SAM-WQ) general water quality variables measured at ALS labs during Year 4 (2017).

Year	Date	Alkalinity, Total (as CaCO3) mg/L				Conductivity (lab) µS/cm				Total Dissolved Solids mg/L				Total Suspended Solids mg/L				Turbidity NTU				pH pH units			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2017	09-May	12.6	12.4	12.8	0.3	28.3	28.2	28.4	0.1	19	18	20	1	<2.1	<1.0	3.1	1.5	0.33	0.30	0.36	0.04	7.41	7.41	7.41	0.00
	13-Jun	12.6	12.6	12.6	0.0	28.2	27.9	28.4	0.4	28	27	28	1	<1.0	<1.0	<1.0	0.0	0.20	0.18	0.21	0.02	7.55	7.52	7.57	0.04
	11-Jul	17.0	16.9	17.0	0.1	35.1	35.0	35.2	0.1	31	29	32	2	<1.9	<1.0	2.7	1.2	0.18	0.17	0.19	0.01	7.59	7.57	7.60	0.02
	08-Aug	20.8	19.4	22.1	1.9	46.3	46.0	46.5	0.4	36	34	37	2	<1.0	<1.0	<1.0	0.0	0.21	0.18	0.23	0.04	7.58	7.57	7.59	0.01
	12-Sep	25.4	25.3	25.4	0.1	54.8	53.5	56.0	1.8	46	44	47	2	<1.0	<1.0	<1.0	0.0	0.31	0.29	0.33	0.03	7.67	7.65	7.68	0.02
	10-Oct	23.2	23.0	23.3	0.2	55.1	52.8	57.3	3.2	37	36	38	1	<1.0	<1.0	<1.0	0.0	0.19	0.18	0.19	0.01	7.32	7.31	7.32	0.01

[1] Average of two replicates (n=2) on each date.

Parameters that have a concentration below the detection limit are assumed to have a concentration equal to the detection limit for calculation purposes.

Table 33. Salmon River (SAM-WQ) nutrient concentrations measured at ALS labs during Year 4 (2017).

Year	Date	Ammonia, Total (as N) µg/L				Orthophosphate (as P) µg/L				Nitrate (as N) µg/L				Nitrite (as N) µg/L				Total Phosphorus (P) µg/L			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2017	09-May	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	16.1	15.7	16.4	0.5	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	13-Jun	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	10.1	10.0	10.1	0.1	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	11-Jul	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	21.5	20.6	22.3	1.2	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	3.1	0.8
	08-Aug	<5.0	<5.0	12.9	5.6	<1.0	<1.0	<1.0	0.0	56.6	56.1	57.1	0.7	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	12-Sep	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	133.0	133.0	133.0	0.0	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	10-Oct	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	77.4	77.2	77.5	0.2	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0

[1] Average of two replicates (n=2) on each date.

Parameters that have a concentration below the detection limit are assumed to have a concentration equal to the detection limit for calculation purposes.

3.2.2.3. Quinsam River

The *in situ* and lab water chemistry results for the Quinsam River at QUN-WQ are summarized in Table 34 (general variables measured *in situ*), Table 35 (DO measured *in situ*), Table 36 (general variables measured at ALS labs), and Table 37 (low level nutrients measured at ALS labs).

Alkalinity

Alkalinity (as $CaCO_3$) measured at ALS labs ranged from 32.2 mg/L (May) to 45.6 mg/L (October; Table 34) in 2017, similar to previous years. Alkalinity concentrations were consistently greater than 20 mg/L, indicating that the Quinsam River has low sensitivity to acidic inputs (RISC 1997b).

Specific Conductivity and Total Dissolved Solids

In situ specific conductivity (conductivity normalized to 25°C) ranged from 105.7 µS/cm (May) to 178.1 µS/cm (October; Table 34). Similarly, lab values for specific conductivity ranged from 104.0 µS/cm (May) to 169.0 µS/cm (October). Values were similar to previous years. Coastal BC streams generally have specific conductivity of ~100 µS/cm (RISC 1997b). Most specific conductivity values in the Quinsam River were higher than typical levels in coastal streams. This may reflect the influence of primary productivity in the two lakes upstream of the monitoring site. Alternatively, high values of specific conductivity measured in the past have previously been linked with coal mining activities in the watershed (Redenbach 1990, cited in Burt 2003).

Total dissolved solids measured in the lab for the Quinsam River ranged from 72 mg/L (May) to 128 mg/L (October; Table 32).

pH

pH values measured in the laboratory ranged from 7.62 to 7.94, while *in situ* pH ranged from 7.05 to 7.58 (Table 36 and Table 34, respectively). Natural fresh waters have a pH range from 4 to 10, BC lakes tend to have a pH $\geq$ 7.0, and coastal streams commonly have pH values of 5.5 to 6.5 (RISC 1997b). The pH measured *in situ* are closer to the range expected for coastal streams and may represent more reliable measurements of the stream pH than the laboratory pH, given that the pH measured in the laboratory samples exceeded the recommended hold time.

Turbidity and Total Suspended Solids (TSS)

Turbidity in the Quinsam River at QUN-WQ was low in all three monitoring years, indicating high water clarity (values ranged from 0.41 NTU to 0.68 NTU; Table 36). Similarly, TSS concentrations were predominantly non-detectable (<1.0 mg/L to 2.4 mg/L).

Dissolved Oxygen

Dissolved oxygen concentrations and % saturation in the Quinsam River were high in June and October 2017 (when flows were elevated). However, during the May and July to September sampling in 2017, the average DO concentration did not meet the more conservative provincial WQG-AL (DO instantaneous minimum of 9 mg/L) for the protection of buried embryos/alevins

(Table 35; BC MOE 1997). The May measurement (average of 8.94 mg/L on May 10, 2017; Table 35) indicates that the 9 mg/L WQG-AL was not achieved during part of the incubation period for resident Rainbow Trout and steelhead (see Table 48 for periodicity information). The September measurement (average of 8.21 mg/L on September 13, 2017) indicates that the 9 mg/L WQG-AL may not have been achieved at during the early stages of the Pink Salmon incubation period, which is reported to start two days after the sample was collected on September 15 (Table 48 for periodicity information).

All samples met the WQG-AL for life stages other than buried embryo/alevin (DO instantaneous minimum of 5 mg/L). In BC, surface waters generally exhibit DO concentrations greater than 10 mg/L, and are close to equilibrium with the atmosphere (i.e., ~100% saturation; RISC 1997b).

Total Gas Pressure

Monitoring of total gas pressure (TGP) was discontinued in Year 2 following evaluation of results in Year 1, and the limited potential of the Quinsam River diversion to cause elevated TGP concentrations.

Nitrogen

Total ammonia concentrations in the Quinsam River at QUN-WQ were less than the detection limit of 5.0 µg N/L in five of the six sampling events in 2017 (Table 37), similar to previous years. During the October sampling event, total ammonia concentrations were detectable (average of 23.7 µg/L as N), but well below the WQG-AL. Ammonia is usually present at low concentrations (<100 µg N/L) in waters not affected by waste discharges (Nordin and Pommen 1986).

Nitrite concentrations were below the detection limit of 1.0 µg N/L for all the monthly sampling dates in 2017, the same result as in previous years (Table 37). Nitrite is an unstable intermediate ion serving as an indicator of recent contamination from sewage and/or agricultural runoff; levels are typically <1.0 µg N/L (RISC 1997b).

Nitrate concentrations were low and ranged from 12.1 µg N/L (September) to 47.8 µg N/L (October) during the sampling in 2017, similar to previous years (Table 37). In oligotrophic lakes and streams, nitrate concentrations are usually lower than 100 µg N/L (Nordin and Pommen 1986).

Phosphorus

Orthophosphate concentrations were below the detection limit of 1.0 µg P/L during sampling in 2017, similar to previous years (Table 37). Very low orthophosphate concentrations are typical of coastal BC streams, which generally have orthophosphate concentrations <1.0 µg P/L (Slaney and Ward 1993; Ashley and Slaney 1997). It is possible that uptake of nutrients by phytoplankton in lakes upstream ("nutrient stripping") also contributes to the low orthophosphate concentrations at the site.

Total phosphorus concentrations over the Year 4 (2017) sampling period were low, similar to previous years, ranging from below detection limits (<2.0 µg P/L) to 3.9 µg P/L (Table 37).

Table 34. Quinsam River (QUN-WQ) general water quality variables measured *in situ* during Year 4 (2017).

Year	Date	Air Temperature °C				Water Temperature °C				Conductivity µS/cm				Specific Conductivity µS/cm				pH pH units				Salinity ppt			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2017	10-May	7	7	7	0	8.9	8.9	8.9	0.0	73.3	73.3	73.3	0.0	105.7	105.7	105.8	0.1	7.58	7.58	7.58	0.00	-	-	-	-
	14-Jun	9	9	9	0	15.0	15.0	15.0	0.0	99.3	99.3	99.3	0.0	124.1	124.1	124.1	0.0	7.47	7.46	7.47	0.01	0.06	0.06	0.06	0.00
	12-Jul	17	17	17	0	19.4	19.4	19.4	0.0	140.4	140.4	140.4	0.0	158.2	158.2	158.2	0.0	7.08	7.05	7.10	0.03	0.07	0.07	0.07	0.00
	09-Aug	13	13	13	0	21.1	21.1	21.1	0.0	149.8	149.8	149.8	0.0	162.7	162.6	162.7	0.1	7.17	7.17	7.17	0.00	0.08	0.08	0.08	0.00
	13-Sep	8	8	8	0	16.2	16.2	16.2	0.0	137.6	137.6	137.6	0.0	166.8	166.8	166.9	0.1	7.21	7.20	7.22	0.01	0.08	0.08	0.08	0.00
	11-Oct	2	2	2	0	11.2	11.2	11.2	0.0	128.9	128.8	128.9	0.1	178.0	178.0	178.1	0.1	7.21	7.17	7.24	0.04	0.08	0.08	0.08	0.00

[1] Average of three replicates (n=3) on each date unless otherwise indicated. Dashes (-) indicate no data were collected

Table 35. Quinsam River (QUN-WQ) dissolved gases measured *in situ* during Year 4 (2017).

Year	Date	Dissolved Oxygen %				Dissolved Oxygen mg/L			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2017	10-May	76.9	76.6	77.3	0.4	8.94	8.92	8.96	0.02
	14-Jun	89.6	89.5	89.7	0.1	9.03	9.01	9.05	0.02
	12-Jul	87.1	87.0	87.1	0.1	8.02	8.01	8.03	0.01
	09-Aug	80.0	79.5	80.3	0.5	7.13	7.13	7.13	0.00
	13-Sep	83.7	83.5	83.8	0.2	8.21	8.20	8.22	0.01
	11-Oct	91.6	91.6	91.7	0.1	10.05	10.04	10.06	0.01

[1] Average of three replicates (n=3) on each date unless otherwise indicated. Dashes (-) indicate no data were collected

Blue shading indicates that the more conservative provincial guideline (DO instantaneous minimum of 9 mg/L) for

Table 36. Quinsam River (QUN-WQ) general water quality variables measured at ALS labs during Year 4 (2017).

Year	Date	Alkalinity, Total (as CaCO3) mg/L				Conductivity µS/cm				Total Dissolved Solids mg/L				Total Suspended Solids mg/L				Turbidity NTU				pH pH units			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2017	10-May	32.4	32.2	32.6	0.3	106	104	107	2	90	72	107	25	2.1	1.7	2.4	0.5	0.59	0.55	0.62	0.05	7.71	7.69	7.72	0.02
	14-Jun	41.1	41.1	41.1	0.0	146	145	146	1	99	95	102	5	<1.0	<1.0	<1.0	0.0	0.54	0.53	0.54	0.01	7.94	7.93	7.94	0.01
	12-Jul	44.3	43.5	45.0	1.1	148	147	149	1	93	92	94	1	1.4	1.3	1.4	0.1	0.57	0.53	0.61	0.06	7.91	7.89	7.93	0.03
	09-Aug	43.8	43.7	43.9	0.1	161	160	162	1	102	101	103	1	<1.0	<1.0	<1.0	0.0	0.61	0.54	0.68	0.10	7.80	7.79	7.80	0.01
	13-Sep	43.2	42.7	43.7	0.7	162	162	162	0	103	98	107	6	<1.0	<1.0	<1.0	0.0	0.46	0.44	0.47	0.02	7.91	7.91	7.91	0.00
	11-Oct	45.4	45.1	45.6	0.4	169	169	169	0	127	125	128	2	<1.0	<1.0	<1.0	0.0	0.41	0.41	0.41	0.00	7.63	7.62	7.63	0.01

[1] Average of two duplicates (n=2) on each date.

Parameters that have a concentration below the detection limit are assumed to have a concentration equal to the detection limit for calculation purposes.

Table 37. Quinsam River (QUN-WQ) nutrient concentrations measured at ALS labs during Year 4 (2017).

Year	Date	Ammonia, Total (as N) µg/L				Orthophosphate (as P) µg/L				Nitrate (as N) µg/L				Nitrite (as N) µg/L				Total Phosphorus (P) µg/L			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2017	10-May	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	13.5	13.0	14.0	0.7	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	14-Jun	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	17.8	17.7	17.8	0.1	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	12-Jul	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	20.4	20.1	20.6	0.4	<1.0	<1.0	<1.0	0.0	2.9	2.4	3.3	0.6
	09-Aug	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	18.1	17.7	18.5	0.6	<1.0	<1.0	<1.0	0.0	2.4	2.3	2.5	0.0
	13-Sep	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	12.3	12.1	12.5	0.3	<1.0	<1.0	<1.0	0.0	<2.1	<2.0	2.2	0.0
	11-Oct	23.7	22.9	24.5	1.1	<1.0	<1.0	<1.0	0.0	47.4	47.0	47.8	0.6	<1.0	<1.0	<1.0	0.0	3.8	3.6	3.9	0.2

[1] Average of two duplicates (n=2) on each date.

Parameters that have a concentration below the detection limit are assumed to have a concentration equal to the detection limit for calculation purposes.

3.2.3. Water and Air Temperature Monitoring

3.2.3.1. Salmon River

Summary

The water temperature measurements from 2014 to 2017 at SAM-WQ are shown in Figure 28 and the mean, minimum, and maximum water temperatures for each month of the record are summarized in Table 38.

In 2017, mean monthly water temperatures were lower than in previous years from January to July (Table 38). However, mean monthly temperatures were similar across years in August (range 17.1 to 17.7°C), except in 2014 when mean monthly temperatures in August were 18.7°C. Mean monthly temperatures for September 2017 (14.6°C) were similar to those measured in 2014 (14.9°C), and were higher than those measured in both 2015 and 2016 (Table 38). Based on the available data, the coolest temperature measurement was 0.0°C in January 2016, December 2016, January 2017, and February 2017 and the warmest temperature measurement was 24.5°C in July 2015 (Table 38).

From a fisheries biology perspective, the water temperature records for the Salmon River indicate occurrences of warm water temperatures, although maximum summer water temperatures in 2017 were similar to that of 2016 (21.7°C) and were lower than in 2014 and 2015 (Figure 28). Over the period of record in 2017 (282 days), there were 19 days (7%) with daily-mean temperatures above 18°C, but zero days with daily mean temperatures above 20°C (Table 39). In contrast, between 2014 and 2016, there were between 15 and 41 days with daily mean temperatures above 18°C, and 2 days (in 2014) or 9 days (in 2015) that were above 20°C. Daily mean water temperatures below 1°C occurred on 31 days (11%) during 2017, compared to the range of 0 to 32 days between 2014 and 2016 (Table 39).

Figure 28. Water temperature in the Salmon River (SAM-WQ) between May 2014 and October 2017. The gap in the records is due to missing TidbiTs.

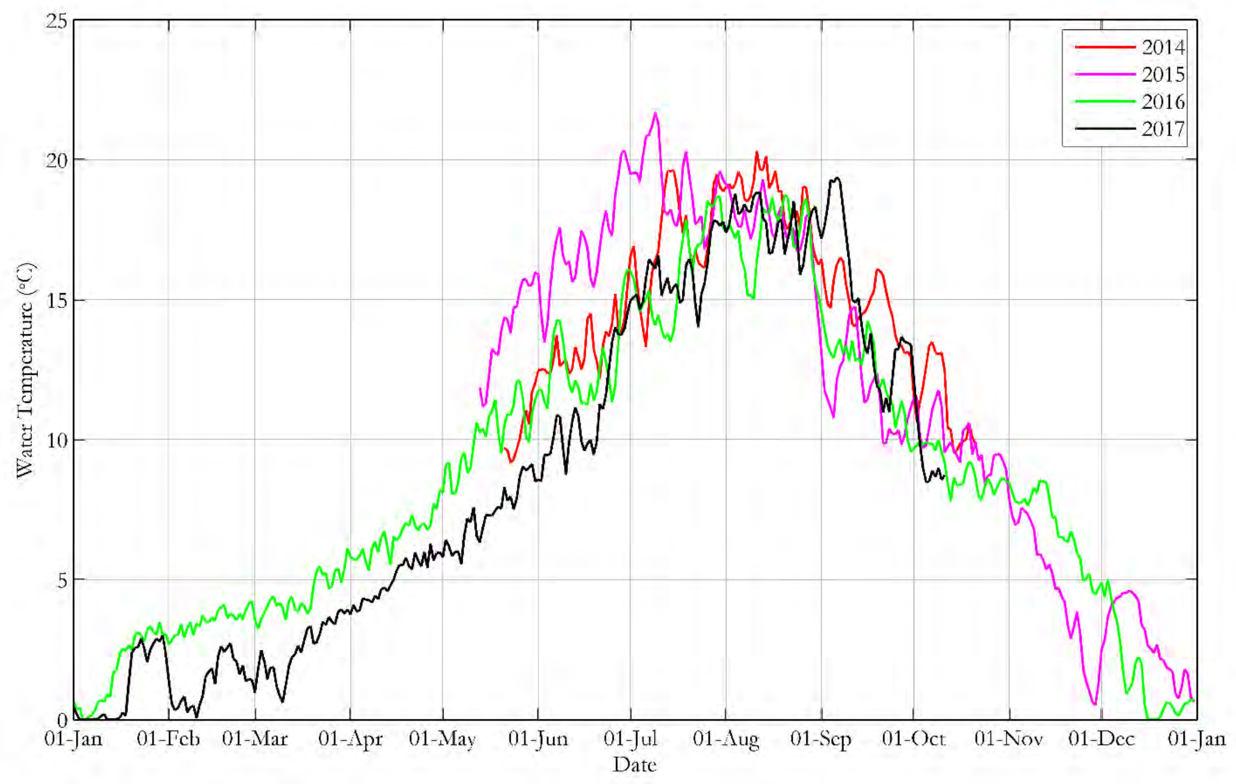


Table 38. Monthly water temperature statistics in the Salmon River (SAM-WQ) from 2014 to 2017. Statistics were not generated for months with less than 3 weeks of observations and minimum temperatures are not shaded for years with missing data during fall/winter/spring.

Month	2014				2015				2016				2017			
	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD
Jan	n/a	n/a	n/a	n/a	-	-	-	-	1.8	0.0	3.7	1.2	1.1	0.0	3.4	1.2
Feb	n/a	n/a	n/a	n/a	-	-	-	-	3.5	2.3	4.5	0.4	1.3	0.0	3.2	0.8
Mar	n/a	n/a	n/a	n/a	-	-	-	-	4.5	2.3	7.2	0.9	2.6	0.2	5.2	1.0
Apr	n/a	n/a	n/a	n/a	-	-	-	-	6.6	4.6	9.6	1.0	5.1	2.6	7.6	1.0
May	n/a	n/a	n/a	n/a	-	-	-	-	10.2	6.4	14.0	1.6	7.4	4.4	11.2	1.4
Jun	13.3	10.2	18.0	1.4	16.9	11.7	23.3	2.4	12.7	9.9	18.3	1.8	11.1	7.7	16.7	2.1
Jul	17.2	12.6	23.0	2.3	19.1	14.9	24.5	2.0	16.0	11.8	21.7	2.1	15.9	12.4	20.9	1.7
Aug	18.7	15.3	23.2	1.7	17.6	13.6	21.7	1.5	17.1	13.9	21.6	1.8	17.7	14.4	21.9	1.7
Sep	14.9	11.7	18.6	1.5	11.7	8.7	17.1	1.6	12.3	8.6	16.5	1.5	14.6	9.2	21.6	2.9
Oct	-	-	-	-	9.9	8.0	12.7	1.0	8.9	7.1	10.7	0.7	-	-	-	-
Nov	-	-	-	-	4.7	0.1	8.3	2.3	6.8	4.2	8.8	1.3				
Dec	-	-	-	-	2.8	0.4	4.8	1.3	1.3	0.0	5.2	1.5				

“Avg”, “Min”, “Max” and “SD” denote the monthly average, minimum, maximum, and standard

"n/a" indicates that TidbiTs weren't installed. "-" indicates that data gap is due to missing Tidbits.

Blue and orange shadings highlight minimum and maximum temperatures, respectively.

Rates of Change

Large, rapid temperature changes can affect fish growth and survival (Oliver and Fidler 2001). Therefore, rates of change in water temperature at SAM-WQ were examined; these are summarized in Table 40 and presented in Figure 29. Hourly rates of temperature change were between -0.4°C/hr and +0.6°C/hr for at least 90% of the time (based on the 5th and 95th percentiles), and were between -0.5°C/hr and +1.0°C/hr for at least 98% of the time (based on the 1st and 99th percentiles).

For all years, the maximum positive rate of water temperature change was 1.4°C/hr and the negative rate of water temperature change was -0.8°C/hr. The majority of rates of hourly temperature change were within ± 1°C/hr (Table 40). Based on our experience with monitoring other streams in BC, it is normal for a small percentage of data points to represent hourly rates of water temperature change that exceed ±1°C.

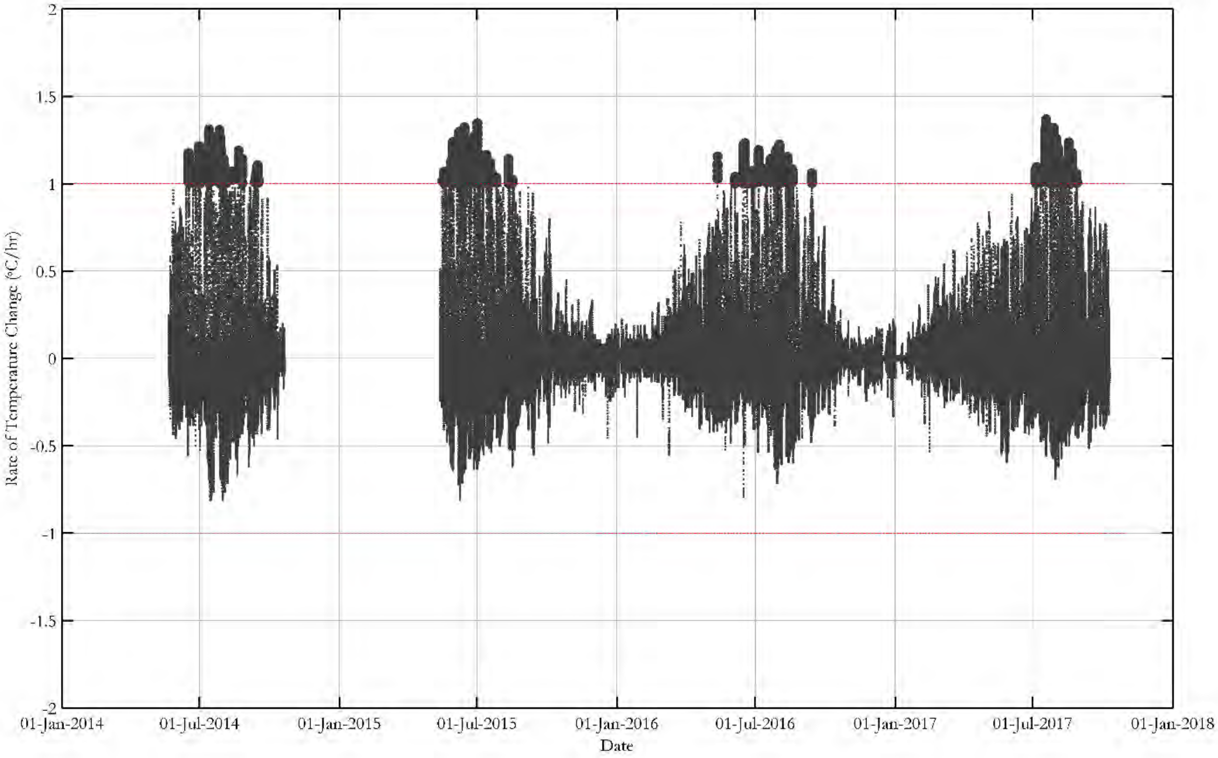
Table 39. Summary of the number of exceedances of mean daily water temperature extremes (T_{water}>18°C, T_{water}>20°C, and T_{water}<1°C) in the Salmon River (SAM-WQ) from 2014 to 2017.

Year	Record Length (days)	Days T_{water}> 20°C	Days T_{water}> 18°C	Days T_{water} < 1°C
2014	152	2	35	0
2015	231	9	41	6
2016	364	0	15	32
2017	282	0	19	31

Table 40. Statistics for the hourly rates of change in water temperature at SAM-WQ in the Salmon River from 2014 to 2017. The frequency of rates of change exceeding a magnitude of 1°C/hr is also shown.

Start of record	End of record	Number of Datapoints	Occurrence of rates >1°C/hr		Maximum Negative Rate	Percentile				Maximum Positive Rate
			Number	% of record		1th	5th	95th	99th	
21-May-2014	10-Oct-2017	396,900	2757	0.69	-0.8	-0.5	-0.4	0.6	1.0	1.4

Figure 29. **Rate of change in hourly water temperature in the Salmon River (SAM-WQ) from 2014 to 2017. Large dots indicate rates with magnitudes exceeding ±1°C/hr. Data gap between October 2014 and May 2015 is due to missing TidbiTs.**



Growing Season and Accumulated Thermal Units

The length of the growing season and accumulated thermal units are important indicators of the productivity of aquatic systems. As explained in Table 16, the growing season was assumed to begin when the weekly average water temperature exceeded and remained above 5°C, and to end when the weekly average temperature dropped below 4°C (as per Coleman and Fausch 2007).

The growing season at SAM-WQ was determined for 2016, which was the only year in which a complete annual record was available (Table 41). The growing season in 2016 commenced on March 19, ended on December 7, covered a period of 264 days, and had 2,866 accumulated thermal units (or degree days). The temperature sensors were removed from the Salmon River sites in October 2017.

Table 41. The growing season and growing degree days at SAM-WQ in the Salmon River (2014 to 2017).

Year	Number of days with valid data	Growing Season				
		Start Date	End Date	Length (day)	Gap (day)	Degree Days
2014†	152	-	-	-	-	-
2015†	231	-	19-Nov-2015			
2016	366	19-Mar-2016	7-Dec-2016	264	0	2,866
2017‡	283	11-Apr-2017	-	-	-	-

†Growing season could not be estimated because a complete data set over the course of the growing season is not available.

‡Growing season will be reported once the dataset covers a complete growing season.

Mean Weekly Maximum Water Temperatures

The mean weekly maximum water temperature (MWMxT) is a standard metric used to evaluate the exposure of fish to prolonged periods of undesirably cool or warm water temperatures. The WQG-AL state "Where fish distribution information is available, then mean weekly maximum water temperatures should only vary + or - 1 degrees C beyond the optimum temperature range of each life history phase (incubation, rearing, migration and spawning) for the most sensitive salmonid species present" (Oliver and Fidler 2001). Accordingly, data collected from 2014 to 2017 were compared with the optimum temperature ranges reported by Oliver and Fidler (2001).

Fish species of primary interest for JHTMON-8 in the Salmon River are steelhead, Coho Salmon and Chinook Salmon. Steelhead and Coho Salmon are present both upstream and downstream of SAM-WQ, while the range for Chinook Salmon extends to the Memekay River confluence, approximately 15 km downstream of SAM-WQ (based on distributions presented in Burt 2010). The MWMxT data are compared to optimum temperature ranges for different fish species in Table 42. For each life stage, Table 42 also shows the percentage of MWMxT data that are above, within, and below the optimum ranges for fish life stages during baseline monitoring. The percentages of MWMxT data that are above and below the optimum ranges by more than 1°C are also presented.

Comparisons to the provincial WQG-AL are not made when "Percent Complete" is ≤50% (Table 42). In addition, if the water temperature records are only slightly >50% complete for a particular species/life stage, comparisons to the provincial WQG-AL are interpreted with caution. In particular, the analysis provides useful information about whether water temperatures were excessively warm at times for juvenile steelhead and Coho Salmon during the rearing life stage.

For Chinook Salmon, MWMxT were above upper bounds by > 1°C at times for all four relevant life stages from 2014 to 2017 (where sufficient data are available to make comparisons). The MWMxT did not exceed the lower bound of the optimum ranges by > 1°C for the migration and spawning stages. For the incubation stage, the MWMxT data were more than 1°C below the lower bound for 33.0% of the record during 2015 and 46.6% of record during 2016 (data were not available for 2017). Similarly, for the rearing stage, the MWMxT data were more than 1°C below the lower bound for 38.2% of the record during 2015 and 52.6% of record during 2016. Considering all life stages, MWMxT data were within the optimum temperature range for ~10% to ~90% of the records from 2014 to 2017 (Table 42).

For Coho Salmon, MWMxT were above the upper bound by > 1°C at times for the migration stage during 2014, and rearing stage during 2015, 2016, and 2017 (rearing conditions could not be evaluated in 2014). In 2015 and 2016, the MWMxT were below the lower bound by > 1°C at times for all life stages; data were not available for most Coho Salmon life stages in 2017, but were below the lower bound by > 1°C at times for the rearing stage. Considering all life stages, MWMxT data were within the optimum temperature ranges for ~20% to ~85% of the records (Table 42).

For Rainbow Trout and steelhead, MWMxT were below the lower bound by > 1°C for ~50% to ~90% of the records for spawning, incubation, and rearing stages between 2015 and 2017 (not evaluated in 2014). For all three life stages, MWMxT were above the upper bounds by > 1°C for ~10% to ~30% of the records; only ~4% to ~23% of the MWMxT data were within the optimum temperature ranges (Table 42).

Table 42. Mean weekly maximum temperatures (MWMxT) in the Salmon River from 2014 to 2017 compared to optimum temperature ranges for fish species present. Periodicity information is from Burt (2010).

Species	Life Stage			Year	Percent Complete	MWMxT (°C)		% of MWMxT				
	Periodicity	Optimum Temperature Range (°C)	Duration (days)			Min.	Max.	Below Lower Bound by >1°C	Below Lower Bound	Between Bounds	Above Upper Bound	Above Upper Bound by >1°C
Chinook Salmon	Migration (Jul. 16 to Sep. 30)	3.3-19.0	77	2014	100	13.1	22.2	0.0	0.0	51.9	48.1	36.4
				2015	100	10.6	21.0	0.0	0.0	50.6	49.4	23.4
				2016	98.7	10.8	21.1	0.0	0.0	63.2	36.8	26.3
				2017	100	13.1	21.1	0.0	0.0	42.9	57.1	32.5
	Spawning (Sep. 01 to Oct. 31)	5.6-13.9	61	2014	80.3	10.2	17.7	0.0	0.0	42.9	57.1	46.9
				2015	98.4	8.4	15.4	0.0	0.0	88.3	11.7	8.3
				2016	98.4	8.5	15.3	0.0	0.0	71.7	28.3	5.0
				2017	63.9	9.7	20.7	0.0	0.0	43.6	56.4	38.5
	Incubation (Sep. 01 to Apr. 22)	5.0-14.0	234	2014	21.4	-	-	-	-	-	-	-
				2015	99.6	0.4	15.4	33.0	52.4	44.6	3.0	1.7
				2016	100	0.0	15.3	46.6	54.7	38.0	7.3	1.3
				2017	16.7	-	-	-	-	-	-	-
	Rearing (Mar. 08 to Jul. 22)	10.0-15.5	137	2014	45.3	-	-	-	-	-	-	-
				2015	51.8	12.9	23.3	0.0	0.0	9.9	90.1	85.9
				2016	99.3	4.6	18.9	38.2	41.2	42.6	16.2	9.6
				2017	100	1.9	18.1	52.6	55.5	24.8	19.7	15.3
Coho Salmon	Migration (Sep. 01 to Nov. 30)	7.2-15.6	91	2014	53.8	10.2	17.7	0.0	0.0	55.1	44.9	24.5
				2015	98.9	1.7	15.4	22.2	26.7	73.3	0.0	0.0
				2016	98.9	5.1	15.3	8.9	15.6	84.4	0.0	0.0
				2017	42.9	-	-	-	-	-	-	-
	Spawning (Oct. 01 to Dec. 15)	4.4-12.8	76	2014	26.3	-	-	-	-	-	-	-
				2015	98.7	1.7	11.9	14.7	29.3	70.7	0.0	0.0
				2016	100	1.2	10.8	11.8	14.5	85.5	0.0	0.0
				2017	11.8	-	-	-	-	-	-	-
	Incubation (Oct. 01 to Apr. 15)	4.0-13.0	197	2014	10.2	-	-	-	-	-	-	-
				2015	99.5	0.4	11.9	21.4	39.3	60.7	0.0	0.0
				2016	100	0.0	10.8	49.5	55.1	44.9	0.0	0.0
				2017	4.6	-	-	-	-	-	-	-
	Rearing (Jan. 01 to Dec. 31)	9.0-16.0	365	2014	41.6	-	-	-	-	-	-	-
				2015	63.4	1.0	23.3	25.9	27.2	29.3	43.5	41.4
				2016	99.5	0.2	21.1	44.9	53.7	30.3	16.0	12.9
				2017	77.3	0.0	21.1	46.8	48.9	23.8	27.3	24.8
Rainbow Trout/ Steelhead	Spawning (Mar. 01 to May. 31)	10.0-10.5	92	2014	10.9	-	-	-	-	-	-	-
				2015	19.6	-	-	-	-	-	-	-
				2016	98.9	4.2	12.8	64.8	69.2	4.4	26.4	20.9
				2017	100	1.9	10.6	85.9	90.2	6.5	3.3	0.0
	Incubation (Mar. 01 to Jun. 30)	10.0-12.0	122	2014	32.8	-	-	-	-	-	-	-
				2015	39.3	-	-	-	-	-	-	-
				2016	99.2	4.2	17.0	48.8	52.1	14.0	33.9	19.8
				2017	100	1.9	16.3	64.8	68.0	23.0	9.0	7.4
	Rearing (Jan. 01 to Dec. 31)	16.0-18.0	365	2014	41.6	-	-	-	-	-	-	-
				2015	63.4	1.0	23.3	53.0	56.5	6.9	36.6	31.0
				2016	99.5	0.2	21.1	81.3	84.0	5.5	10.5	7.7
				2017	77.3	0.0	21.1	70.6	72.7	10.3	17.0	15.6

Blue shading indicates provincial guideline exceedance of the lower bound of the optimum temperature range by more than 1°C (Oliver and Fidler 2001).
Red shading indicates provincial guideline exceedance of the upper bound of the optimum temperature range by more than 1°C (Oliver and Fidler 2001).

Air Temperature

Air temperatures measured from May 2014 to October 2017 are shown in Figure 30. The monthly average air temperature ranged from -2.0°C (January 2017) to 18.1°C (July 2015; Table 43). The lowest air temperature measured during the monitoring period was -15.3°C measured in January 2017, while the highest air temperature was 33.3°C in July 2015. Average air temperatures during the 2017 growing season were generally similar to 2016, and slightly cooler than during the two previous years (2014 and 2015).

Air and water temperatures were highly correlated, with a linear correlation coefficient (*r*) of 0.95. A linear model showed close correspondence between mean daily air and water temperatures (Figure 32), which likely reflects the relatively wide channel upstream (and resulting absence of full canopy cover; Figure 5), rainfall-driven hydrology during the mid- to late-growing season, and limited presence of wetlands and lakes in the upper watershed (Stefan and Preud'homme 1993). Congruence between the two datasets is greatest in the range 10°C to 20°C; inspection of the data indicates that an S-shaped function (Mohseni and Stefan 1999) would be preferable to a linear function to model water temperature in the Salmon River and the Quinsam River (Section 3.2.3.2) based on air temperature records.

Table 43. Monthly air temperature at the Salmon River (SAM-AT) from 2014 to 2017. Statistics were not generated for months with less than 3 weeks of observations.

Month	2014				2015				2016				2017			
	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD
Jan	n/a	n/a	n/a	n/a	1.9	-4.8	8.4	2.6	0.8	-9.5	9.2	3.3	-2.0	-15.3	6.4	4.8
Feb	n/a	n/a	n/a	n/a	4.5	-2.7	10.2	3.1	3.5	-1.9	7.8	2.0	-0.9	-8.7	6.9	2.5
Mar	n/a	n/a	n/a	n/a	5.6	-2.5	12.8	3.3	4.8	-2.1	18.1	3.3	1.8	-4.8	10.8	2.7
Apr	n/a	n/a	n/a	n/a	6.4	-1.3	20.3	3.9	9.0	-0.5	22.8	3.7	6.0	-2.0	15.5	2.9
May	n/a	n/a	n/a	n/a	12.6	0.4	24.3	4.9	12.0	1.7	23.7	4.6	10.6	-0.4	26.0	4.7
Jun	13.7	6.8	23.6	3.4	15.9	6.4	32.3	4.8	13.5	3.6	28.7	4.2	13.3	4.5	28.1	4.3
Jul	16.9	7.9	30.4	4.4	18.1	8.3	33.3	5.1	16.1	8.8	25.8	3.3	15.9	6.0	27.0	4.0
Aug	17.8	9.0	31.9	4.4	16.2	7.7	26.2	3.7	16.4	8.9	31.0	4.1	16.9	7.5	29.1	4.5
Sep	13.7	4.3	26.2	4.2	10.9	1.7	22.3	3.5	11.3	0.6	20.9	3.5	13.3	2.1	31.2	5.2
Oct	9.9	0.9	16.7	2.9	9.4	1.8	16.0	2.9	8.0	-1.3	12.5	2.3	-	-	-	-
Nov	2.2	-7.9	11.9	4.7	1.3	-7.3	9.1	3.5	6.3	-0.6	12.2	3.0				
Dec	1.9	-6.9	9.8	3.7	1.7	-3.7	8.2	2.8	-2.0	-14.6	6.7	3.9				

"Avg", "Min", "Max" and "SD" denote the monthly average, minimum, maximum, and standard deviation of water temperatures (°C).

"n/a" indicates that TidbiTs weren't installed. "-" indicates that data gap is due to missing Tidbits.

Blue and orange shadings highlight minimum and maximum temperatures, respectively.

Figure 30. Air temperature at the Salmon River (SAM-AT) between May 2014 and October 2017.

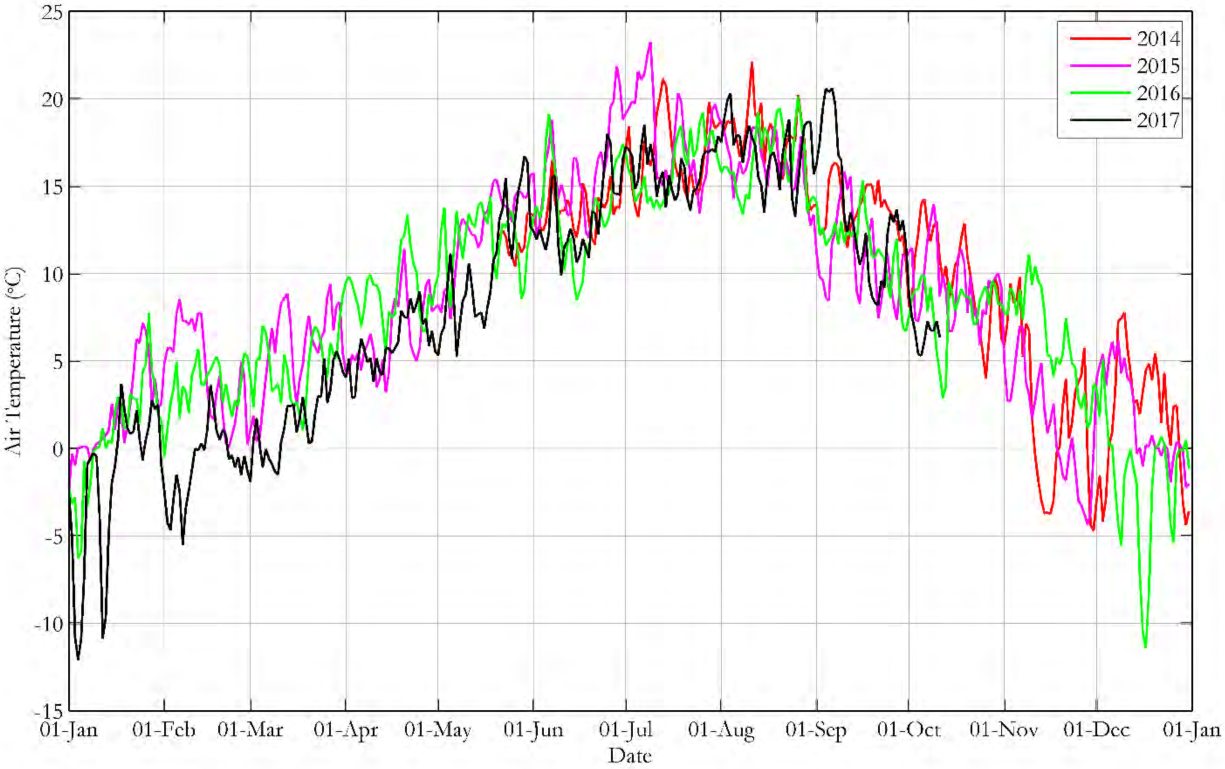
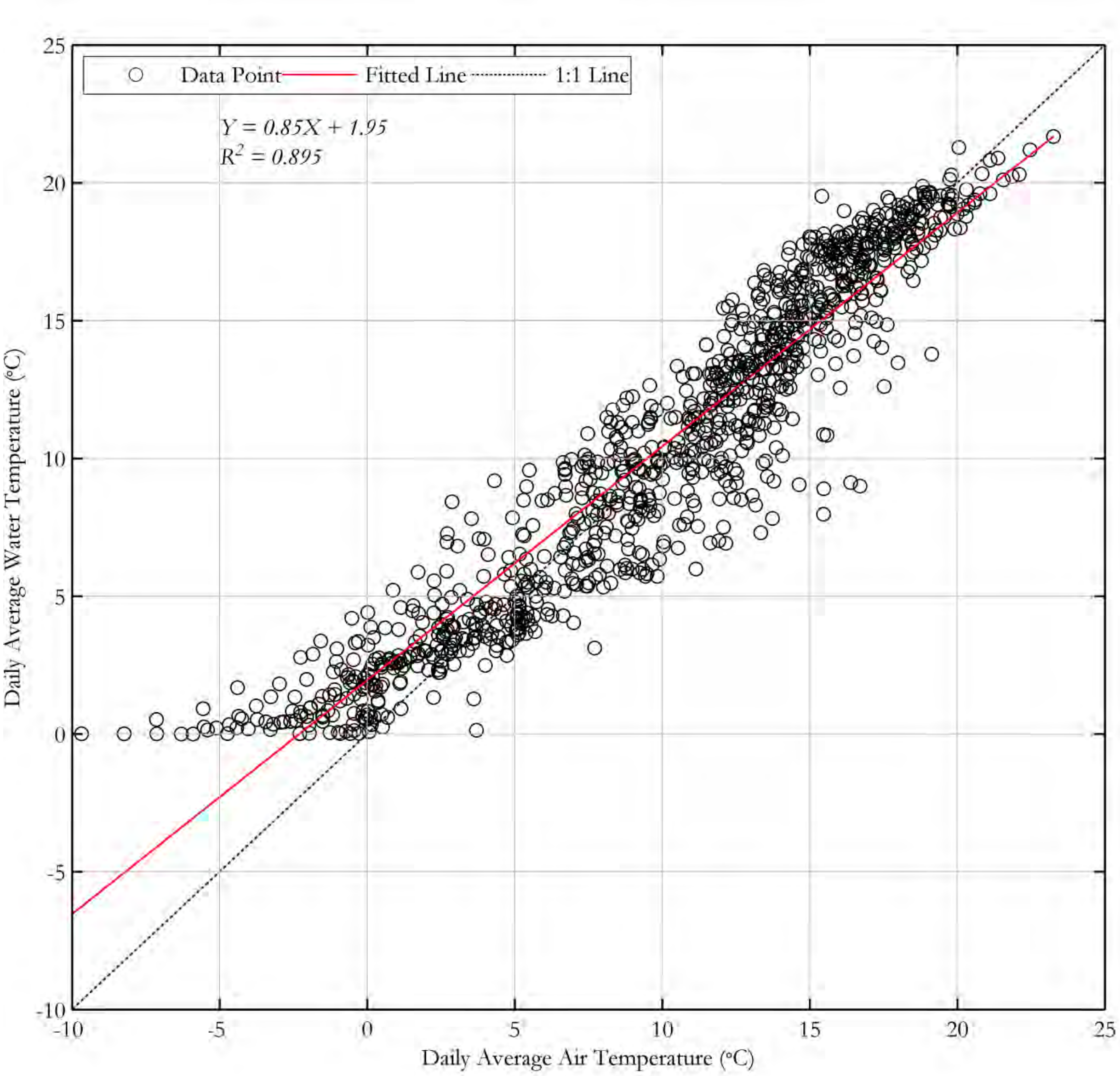


Figure 31. **Relationship between the daily average water and air temperatures in the Salmon River (SAM-WQ) between May 2014 and October 2017.**



3.2.3.2. Quinsam River

Summary

Figure 32 shows the daily average, maximum, and minimum water temperatures at QUN-WQ for May 2014 to October 2017. In the 2017 record for Quinsam River, monthly average water temperature ranged between 1.7°C (January 2017) and 20.0°C (August 2017; Table 44). These were also the coolest and warmest monthly mean water temperatures recorded between 2014 and 2017 (Table 44).

From a fisheries biology perspective, the water temperature records for the Quinsam River indicate occurrences of warm water temperatures. In 2017 there were 78 days (28%) with daily mean temperatures above 18°C, and 25 days (9%) with daily mean temperature above 20°C. Similarly, over the period of record between 2014 and 2016, there were 51 to 69 days (14 to 29%) with daily mean temperatures above 18°C, and 14 to 21 days (4 to 9%) with daily mean temperature above 20°C (Table 45).

Figure 32. Water temperature in the Quinsam River (QUN-WQ) between May 2014 and October 2017.

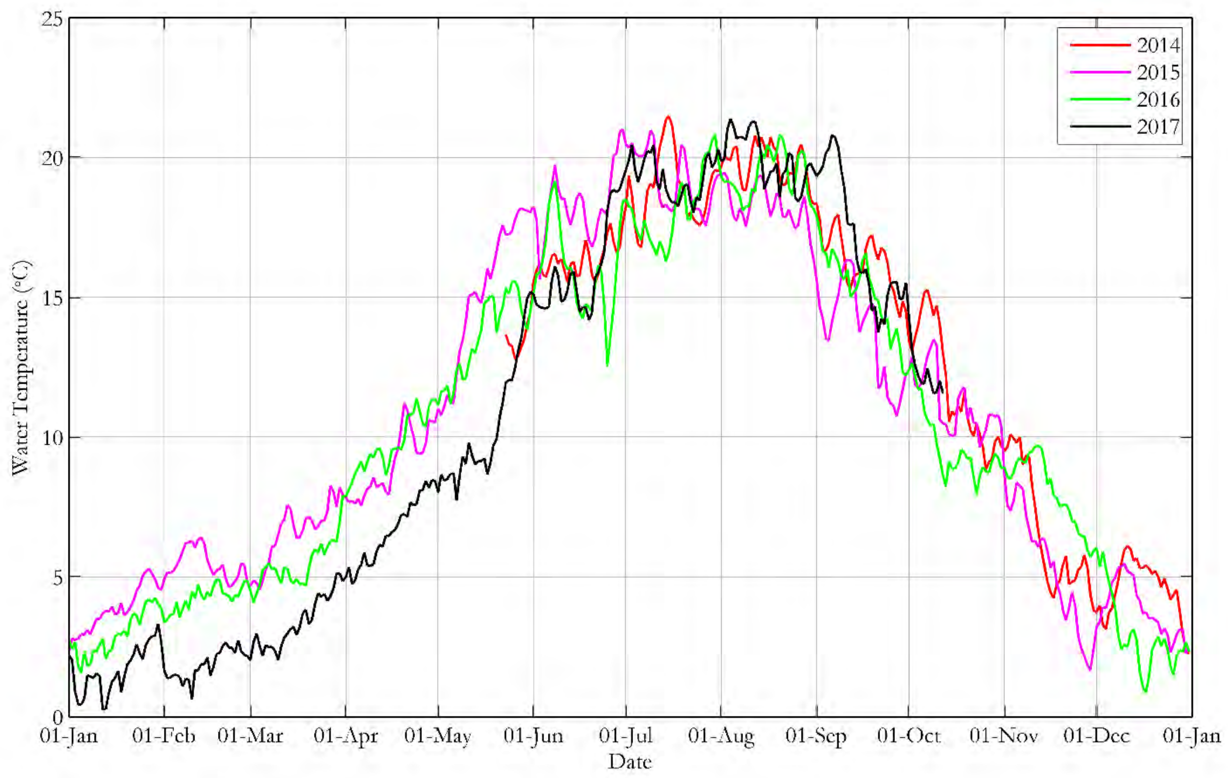


Table 44. Monthly water temperature in the Quinsam River (QUN-WQ) from 2014 to 2017. Statistics were not generated for months with less than 3 weeks of observations. Minimum temperatures are not shaded for 2014 as data were not collected during January to May.

Month	2014				2015				2016				2017			
	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD
Jan	n/a	n/a	n/a	n/a	3.8	2.0	5.6	0.8	2.9	1.2	4.6	0.8	1.7	0.0	3.5	0.9
Feb	n/a	n/a	n/a	n/a	5.5	4.1	6.5	0.6	4.3	3.1	5.2	0.5	1.9	0.1	3.1	0.6
Mar	n/a	n/a	n/a	n/a	6.6	4.0	8.9	1.1	5.5	3.3	9.2	1.0	3.5	1.6	5.9	1.0
Apr	n/a	n/a	n/a	n/a	9.0	6.6	12.7	1.3	9.8	6.8	12.4	1.2	6.7	3.9	9.9	1.3
May	n/a	n/a	n/a	n/a	15.1	9.6	18.5	2.5	13.7	10.1	16.2	1.5	10.6	6.7	16.6	2.4
Jun	16.3	14.4	18.8	0.7	18.3	15.0	23.0	1.4	16.1	11.9	19.8	1.7	16.1	13.6	20.2	1.8
Jul	18.9	16.5	22.7	1.4	19.2	16.0	23.0	1.6	18.2	15.5	21.2	1.3	19.3	17.6	20.9	0.8
Aug	19.8	17.5	22.2	1.0	18.3	15.9	21.2	1.1	19.3	17.7	21.3	0.9	20.0	18.0	21.8	0.9
Sep	16.3	13.9	18.6	1.1	13.7	10.2	17.0	1.8	15.1	11.8	18.1	1.4	16.8	13.4	21.1	2.3
Oct	11.8	8.3	15.5	2.1	11.2	9.3	13.7	1.1	9.6	7.4	13.1	1.2	-	-	-	-
Nov	6.6	3.6	10.3	2.2	5.3	1.5	10.0	2.1	8.0	5.5	9.8	1.3				
Dec	4.5	2.1	6.2	1.0	3.8	2.0	5.6	1.0	2.8	0.6	6.2	1.2				

"Avg", "Min", "Max" and "SD" denote the monthly average, minimum, maximum, and standard deviation of water temperatures (°C).
"n/a" indicates that TidbiTs weren't installed. "-" indicates that data gap is due to missing Tidbits.
Blue and orange shadings highlight minimum and maximum temperatures, respectively.

Rates of Change

Rates of change in water temperature at QUN-WQ are summarized in Table 46 and presented in Figure 33. For the period of record, the hourly rates of temperature change at QUN-WQ were between -0.2°C/hr and +0.2°C/hr for at least 90% of the time (based on the 5th and 95th percentiles) and were between -0.3°C/hr and +0.4°C/hr for at least 98% of the time (based on the 1st and 99th percentiles).

The maximum rate of temperature increase was +1.1°C/hr, and the maximum rate of temperature decrease was -1.3°C/hr (Table 46). Rates of temperature change with magnitudes >1°C/hr occurred for 0.02% of the records. Based on our experience on other streams in BC, it is normal for a small percentage of data points to have hourly rates of water temperature change that exceed ±1°C.

Growing Season and Accumulated Thermal Units

The length of the growing season and accumulated thermal units are important indicators of the productivity of aquatic systems. As explained in Table 16, the growing season was taken to begin when the weekly average water temperature exceeded and remained above 5°C, and to end when the weekly average temperature dropped below 4°C (as per Coleman and Fausch 2007a).

The growing season at QUN-WQ was determined for 2015 and 2016, when a complete annual record is available (Table 47). The growing season in 2015 commenced on March 2, ended on November 25, covered a period of 269 days, and had 3,561 accumulated thermal units (or degree days). Similarly, in 2016, the growing season commenced on March 15, ended on December 9, covered a period of 270 days, and had 3,492 accumulated thermal units. The accumulated thermal units for the 2017 growing season will be presented in the Year 5 Annual Report when the data for the remainder of 2017 will be available.

Table 45. Summary of the number of exceedances of mean daily water temperature extremes (T_{water}>18°C, T_{water}>20°C, and T_{water}<1°C) in the Quinsam River at QUN-WQ from 2014 to 2017.

Year	Record Length (days)	Days T_{water}> 20°C	Days T_{water}> 18°C	Days T_{water} < 1°C
2014	222	21	54	0
2015	365	16	69	0
2016	364	14	51	1
2017	283	25	78	9

Table 46. Statistics for the hourly rates of change in water temperature at QUN-WQ in the Quinsam River. The frequency of rates of change exceeding a magnitude of 1°C/hr is also shown.

Start of record	End of record	Number of Datapoints	Occurrence of rates >1°C/hr		Maximum Negative Rate	Percentile				Maximum Positive Rate
			Number	% of record		1th	5th	95th	99th	
23-May-2014	11-Oct-2017	474,926	82	0.02	-1.3	-0.3	-0.2	0.2	0.4	1.1

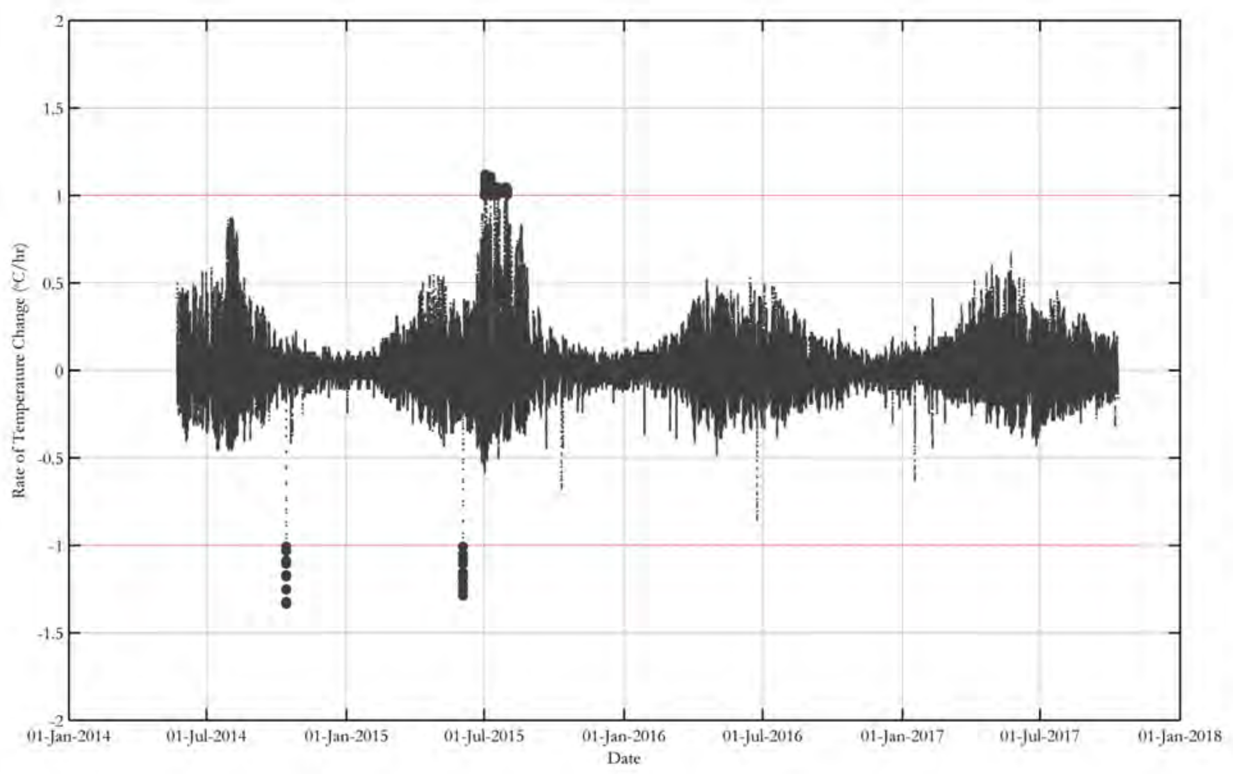
Table 47. **The growing season and growing degree days at QUN-WQ in the Quinsam River (2014 to 2017).**

Year	Number of days with valid data	Growing Season				
		Start Date	End Date	Length (day)	Gap (day)	Degree Days
2014†	222	-	4-Dec-2014	-	-	-
2015	365	2-Mar-2015	25-Nov-2015	269	0	3,561
2016	366	15-Mar-2016	9-Dec-2016	270	0	3,492
2017‡	284	28-Mar-2017	-	-	-	-

†Growing season could not be estimated because a complete data set over the course of the growing season is not available.

‡Growing season will be reported once the dataset covers a complete growing season.

Figure 33. **Rate of change in hourly water temperature in the Quinsam River (QUN-WQ) from 2014 to 2017. Large dots indicate rates with magnitudes exceeding ±1°C/hr.**



Mean Weekly Maximum Water Temperatures

Fish species of primary interest for JHTMON-8 in the Quinsam River are steelhead, Coho Salmon and Chinook Salmon, although Pink Salmon is also particularly important to fishery managers due to its importance as a food source and a target for anglers. Steelhead and Coho Salmon are present both upstream and downstream of QUN-WQ, although falls and cascades downstream of Lower Quinsam Lake are complete barriers to Chinook Salmon and Pink Salmon (Burt 2003). Thus, results for the latter two species should be interpreted with caution.

The MWMxT data for 2014 through 2017 are compared to optimum temperature ranges for fish species in Table 48. For each life stage, Table 48 also shows the percentage of MWMxT data that are above, within, and below the optimum ranges for fish life stages during baseline monitoring. The percentages of MWMxT data above and below the optimum ranges by more than 1°C are also shown. Comparisons to the provincial WQG-AL are not made when records are ≤50% complete for the period of interest (Table 48). In addition, if the water temperature records are only slightly >50% complete for a particular species/life stage, comparisons to the provincial WQG-AL should be interpreted with caution.

Considering all years and all species/life stages, MWMxT in the Quinsam River exceeded optimum ranges by more than 1°C an average of 18.8% of the time, and were below optimum ranges an average of 26.6%% of the time (Table 48).

For Chinook Salmon, temperatures were within optimum ranges during the migration stage. During the spawning period, 1.6% (2014) to 18.0% (2015) of MWMxT data were > 1°C cooler than the lower bound of the optimum range of 5.6°C for spawning, and 3.3% of the data in 2014 were > 1°C warmer than the upper bound of the optimum range of 13.9°C for spawning. MWMxT did not exceed the upper bound of the optimum ranges by > 1°C for the incubation stage in 2014, 2015, or 2016; while 9.6% (2014) to 50.5% (2016) of MWMxT data were > 1°C cooler than the lower bound of the optimum range for incubation (5.0°C). During the rearing stage, 17.6% (2016) to 35.0% (2017) of MWMxT data were > 1°C cooler the lower bound of the optimum range, while 23.4% (2017) to 48.9% (2016) of data were warmer than upper bound (Table 48).

For Coho Salmon, temperatures were typically below the upper bound of the optimum ranges for migration, spawning, and incubation stages (except migration in 2014, where 5.6% of the temperatures were > 1°C higher than the upper bound of optimum ranges). However, 1.3% (2014; incubation) to 45.8% (2015; migration) of MWMxT data were > 1°C cooler than the lower bound of the optimum ranges. For the rearing stage (year-round), temperatures were within the optimum bounds for a minority (23.8 to 35.8%) of the time. In all years, temperatures were recorded that were more than 1°C cooler and warmer than the lower and upper bound of the optimum ranges, respectively.

For Pink Salmon, the analysis indicates that high water temperatures occurred during migration, spawning, and incubation. In 2017, temperatures exceeded the upper bound of the optimum range by > 1°C for 63.4% of the adult migration period, 64.0% of the spawning period, and 64.0% of the incubation period. In contrast, during the incubation stage between 2014 and 2016, MWMxT data were within the optimum range for 43.9% (2016) to 77.9% (2014) of the period.

For steelhead, MWMxT were rarely (0% to 22.0% of the records) within the optimum ranges for any life stage. Most notably, water temperatures during the spawning stage between 2015 and 2017 were below the optimum range for 86.7% to 100% of the records, and > 1°C below the lower bound for 75.0% to 100.0% of the time. In 2017, water temperatures were within the optimum bounds for 0% of the spawning stage, 4.2% of the incubation stage, and 5.7% or the rearing stage.

Note that the WQG-AL temperature ranges for steelhead life stages are based on those for 'Rainbow Trout' (Oliver and Fidler 2001) and are not specific to fish with an anadromous life history (i.e., steelhead). Data specific to steelhead (Carter 2005 and references therein) indicate that steelhead are adapted to tolerate MWMxT considerably lower than the optimum ranges presented in Table 48 during spawning and incubation, although survival is likely to be affected by temperatures that exceed these ranges. For example, Carter (2005) cites WDOE (2002), which reports that the low end of the range of preferred spawning temperatures for steelhead is 4.4°C, rather than the value of 10.0°C reported in Table 48 for Rainbow Trout. Thus, although the alternative values cited above may not be fully representative of steelhead populations on Vancouver Island, the occurrence of MWMxT in the Quinsam River that are below 10.0°C do not necessarily indicate poor conditions for spawning and incubation steelhead life stages.

Table 48. Mean weekly maximum temperatures (MWMxT) in the Quinsam River from 2014 to 2017 compared to optimum temperature ranges for fish species present. Periodicity information is from Burt (2003).

Species	Life Stage			Year	Percent Complete	MWMxT (°C)		% of MWMxT				
	Periodicity	Optimum Temperature Range (°C)	Duration (days)			Min.	Max.	Below Lower Bound by >1°C	Below Lower Bound	Between Bounds	Above Upper Bound	Above Upper Bound by >1°C
Chinook Salmon	Migration (Sep. 23 to Nov. 22)	3.3-19.0	61	2014	100	5.2	16.2	0.0	0.0	100.0	0.0	0.0
				2015	100	4.0	12.9	0.0	0.0	100.0	0.0	0.0
				2016	100	7.4	14.6	0.0	0.0	100.0	0.0	0.0
				2017	29.5	-	-	-	-	-	-	-
	Spawning (Oct. 01 to Nov. 30)	5.6-13.9	61	2014	100	4.3	15.0	1.6	27.9	57.4	14.8	3.3
				2015	100	2.7	12.9	18.0	24.6	75.4	0.0	0.0
				2016	100	6.1	12.9	0.0	0.0	100.0	0.0	0.0
				2017	16.4	-	-	-	-	-	-	-
	Incubation (Oct. 16 to Apr. 30)	5.0-14.0	197	2014	100	2.8	11.8	9.6	21.3	78.7	0.0	0.0
				2015	100	2.4	12.5	27.4	49.2	50.8	0.0	0.0
				2016	100	1.3	9.6	50.5	56.1	43.9	0.0	0.0
				2017	0	-	-	-	-	-	-	-
	Rearing (Mar. 08 to Jul. 22)	10.0-15.5	137	2014	43.8	-	-	-	-	-	-	-
				2015	100	6.9	22.5	21.9	28.5	19.0	52.6	48.9
				2016	99.3	5.4	19.3	17.6	22.8	36.8	40.4	26.5
				2017	100	3.0	20.3	35.0	50.4	12.4	37.2	23.4
Coho Salmon	Migration (Sep. 16 to Dec. 31)	7.2-15.6	107	2014	100	2.9	17.1	45.8	46.7	44.9	8.4	5.6
				2015	100	2.7	14.7	44.9	49.5	50.5	0.0	0.0
				2016	100	2.3	16.3	30.8	35.5	60.7	3.7	0.0
				2017	23.4	-	-	-	-	-	-	-
	Spawning (Oct. 16 to Jan. 15)	4.4-12.8	91	2014	100	2.8	11.3	11.0	28.6	71.4	0.0	0.0
				2015	100	2.4	11.4	34.1	48.4	51.6	0.0	0.0
				2016	100	1.3	9.6	41.9	44.1	55.9	0.0	0.0
				2017	0	-	-	-	-	-	-	-
	Incubation (Oct. 16 to Dec. 31)	4.0-13.0	77	2014	100	2.9	11.3	1.3	7.8	92.2	0.0	0.0
				2015	100	2.7	11.4	9.1	35.1	64.9	0.0	0.0
				2016	100	2.3	9.6	27.3	31.2	68.8	0.0	0.0
				2017	0	-	-	-	-	-	-	-
	Rearing (Jan. 01 to Dec. 31)	9.0-16.0	365	2014	60.9	2.9	21.8	23.3	24.2	23.8	52.0	38.1
				2015	100	2.7	22.5	38.5	42.9	26.5	30.6	28.4
				2016	99.5	2.3	20.8	36.1	38.3	35.8	25.9	20.9
				2017	77.5	1.3	21.3	38.5	40.3	25.4	34.3	29.7
Pink Salmon	Migration (Aug. 01 to Oct. 15)	7.2-15.6	76	2014	100	11.6	21.8	0.0	0.0	27.6	72.4	65.8
				2015	100	11.0	20.6	0.0	0.0	52.6	47.4	39.5
				2016	98.7	9.4	20.8	0.0	0.0	34.7	65.3	49.3
				2017	93.4	12.3	21.3	0.0	0.0	31.0	69.0	63.4
	Spawning (Sep. 16 to Oct. 15)	7.2-12.8	30	2014	100	11.6	17.1	0.0	0.0	13.3	86.7	80.0
				2015	100	11.0	14.7	0.0	0.0	73.3	26.7	13.3
				2016	100	9.4	16.3	0.0	0.0	46.7	53.3	36.7
				2017	83.3	12.3	16.1	0.0	0.0	28.0	72.0	64.0
	Incubation (Sep. 16 to Apr. 07)	4.0-13.0	204	2014	100	2.8	17.1	1.5	9.3	77.9	12.7	11.8
				2015	100	2.4	14.7	10.8	26.5	71.1	2.5	1.5
				2016	100	1.3	16.3	42.0	48.8	43.9	7.3	5.4
				2017	12.3	12.3	16.1	0.0	0.0	28.0	72.0	64.0
Rainbow Trout/ Steelhead	Spawning (Feb. 16 to Apr. 15)	10.0-10.5	60	2014	0	-	-	-	-	-	-	-
				2015	100	5.3	9.8	85.0	100.0	0.0	0.0	0.0
				2016	100	4.7	10.2	75.0	86.7	13.3	0.0	0.0
				2017	100	2.5	7.3	100.0	100.0	0.0	0.0	0.0
	Incubation (Feb. 16 to Jun. 15)	10.0-12.0	121	2014	19.2	-	-	-	-	-	-	-
				2015	100	5.3	19.3	42.1	49.6	14.0	36.4	34.7
				2016	99.2	4.7	18.6	37.5	43.3	16.7	40.0	33.3
				2017	100	2.5	16.5	56.7	74.2	4.2	21.7	20.0
	Rearing (Jan. 01 to Dec. 31)	16.0-18.0	365	2014	60.9	2.9	21.8	45.7	48.0	22.0	30.0	22.4
				2015	100	2.7	22.5	66.1	69.4	4.4	26.2	17.8
				2016	99.5	2.3	20.8	65.6	74.1	10.2	15.7	10.5
				2017	77.5	1.3	21.3	56.5	65.7	5.7	28.6	26.1

Blue shading indicates provincial guideline exceedance of the lower bound of the optimum temperature range by more than 1°C (Oliver and Fidler 2001).
Red shading indicates provincial guideline exceedance of the upper bound of the optimum temperature range by more than 1°C (Oliver and Fidler 2001).

Air Temperature

Figure 34 shows the daily average, maximum, and minimum air temperature for the period of record from May 2014 to October 2017. The monthly average air temperatures are shown in Table 49. The mean monthly air temperature ranged from -1.5°C to 18.7°C during the period of record. The lowest air temperature measured during the monitoring period was -12.8°C measured in January 2017, while the highest air temperature was 32.9°C in June 2015. The maximum monthly mean air temperature (18.7°C) was in July 2015.

Air and water temperatures were highly correlated (Figure 35), with a linear correlation coefficient (*r*) of 0.95. Daily mean water temperatures typically exceeded daily mean air temperatures, which likely partly reflected the influence of warming in lakes upstream.

Table 49. Monthly air temperature statistics at the Quinsam River (QUN-AT) from 2014 to 2017. Statistics were not generated for months with less than 3 weeks of observations.

Month	2014				2015				2016				2017			
	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD
Jan	n/a	n/a	n/a	n/a	3.1	-4.6	9.5	2.7	1.7	-8.2	9.2	3.4	-0.7	-12.8	7.6	4.7
Feb	n/a	n/a	n/a	n/a	5.2	-1.9	10.9	3.1	3.9	-2.0	10.2	2.2	-0.3	-8.9	9.8	3.0
Mar	n/a	n/a	n/a	n/a	6.1	-2.4	14.6	3.5	5.5	-2.1	19.3	3.6	2.9	-5.1	11.6	3.3
Apr	n/a	n/a	n/a	n/a	7.0	-1.0	20.7	4.1	9.8	0.6	25.3	4.2	6.2	-1.6	14.4	2.7
May	n/a	n/a	n/a	n/a	13.7	0.6	26.5	5.1	12.9	2.8	25.2	4.8	-	-	-	-
Jun	14.3	4.6	23.9	3.8	16.9	5.4	32.9	5.2	14.5	4.1	29.8	4.7	-	-	-	-
Jul	17.8	8.4	32.1	4.9	18.7	8.6	31.5	5.3	16.7	8.9	27.8	3.8	17.0	7.2	27.4	4.1
Aug	18.5	8.8	30.5	4.7	16.8	7.9	29.0	4.4	17.5	9.0	31.3	4.8	18.4	7.8	32.0	5.0
Sep	14.1	4.4	27.3	4.4	11.5	2.7	24.6	3.8	11.8	2.6	22.8	3.5	14.0	2.4	30.9	5.4
Oct	10.1	1.2	18.4	2.9	9.9	1.8	19.8	3.0	8.2	-0.8	13.0	2.3	-	-	-	-
Nov	3.1	-7.6	12.4	4.7	1.7	-7.8	9.7	3.6	6.5	-0.7	14.3	3.1				
Dec	2.4	-7.1	10.4	3.7	1.8	-5.8	8.9	3.0	-1.5	-12.1	7.7	3.7				

"Avg", "Min", "Max" and "SD" denote the monthly average, minimum, maximum, and standard deviation of water temperatures (°C).
"n/a" indicates that TidbiTs weren't installed. "-" indicates that data gap is due to missing Tidbits.
Blue and orange shadings highlight minimum and maximum temperatures, respectively.

Figure 34. **Air temperature at the Quinsam River (QUN-AT) between May 2014 and October 2017.**

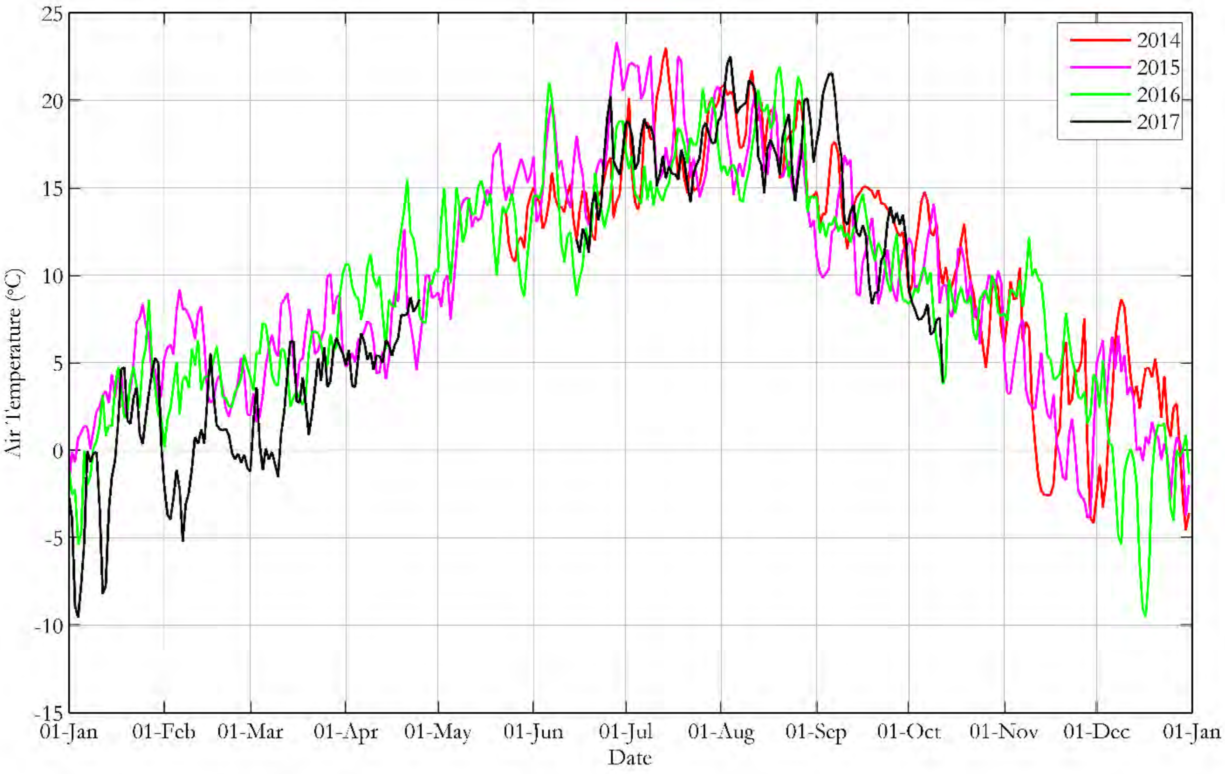
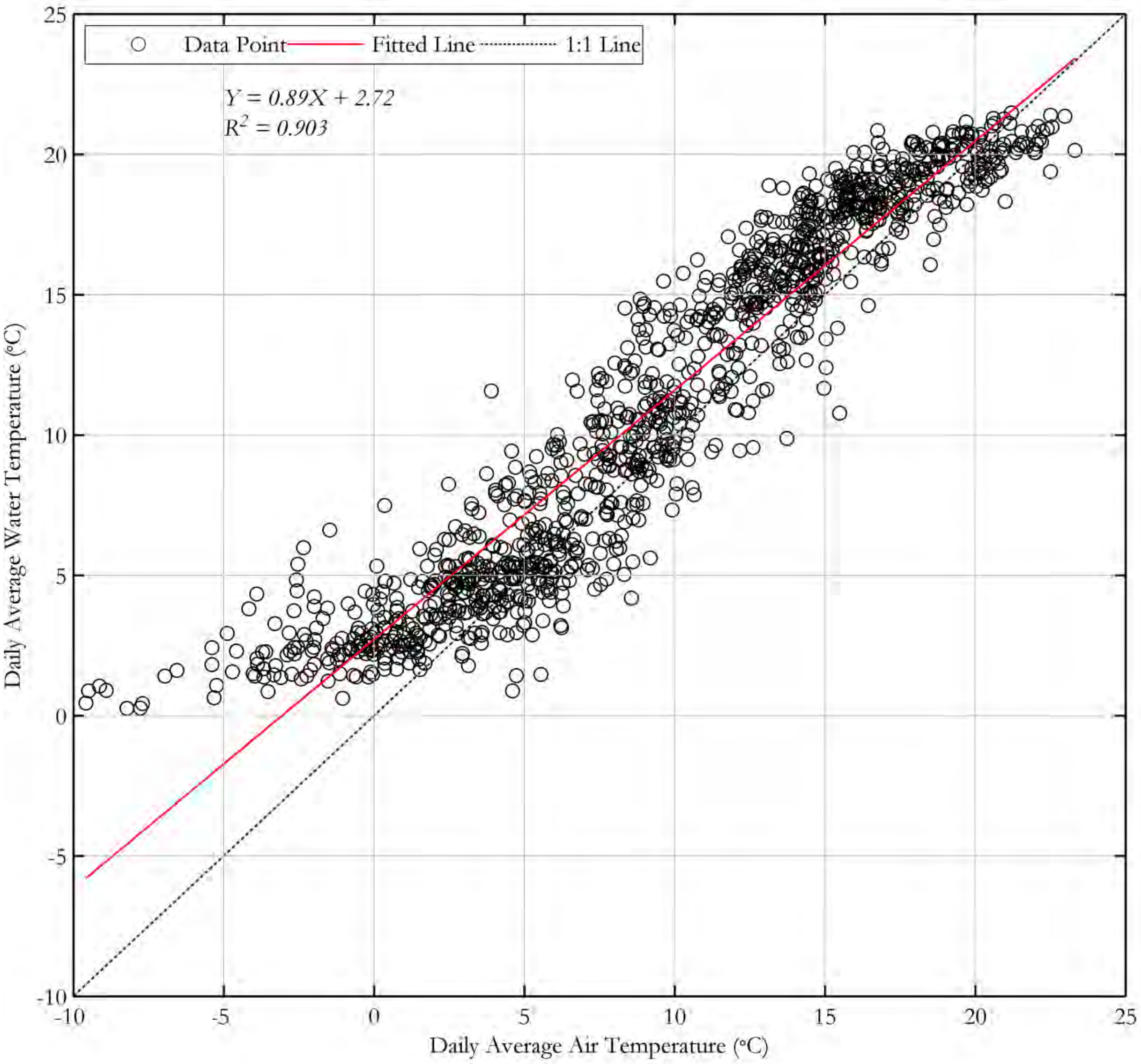


Figure 35. Relationship between daily average water and air temperature in the Quinsam River (QUN-AT) between May 2014 and October 2017.



3.2.4. Interim Evaluation of Potential to Incorporate Water Quality Data into Analysis

3.2.4.1. Overview

The objective of the JHTMON-8 water quality monitoring is to measure biologically important water quality variables to provide data to test H_03: '*annual population abundance is not correlated with water quality*'. A range of water quality parameters are being measured, both in the field and the laboratory, and four years of data have now been collected. It is timely to evaluate the water quality data to assess how water quality data can be used to test H_03. This was specifically identified as an analysis task for Year 4 prior to the study (Abell *et al.* 2015a). Readers should also consult the background water quality review that was completed during Year 2 (Dinn *et al.* (2016) for further evaluation of water quality in the study watersheds.

This analysis is presented as an initial screening of the data collected to date. It does not replace the requirement to consider all data at the end of the monitor when formal hypothesis tests are conducted.

3.2.4.2. Nutrients (Nitrogen and Phosphorus)

Concentrations of ammonia, nitrite, nitrate, orthophosphate, and total phosphorus are measured in water samples from both the Salmon and Quinsam rivers (Section 2.2.1). Data from both rivers show that concentrations of nutrients are frequently below MDLs, with the exception of nitrate that was typically detectable (Table 33 and Table 37). This suggests the systems are likely phosphorus limited, since concentrations of total phosphorus and orthophosphate were generally undetectable while nitrate was still available. This is consistent with the finding of nutrient enrichment monitoring work conducted in the Salmon River (Pellet *et al.* 2011).

Nitrate was detectable at both sampling sites (SAM-WQ and QUN-WQ in Table 33 and Table 37, respectively), and some productivity models have used nitrate as a parameter in the modelling (Lewis and Ganshorn 2007). Nitrate concentrations ranged from 8.5 µg N/L to 133 µg N/L at SAL-WQ and 12.3 µg N/L to 47.4 µg N/L in QUN-WQ over the 4 years of monitoring (Figure 36 and Figure 37, respectively). The range in values of annual average concentration of nitrate is low for the Quinsam River (21.6 µg N/L to 27.9 µg N/L) and slightly greater for the Salmon River (26.3 µg N/L to 52.4 µg N/L).

Inter-year variability was highest in August for the Quinsam River, and August and September for the Salmon River; however, within year variability is higher than between year variability. Inter-year variability (based on the coefficient of variation for annual averages) is 12.8% for the Quinsam River and 29.4% for the Salmon River. These ranges may be too small for nitrate concentration to be a valuable predictor of fish productivity, particularly for the Quinsam River, and may not be relevant if the system if phosphorus limited. Thus, nutrients are not recommended as good parameters for testing $H_0$3.

3.2.4.3. General Water Quality Parameters

A range of general water quality parameters are measured in the Salmon and Quinsam rivers both in the field and in the laboratory. TSS, pH, alkalinity, and specific conductivity have been used as parameters in fish population models previously (Lewis and Ganshorn 2007), making them appropriate parameters to be considered for inclusion in statistical modelling.

However, TSS concentrations were at or near the MDL in both the Salmon and Quinsam rivers, and turbidity levels were below 1 NTU (except in July 2016 at QUN). Since the TSS concentrations were below MDL, and there is no measurable inter-annual variation in turbidity values, these parameters are unlikely to be useful for predicting changes in fish population abundance among years. Further, these variables can vary rapidly in response to changes in flow, although the monthly sampling program is inadequate to capture these dynamics.

Figure 36. Nitrate concentrations measured in the Salmon River (SAM-WQ) between 2014 and 2017.

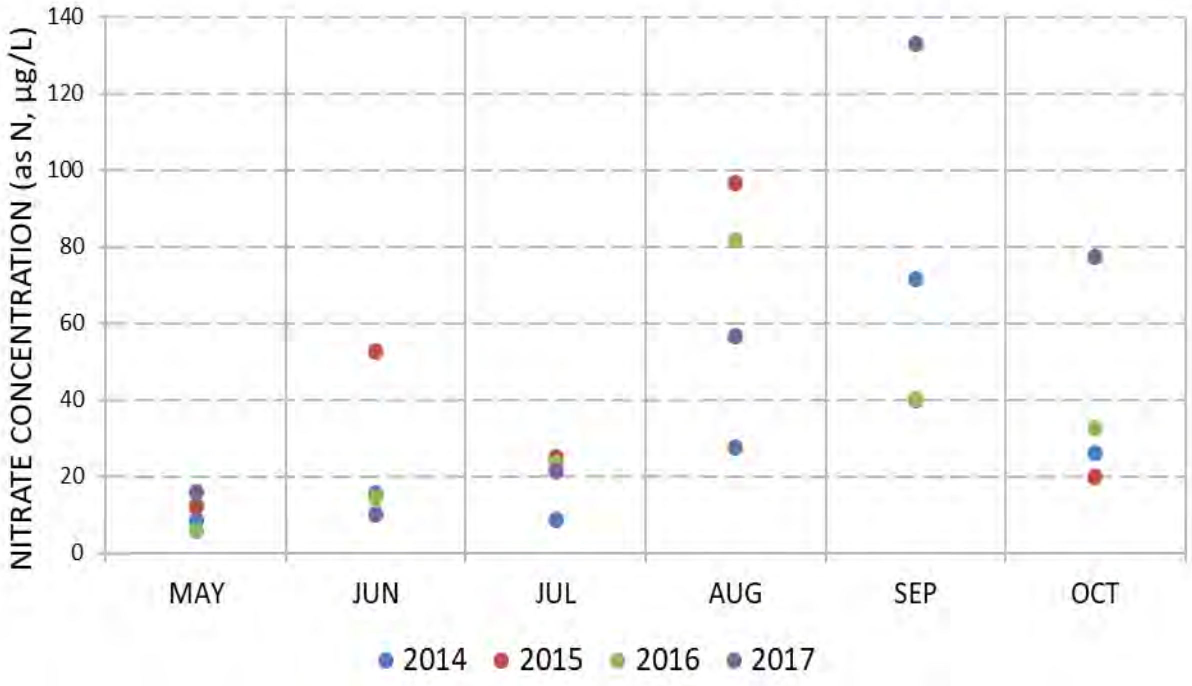
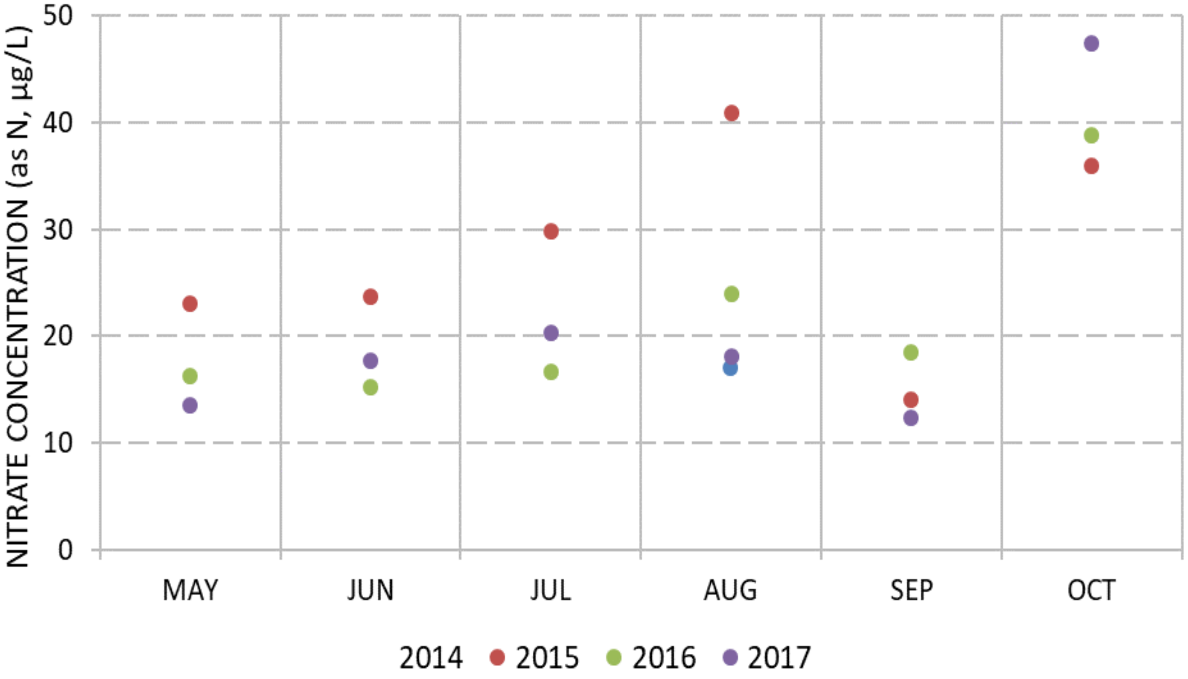


Figure 37. **Nitrate concentrations measured in the Quinsam River (QUN-WQ) between 2014 and 2017.**



While pH can affect fish due to direct toxicity or osmoregulatory imbalance, the pH measured in the Quinsam River (Table 34 and Table 36) is within the range of the BC WQG-AL (6.5 to 9.0), and is not likely to affect fish health or population abundance. On this basis, pH is not expected to provide a useful predictor of fish productivity in the Quinsam River.

The pH measured in the Salmon River was slightly below 6.5 about 50% of the time in 2016 and 2017 (field measured, while in lab it was within acceptable range; Table 30 and Table 32). However, adverse effects to fish when the pH is only marginally outside of acceptable range are not expected. Available data suggest that adverse effects in fish are not likely to occur until pH drops below 6.0 (and more likely 5.5; McKean and Nagpal 1991). Thus, it is unlikely that pH affects fish populations in the Salmon River, and pH is unlikely to be a good predictor of changes in fish abundance between years.

Alkalinity, alone or in combination with other variables, has successfully been used in fish population/density models for Pacific salmon species and other salmonid species in clear streams in BC (e.g., Ptolemy *et al.* 1991; Ptolemy 1993; Parken 1997; Bocking et al., 2005; Ptolemy 2005). Based on data collected over the four years of sampling (Year 1 to 4 from 2014 to 2017), alkalinity and specific conductivity in each water sample are correlated in both the Salmon and Quinsam rivers (SAM r = 0.97, QUN r = 0.94). The range in monthly average level or concentration is greater for specific conductivity than alkalinity, although the inter-annual variability in both alkalinity and specific conductivity (based on annual average concentrations) is relatively low at both sites:

- Alkalinity:
    - SAM-WQ (Figure 38) had alkalinity from 12.3 to 25.4 mg/L as $CaCO_3$, with an inter-annual coefficient of variation of 5.2 mg/L as $CaCO_3$ (based on annual averages);
    - QUN-WQ (Figure 39) had alkalinity from 23.7 to 52.9 mg/L as $CaCO_3$, with an inter-annual coefficient of variation of 11.9 mg/L as $CaCO_3$ (based on annual averages);
- Specific conductivity:
    - SAM-WQ (Figure 40 = 26.4 to 59.9 µs/cm; with an inter-annual coefficient of variation of 6.3 µs/cm (based on annual averages); and
    - QUN-WQ, Figure 41 = 71.3 to 206 µs/cm, with an inter-annual coefficient of variation of 14.9 µs/cm (based on annual averages).

In comparison, alkalinity concentrations used by Ptolemy *et al.* (1991) to derive their fish density model ranged from 1.2 mg/L to 246.0 mg/L, while conductivity ranged from 3.0 to 450.0 µs/cm. The range in alkalinity concentrations or specific conductivity levels in the Salmon and Quinsam rivers may not be wide enough to be a valuable predictor of inter-annual changes in fish populations in these waterways. However, given that there is some inter-month and inter-annual variability in these parameters, and that other researchers have used alkalinity or conductivity to model fish density (albeit among, not within, watersheds), they may be reasonable candidates for inclusion in statistical models to test $H_0$3.

To identify the most appropriate measure to use in JHTMON-8 analysis, it is useful to consider approaches taken in other studies. These have used various metrics to represent total alkalinity in fish population modelling, including using conductivity data or water yields as surrogates for alkalinity (e.g., Ptolomey *et al.* 1991, Bocking *et al.* 2005). Some models have used alkalinity metrics based on single samples collected during a period of interest (e.g., summer low flow; Bocking *et al.* 2005). Where corresponding reach-specific hydrometric data and alkalinity concentrations were available, other researches calculated a 'standardized' alkalinity metric that accounts for stream flow during the critical summer low flow period between July 1 and October 31 (with the critical period stream flow [CPSF] described as a percentage of mean annual discharge). An equation of the form "$\text{Log}_{10}(\textit{alkalinity}) = a - (b \times \text{Log}_{10}(\textit{flow})$" was used to calculate the relevant site-specific CPSF alkalinity concentration (Ptolemy *et al.* 1991, Ptolemy 1993, Ptolemy 2005).

Alkalinity in the Salmon and Quinsam rivers is measured monthly, with samples collected monthly during the CPSF. Therefore, it may be feasible to use the measured concentration during the lowest flow summer month as a predictor variable, consistent with the approach in Bocking *et al.* (2005). Alternatively, a more-sophisticated approach is to develop a relationship between measured alkalinity and stream flow. This could then be used to estimate alkalinity that is representatively of the CPSF for a specific year, recognizing that the monthly sampling does not necessarily coincide precisely with annual minimum flow. Hydrometric data are available from multiple locations on both rivers from Water Survey of Canada gauges (Section 2.3 and 3.3). Therefore, developing a site-specific log regression relationship between alkalinity and stream flow (and using that relationship to calculate alkalinity at the lowest stream flow) may provide the best estimate of the relevant alkalinity for use in population modelling, consistent with the approach used by Ptolemy *et al.* (1991) and Ptolemy (1993 and 2005).

Figure 38. Alkalinity measured in the Salmon River (SAM-WQ) between 2014 and 2017.

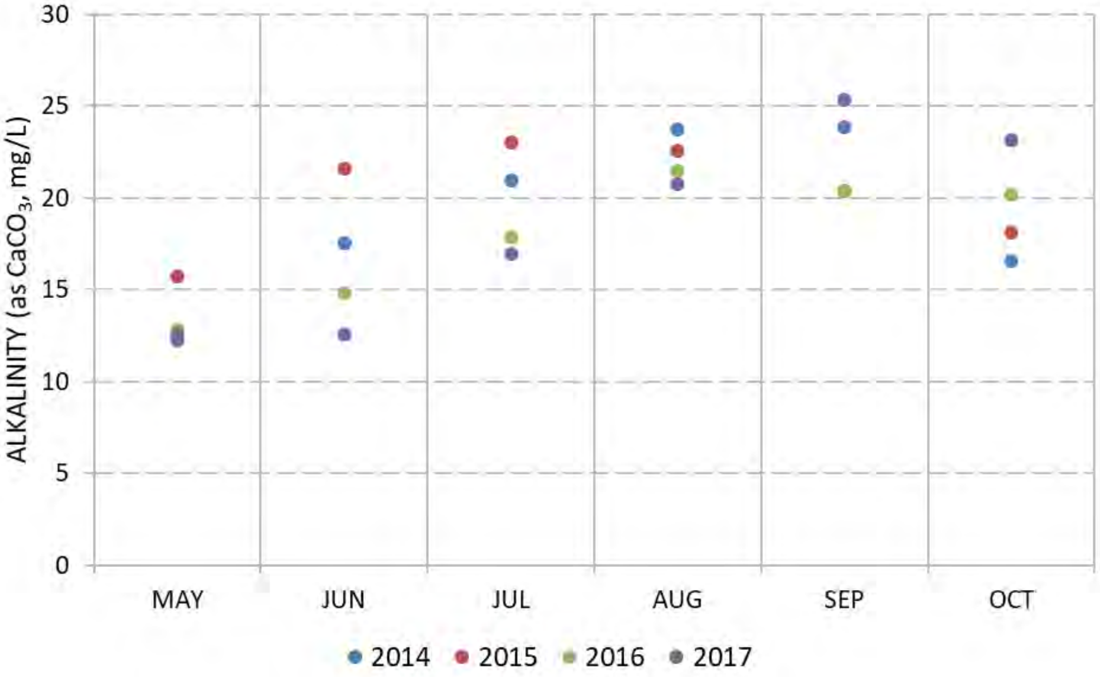


Figure 39. Alkalinity measured in the Quinsam River (QUN-WQ) between 2014 and 2017.

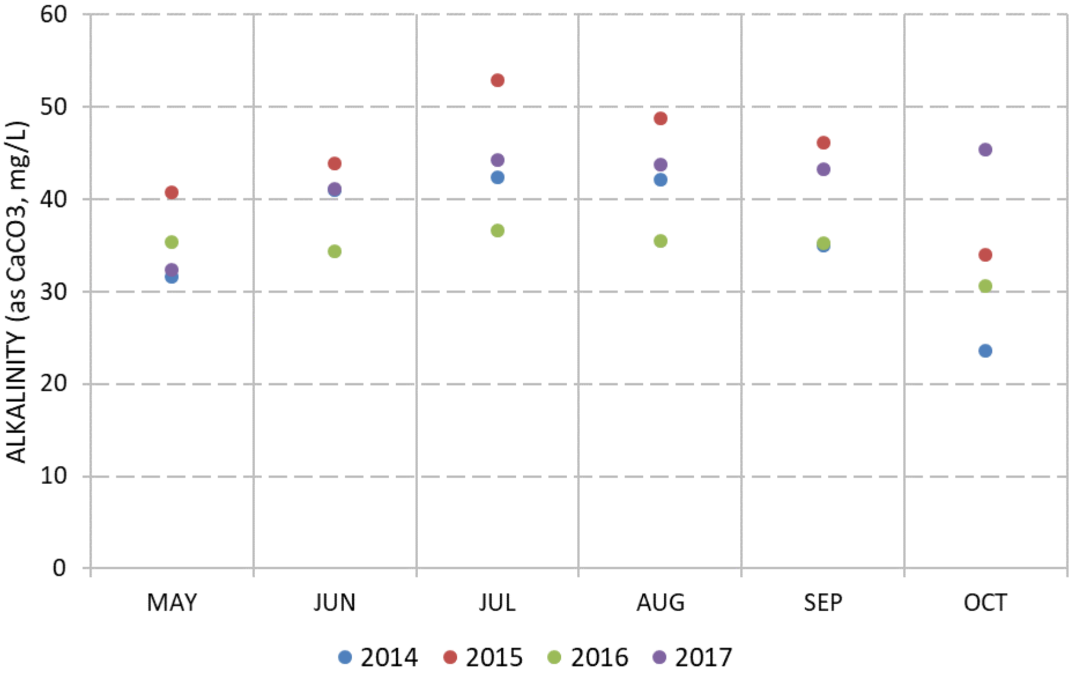


Figure 40. Specific conductivity measured in the Salmon River (SAM-WQ) between 2014 and 2017.

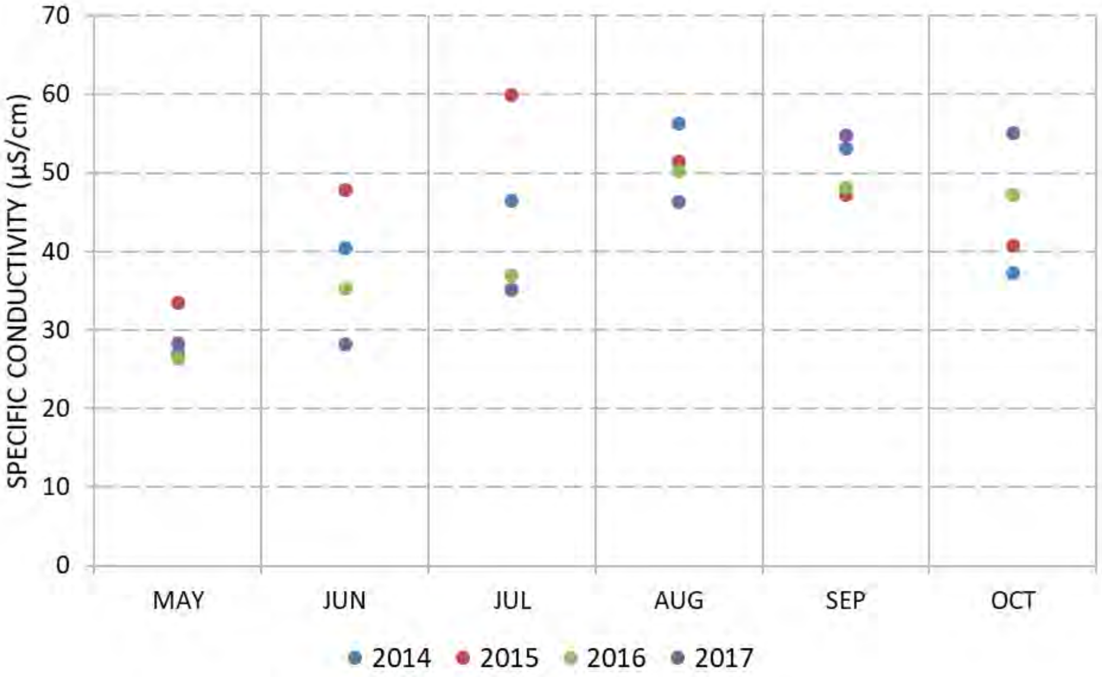
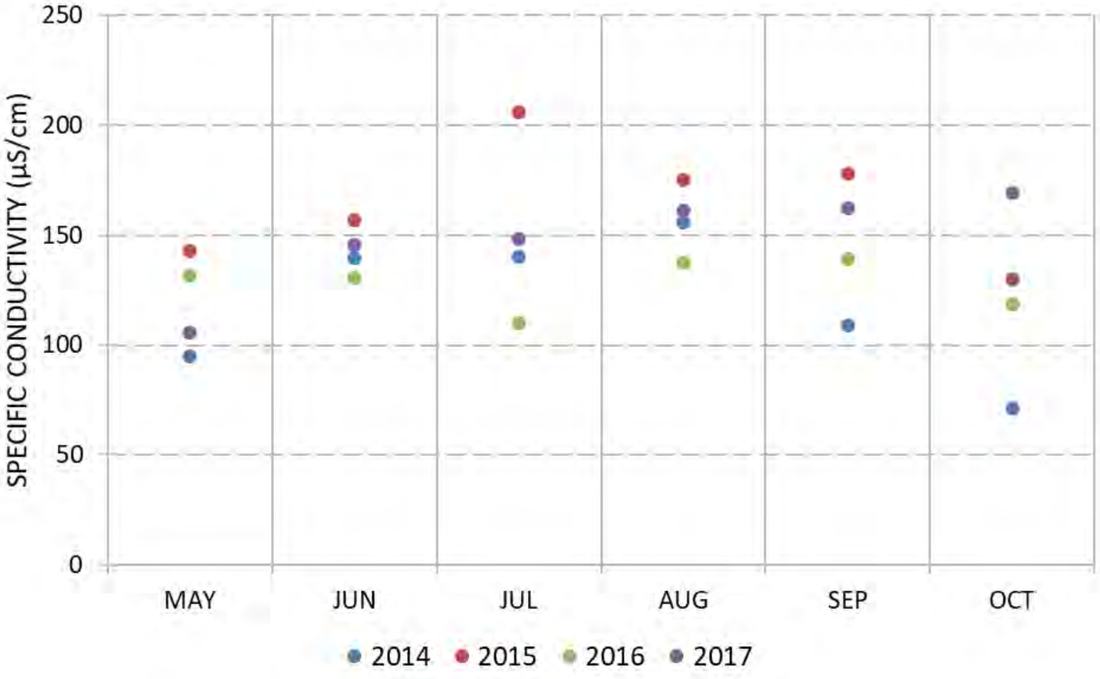


Figure 41. Specific conductivity measured in the Quinsam River (QUN-WQ) between 2014 and 2017.



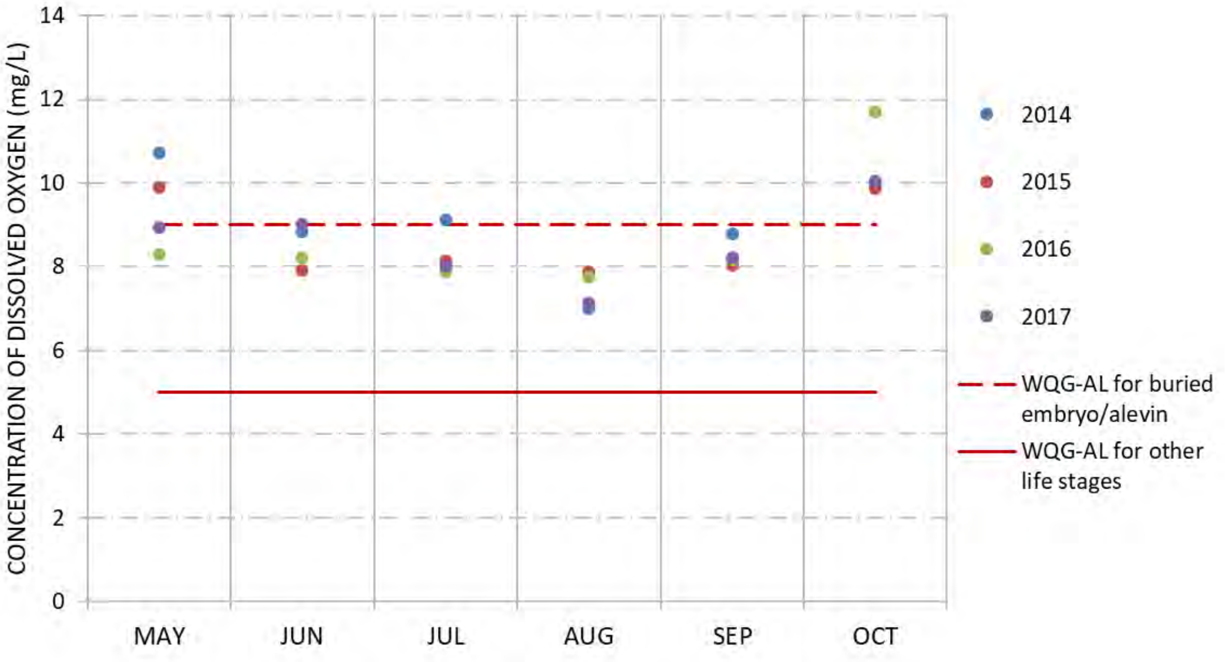
3.2.4.4. Dissolved Oxygen

Dissolved oxygen has been included as a parameter in fish productivity models (Lewis and Ganshorn 2007). Low DO has the potential to cause mortality, decrease growth, or delay hatching (BC MOE 1997), all of which could have population-level effects if the conditions are extreme or persist for extended periods of time.

Dissolved oxygen concentrations were measured once during each month (May to October) between 2014 and 2017. Dissolved oxygen concentrations measured in the Salmon River (SAM-WQ) were generally higher than the instantaneous minimum concentration of 9 mg/L specified by the BC WQG-AL for the most sensitive life stages (buried embryo/alevin), except in a few months in 2014 and 2015 (Table 31).

In contrast, DO concentrations in the Quinsam River (QUN-WQ) were frequently lower than the BC WQG-AL instantaneous minimum concentration of 9 mg/L for buried embryo/alevins (Table 35 and Figure 42), suggesting potential effects to fish due to low DO are possible.

Figure 42. **Dissolved oxygen concentrations measured in the Quinsam River (QUN-WQ) between 2014 and 2017, in comparison to the BC Water Quality Guideline for the Protection of Aquatic Life.**



There is uncertainty in whether effects to fish would occur since the *in situ* measurements of DO were only taken once per month, and may not reflect the average conditions during embryo/alevin development. Further, periods of low DO do not coincide with the incubation periods for all fish species (Burt 2003, 2010). In addition, *in situ* DO concentrations were measured in the morning, which is typically when DO concentrations are lowest (BC MOE 1997). Regardless, given that the instantaneous DO concentrations are lower than the concentration recommended by the BC WQG-AL during spawning and incubation periods in the Quinsam River (at QUN-WQ, see Table 48 for periodicity data), this parameter may limit fish productivity. Therefore, DO concentrations may be a useful predictor variable to support evaluation of H_03.

Other studies have used the average DO concentration within the water column for a specified length of time (Lestelle 2005), or the DO concentration measured during a month of interest (e.g., November, during spawning/egg incubation; Elliott 2004). Thus, for future modelling, potential metrics based on DO should be selected taking into consideration the sensitivity of different life stages, ideally selecting the life stage most likely to be affected by low DO (i.e., average DO concentration measured during the more sensitive egg/alevin stage).

3.2.4.5. Water Temperature

Temperature can influence fish health, growth, and reproductive success. When temperatures are too low or too high, growth may be delayed or accelerated, respectively, affecting the timing of hatch and emergence. When temperatures are too high, fish may become stressed, have impaired swimming ability, experience altered migration timing or success, and become more susceptible to disease. In addition, high temperatures can decrease DO concentrations, resulting in fish not being able to meet their needs due to increased cardiovascular, respiratory, and metabolic functions (Oliver and Fidler 2001).

Table 42 (Salmon River, SAM-WQ) and Table 48 (Quinsam River, QUN-WQ) show that the MWMxT is outside of the range recommended by the BC WQG-AL frequently (>50% of the time), particularly during in both rivers. While fish may be able to adapt or tolerate temperatures outside of the recommended ranges, conditions may not be optimal and effects on population abundance could occur.

There is inter-annual variability in MWMxt, both in terms of magnitude (i.e., minima and maxima outside of the recommended range) and whether the temperatures are above or below the recommended range in a given year. In addition, the degree to which temperature is outside of the recommended range varies for the different life stages (i.e., migration, spawning, incubation, and rearing) and the different fish species (i.e., Chinook Salmon, Coho Salmon, Rainbow Trout/steelhead, and Pink Salmon). Therefore, temperature (as MWMxt) during a period of interest (e.g., incubation or spawning stages) may be a suitable candidate for inclusion in statistical modelling to support evaluation of $H_0$3.

3.2.4.6. Summary

The objective of the JHTMON-8 water quality monitoring is to measure biologically important water quality variables to provide data to test $H_0$3: '*annual population abundance is not correlated with water quality*'. Of the parameters measured in the water quality monitoring program, alkalinity or specific conductivity, DO (Quinsam River only), and water temperature (as MWMxT) were identified as the best candidates for inclusion in statistical models to evaluate $H_0$3. These variables were selected because: they have been used previously in fish population modelling; they are outside of the ranges recommended by the BC WQG-AL for one or more life stages; there is inter-annual or inter-month variability in their concentrations or levels, and/or; they can cause adverse effects on fish at the individual and population levels when the concentrations or levels are outside of ranges recommended by the BC WQG-AL. This analysis does not replace the requirement to continue monitoring the existing suite of water quality variables in the Quinsam River, or to consider all data at the end of the monitor when formal hypothesis tests are conducted.

3.3. Hydrology

Quality assured data collected by the Water Survey of Canada were available until the end of 2016 (Year 3). Hydrographs for 2014–2016 at sites on the Salmon River and Quinsam River are presented in Figure 435 to Figure 44; hydrological metrics for these years are presented in Table 50.

For all years, discharge was low during the summer low-flow period, with minimum mean daily discharge of <0.5 m^3/s measured in the mainstem of both rivers, downstream of the diversion facilities (when they were not operating). It is also notable that maximum discharge was particularly high during the incubation periods for Pacific Salmon species that emerged in 2015 and 2017, reflecting floods during December 2014 and November 2016.

Figure 43. Discharge measured on the Salmon River upstream of Memekay River (Map 2) during 2014–2016.

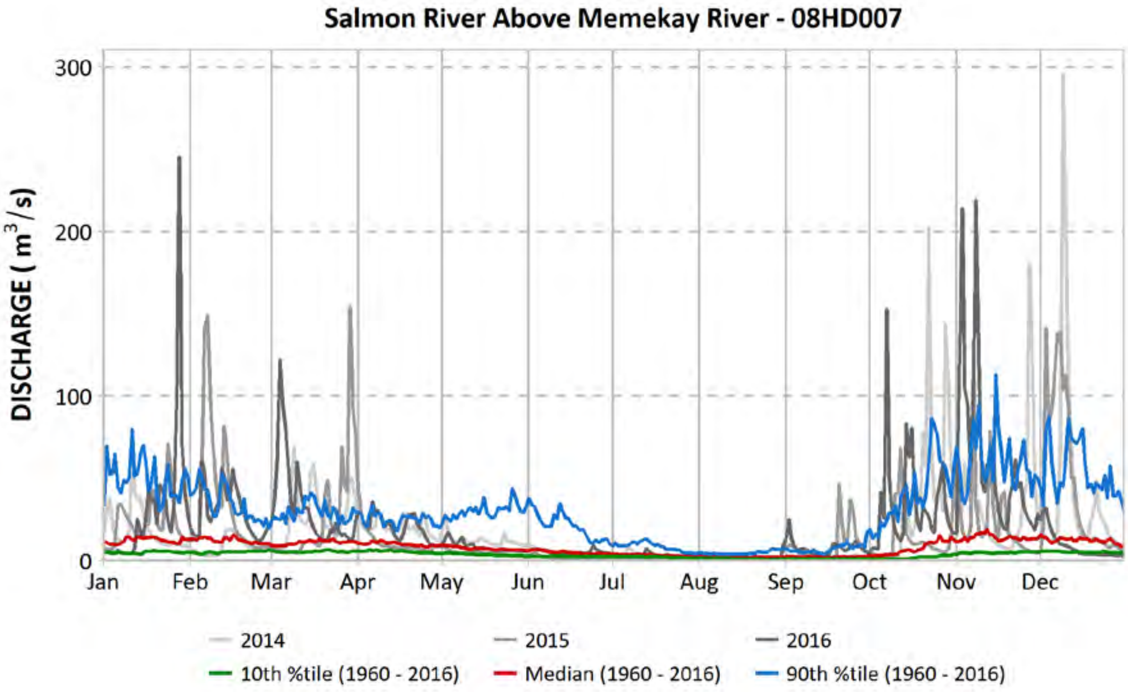


Figure 44. Discharge measured on the Quinsam River upstream of Campbell River (Map 3) during 2014–2016.

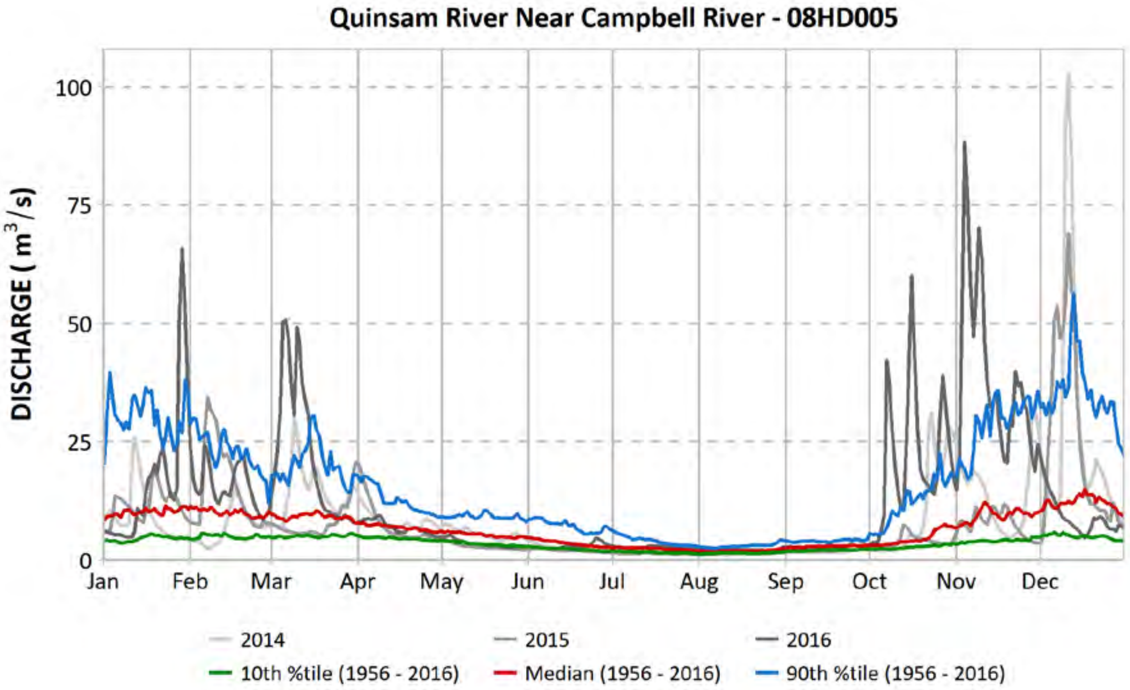


Figure 45. Discharge measured on the Quinsam River at Argonaut Bridge (Map 3) during 2014–2016.

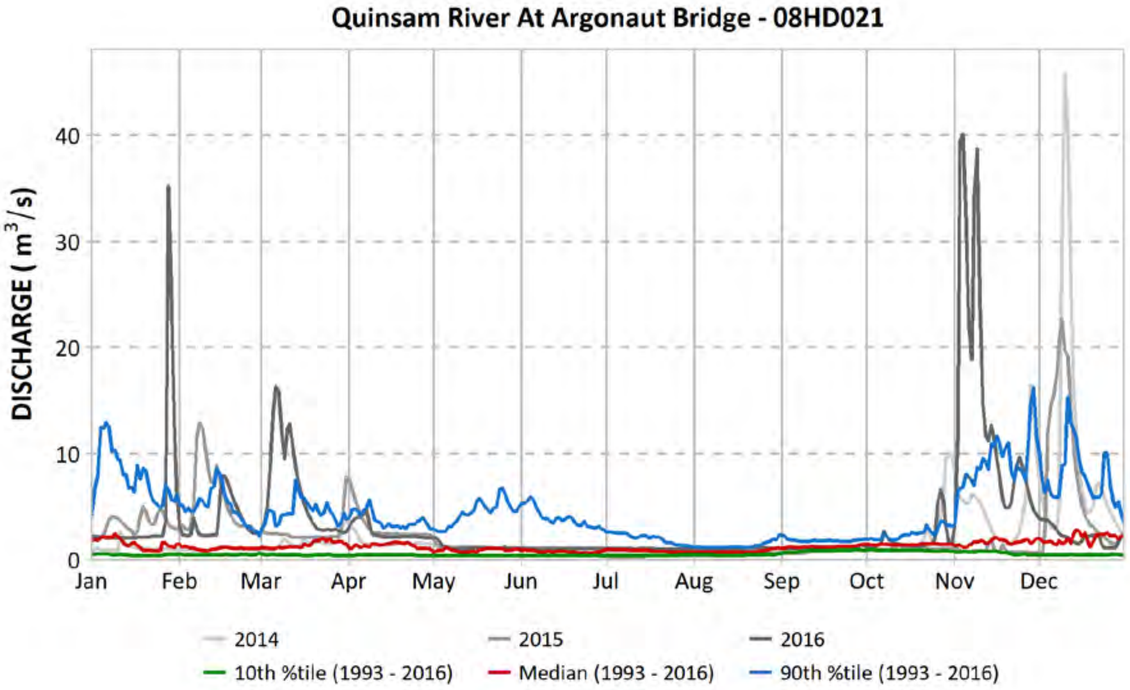


Table 50. **Hydrological metrics calculated for 2014–2016. See Map 2 and Map 3 for hydrometric gauge locations.**

Stream	Gauge	Year	Hydrological Metric (m^3/s)						
			Minimum Mean Discharge (m^3/s)			Maximum Discharge During Spawning and Incubation Periods[1]			
			1-Day Min.	3-Day Min.	30-Day Min.	Coho Salmon	Steelhead	Chinook Salmon	Pink Salmon
Salmon River	08HD007	2014	0.474	0.477	0.571	68.7	68.7	-	-
		2015	0.477	0.488	0.696	296	154	-	-
		2016	0.696	0.706	1.24	245	122	-	-
Quinsam River	08HD021	2014	0.442	0.448	0.565	3.63	3.63	3.63	3.63
		2015	0.265	0.270	0.328	45.9	7.91	45.9	45.9
		2016	0.987	0.994	1.03	35.2	16.3	35.2	35.2
	08HD005	2014	1.15	1.16	1.30	30.4	30.4	30.4	30.4
		2015	1.23	1.24	1.32	103	20.9	103	103
		2016	1.99	2.00	2.16	69.1	50.8	69.1	69.1

[1]'-' denotes that the value was not calculated as juvenile abundance of this species is not monitored. For fall spawners, this metric was calculated based on the discharge between the start of spawning the previous year and fry emergence during the current year.

▨ Value is partially or fully based on data graded as "estimated" by Water Survey of Canada.

3.4. Invertebrate Drift

3.4.1. Salmon River Invertebrate Drift

3.4.1.1. Overview

The invertebrate drift density (individuals/m^3), biomass (mg/m^3), Simpson's family-level diversity index (1-λ), richness (# families), and CEFI at each site on each sample date are provided in Table 51. Mean, standard deviation, and coefficients of variation values are shown for Year 1 (2014) data only, which is the only year when samples from all five drift nets were analyzed separately. Biomass values are also plotted in Figure 46. All values except for the CEFI (for which only aquatic taxa are considered) were calculated based on results for all taxa (aquatic, semi-aquatic, and terrestrial).

3.4.1.2. Density

In 2017, invertebrate drift density in the Salmon River was generally low at the beginning and end of the growing season, averaging 0.53 – 0.76 individuals/m^3 between May and June and 0.78 – 0.88 individuals/m^3 between the end of August and September (Table 51). There was a spike in density in July to mid-August, averaging 0.88 – 1.99 individuals/m^3 with a coefficient of variation of 43% for the four weekly samples (Table 51). This pattern is similar to Year 1 and Year 2 when density peaked in mid-summer (Table 51). However, density was relatively lower in 2017 compared to Year 1, Year 2, and Year 3 when the highest density values ranged from 3.11 – 4.63 individuals/m^3 (Table 51).

3.4.1.3. Biomass

Invertebrate drift biomass in the Salmon River largely declined throughout the growing season in 2017, with values ranging nine-fold from 0.02 mg/m^3 (Sep 12) to 0.17 mg/m^3 (May 9; Figure 46). Biomass was fairly variable among the four weekly samples in August, with a coefficient of variation of 32%. There was no clear relationship between biomass and abundance. Mean biomass measurements were lower in 2017 than in 2016, but relatively similar to values recorded in Years 1 and 2. Biomass values were only slightly lower (0.02 mg/m^3; Sep 12) and higher (0.17 mg/m^3; May 9) in 2017 than those measured in Years 1 and 2 (0.03 – 0.12 mg/m^3).

3.4.1.4. Simpson's Family Level Diversity (1- λ)

Simpson's family level diversity values ranged from 0.85 to 0.91, with no clear seasonal pattern. Diversity was consistent among the four weekly samples in August, with a coefficient of variation of 1%. The minimum value in 2017 was higher than values in Years 1, 2, and 3 (0.38 – 0.75 mg/m^3).

3.4.1.5. Richness (# of Families)

Mean family richness ranged from 29 families (Aug 15) to 37 families (May 9), with no clear seasonal trend (Table 51). Mean richness was consistent among the four weekly samples in August, with a coefficient of variation of 5%. Mean richness was relatively lower in 2017 than in previous years, when the number of families ranged from 26 to 80 (Table 51).

3.4.1.6. Canadian Ecological Flow Index

Low CEFI values are described as <0.25 (Armanini *et al.* 2011) and all CEFI values in the Salmon River were greater than this threshold (Table 51). CEFI values ranged from 0.34 on June 13 to 0.37 on May 9. CEFI values were consistent among the four weekly samples in August, with a coefficient of variation of 2%. CEFI values were generally lowest in mid-summer, indicating a shift to taxa that are less specific in their current velocity requirements (Armanini *et al.* 2011).

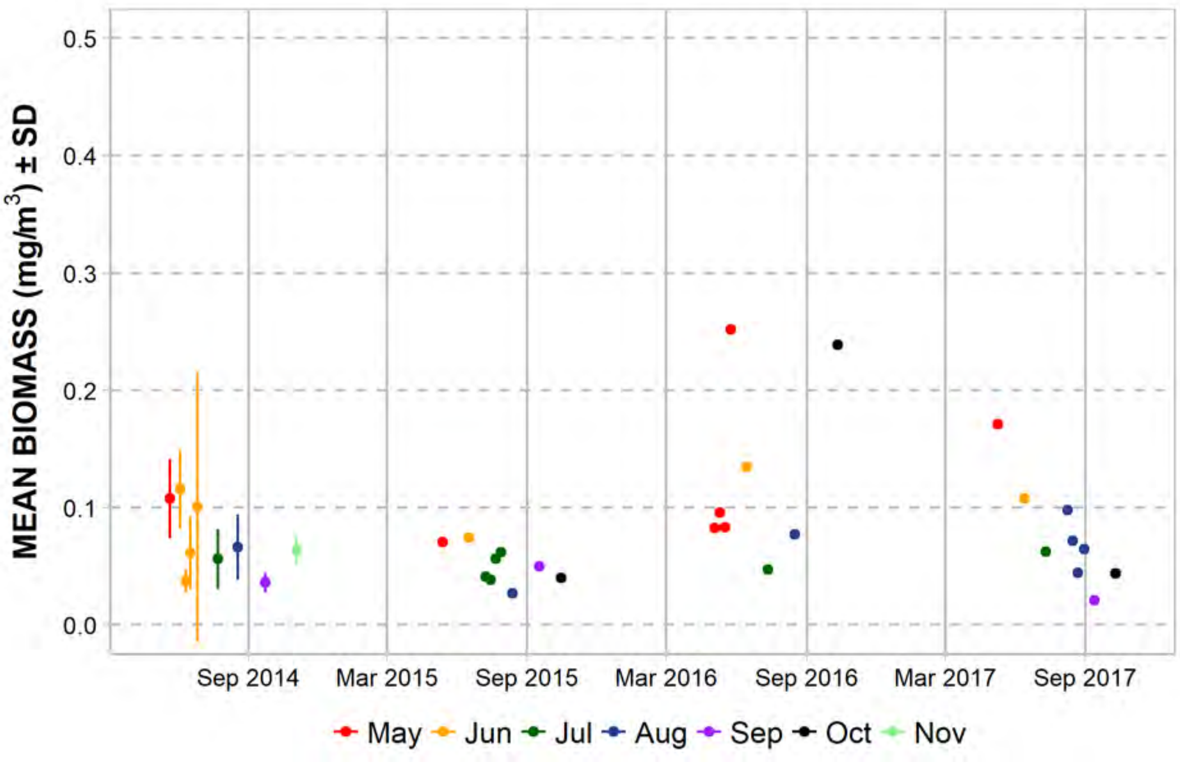
Table 51. **Salmon River invertebrate drift mean density, biomass, Simpson's diversity index (family level), richness and CEFI. Each drift net was analyzed separately in 2014, while nets were combined into one sample in subsequent years.**

All Taxa (Aquatic, Semi-Aquatic, and Terrestrial)													
Year	Date	Number of Replicates	Density (#/m^3)			Biomass (mg/m^3)			CEFI Index[†]			Simpson's Diversity Index (1-λ)[‡]	Richness (# of Families)[‡]
			Mean	S.D.	C.V.	Mean	S.D.	C.V.	Mean	S.D.	C.V.		
2014	21-May	5	0.85	0.26	30.06	0.11	0.03	31.09	0.37	0.01	1.89	0.86	74
	3-Jun	5	0.92	0.24	25.77	0.12	0.03	29.09	0.34	0.01	2.78	0.91	80
	11-Jun	5	0.72	0.29	40.33	0.04	0.01	27.14	0.34	0.01	1.96	0.89	48
	17-Jun	5	1.10	0.37	34.00	0.06	0.03	49.98	0.37	0.01	1.99	0.85	59
	26-Jun	5	0.86	0.33	38.49	0.10	0.11	113.95	0.35	0.01	2.04	0.89	55
	23-Jul	5	1.48	0.52	35.28	0.06	0.03	45.09	0.34	0.01	3.72	0.82	38
	18-Aug	5	3.11	1.43	46.04	0.07	0.03	41.65	0.34	0.01	1.65	0.75	37
	23-Sep	5	1.28	0.21	16.20	0.04	0.01	23.50	0.36	0.01	2.85	0.91	37
	3-Nov	5	0.89	0.21	23.50	0.06	0.01	18.80	0.37	0.01	2.83	0.89	76
2015	13-May	1	1.12	-	-	0.07	-	-	0.34	-	-	0.92	47
	16-Jun	1	3.32	-	-	0.07	-	-	0.35	-	-	0.84	45
	8-Jul	1	2.27	-	-	0.04	-	-	0.33	-	-	0.77	29
	15-Jul	1	2.03	-	-	0.04	-	-	0.32	-	-	0.67	30
	22-Jul	1	3.66	-	-	0.06	-	-	0.33	-	-	0.65	26
	28-Jul	1	1.77	-	-	0.06	-	-	0.32	-	-	0.78	32
	12-Aug	1	0.91	-	-	0.03	-	-	0.33	-	-	0.74	35
	17-Sep	1	1.19	-	-	0.05	-	-	0.35	-	-	0.82	30
	15-Oct	1	1.20	-	-	0.04	-	-	0.37	-	-	0.82	39
2016	3-May	1	0.84	-	-	0.08	-	-	0.36	-	-	0.84	34
	10-May	1	1.38	-	-	0.10	-	-	0.39	-	-	0.62	49
	17-May	1	1.02	-	-	0.08	-	-	0.36	-	-	0.79	35
	24-May	1	1.22	-	-	0.25	-	-	0.35	-	-	0.83	40
	14-Jun	1	1.86	-	-	0.13	-	-	0.35	-	-	0.83	46
	12-Jul	1	4.63	-	-	0.05	-	-	0.33	-	-	0.38	37
	16-Aug	1	1.32	-	-	0.08	-	-	0.35	-	-	0.88	37
	11-Oct	1	4.38	-	-	0.24	-	-	0.38	-	-	0.91	44
2017	9-May	1	0.76	-	-	0.17	-	-	0.37	-	-	0.89	37
	13-Jun	1	0.53	-	-	0.11	-	-	0.34	-	-	0.91	31
	11-Jul	1	1.09	-	-	0.06	-	-	0.36	-	-	0.85	36
	8-Aug	1	1.99	-	-	0.10	-	-	0.36	-	-	0.89	30
	15-Aug	1	1.17	-	-	0.07	-	-	0.36	-	-	0.91	29
	22-Aug	1	0.88	-	-	0.04	-	-	0.35	-	-	0.91	32
	30-Aug	1	0.88	-	-	0.06	-	-	0.35	-	-	0.89	29
	12-Sep	1	0.78	-	-	0.02	-	-	0.36	-	-	0.86	33

[†] Calculation considers only aquatic taxa

[‡] Replicates were averaged where applicable prior to calculating metric

Figure 46. **Salmon River mean invertebrate drift biomass (mg/m³) ± 1 standard deviation (SD). SD was only calculated for 2014, when five drift nets were analyzed separately per site. Sampling occurred weekly during one month each year.**



3.4.1.7. Top Five Families Contributing to Biomass

A summary of the top five families contributing to biomass in the invertebrate drift community on each sample date is provided in Table 52. Note that in some instances, a taxonomic level higher than family is listed (e.g., Plecoptera), as this was the lowest taxonomic level enumerated.

The invertebrate community was dominated (in terms of biomass) by mayflies (Baetidae, Ephemeroptera, and Heptageniidae), true flies (Chironomidae, Empididae, and Simuliidae), caddisflies (Limnephilidae, Rhyacophilidae, Glossosomatidae, and Lepidostomatidae) and aquatic worms (Nematomorpha). Mites (Torrenticolidae), lacewings (Hemerobiidae), barklice (Psocidae), and true bugs (Aphididae) were also occasionally within the top five families during sampling. Mayflies were particularly dominant early (May) and late (September to October) in the growing season while caddisflies and aquatic worms were more dominant early to mid-growing season (June to August).

Table 52. Salmon River: top five families contributing to invertebrate drift biomass.

SAM-IV	9-May-17	SAM-IV	13-Jun-17	SAM-IV	11-Jul-17	SAM-IV	8-Aug-17
Family	% of Total Biomass	Family	% of Total	Family	% of Total Biomass	Family	% of Total Biomass
Heptageniidae	24.7	Limnephilidae	33.6	Limnephilidae	24.7	Nematomorpha	42.5
Nematomorpha	21.8	Nematomorpha	13.4	Baetidae	22.6	Empididae	13.6
Simuliidae	10.8	Heptageniidae	10.1	Nematomorpha	15.8	Baetidae	11.2
Baetidae	10.4	Chironomidae	5.4	Torrenticolidae	7.3	Lepidostomatidae	4.2
Rhyacophilidae	8.2	Baetidae	5.4	Simuliidae	4.7	Torrenticolidae	3.4
Sum	75.90	Sum	67.97	Sum	75.05	Sum	74.81

Key
Aquatic Worms
Mayflies
Caddisflies
True Flies
Mites
True Bugs
Lacewings
Barklice

SAM-IV	15-Aug-17	SAM-IV	22-Aug-17	SAM-IV	30-Aug-17	SAM-IV	12-Sep-17	SAM-IV	10-Oct-17
Family	% of Total Biomass	Family	% of Total Biomass	Family	% of Total Biomass	Family	% of Total Biomass	Family	% of Total Biomass
Nematomorpha	66.2	Nematomorpha	36.3	Nematomorpha	36.9	Baetidae	15.2	Nematomorpha	24.5
Empididae	4.8	Empididae	11.8	Limnephilidae	22.2	Psocidae	11.9	Ephemeroptera	13.6
Torrenticolidae	4.2	Elateridae	6.6	Empididae	9.1	Aphididae	10.8	Baetidae	11.6
Baetidae	4.0	Baetidae	6.2	Chironomidae	5.9	Chironomidae	9.4	Chironomidae	6.2
Heptageniidae	2.7	Glossosomatidae	5.6	Baetidae	3.5	Hemerobiidae	7.5	Heptageniidae	5.9
Sum	81.92	Sum	66.43	Sum	77.54	Sum	54.81	Sum	61.82

3.4.1.8. Cluster Analysis

The results of the cluster analysis (based on density data) are provided in the dendrogram in Figure 47. Density data from the highest available taxonomic resolution were analyzed on each sample date. Results are presented for all samples collected to date. Black lines indicate branching of groups with a dissimilar community composition at a 5% significance level (SIMPROF test); red lines denote groups that are not significantly different in their community composition at a 5% significance level (SIMPROF test).

The analyses show seasonal differences in community composition. The invertebrate drift community compositions of samples collected in the middle of the growing season (July, August, and September) are generally similar to each other and dissimilar to samples collected early (May and June) and later (October and November) in the growing season. In 2016, invertebrate composition in May, June, and October are more dissimilar than any other sampling periods. With the exception of 2016, invertebrate drift community early and late in the growing season are generally more similar. Samples collected at weekly intervals during individual months (rotated each year) are generally similar; this indicates that single samples collected during individual months are representative of that specific month.

The multi-dimensional scaling (MDS) of the Bray Curtis similarity matrix (generated from density data at the highest taxonomic resolution available in the dataset) is shown in an ordination plot in Figure 48. Points that are close together represent samples that are very similar in community composition, while points that are far apart correspond to samples with very different community composition. The MDS plot was generated using density data from each sample date. The MDS has a stress value of 0.18. Stress values ≤0.1 correspond to a good ordination with negligible possibility of a misleading interpretation with respect to differences in community composition among samples

(Clarke and Warwick 2001). Stress values between 0.1 and 0.2 provide a useful 2-dimensional MDS representation as long as there is agreement in groupings between dendrograms (i.e., Figure 47) and the MDS plot (i.e., Figure 48) (Clark and Warwick 2001). The relationships displayed by the MDS plot support those described above in relation to the dendrogram. In particular, this provides further support for the distinction in community composition between the middle of the growing season (July to September) and the beginning and end of the growing season (May to June and October to November).

Figure 47. **Salmon River cluster analysis results on the Bray-Curtis similarity matrix, by date.**

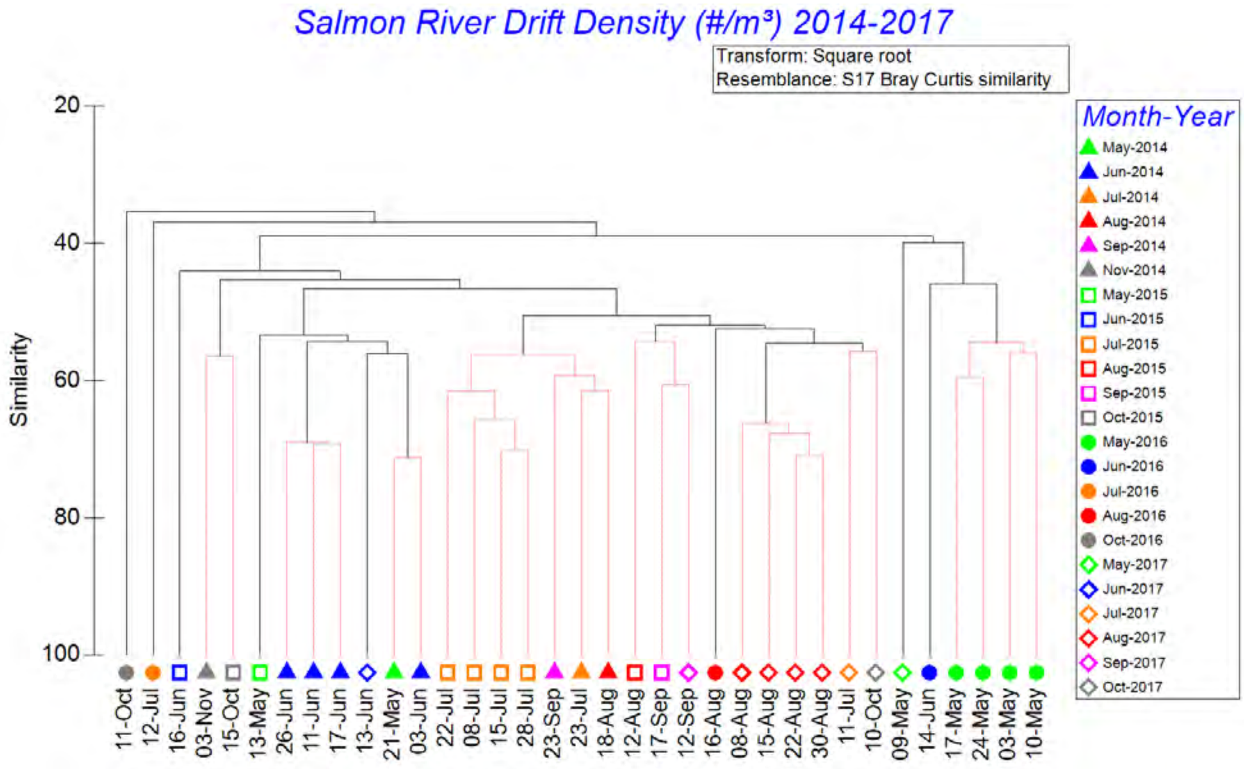
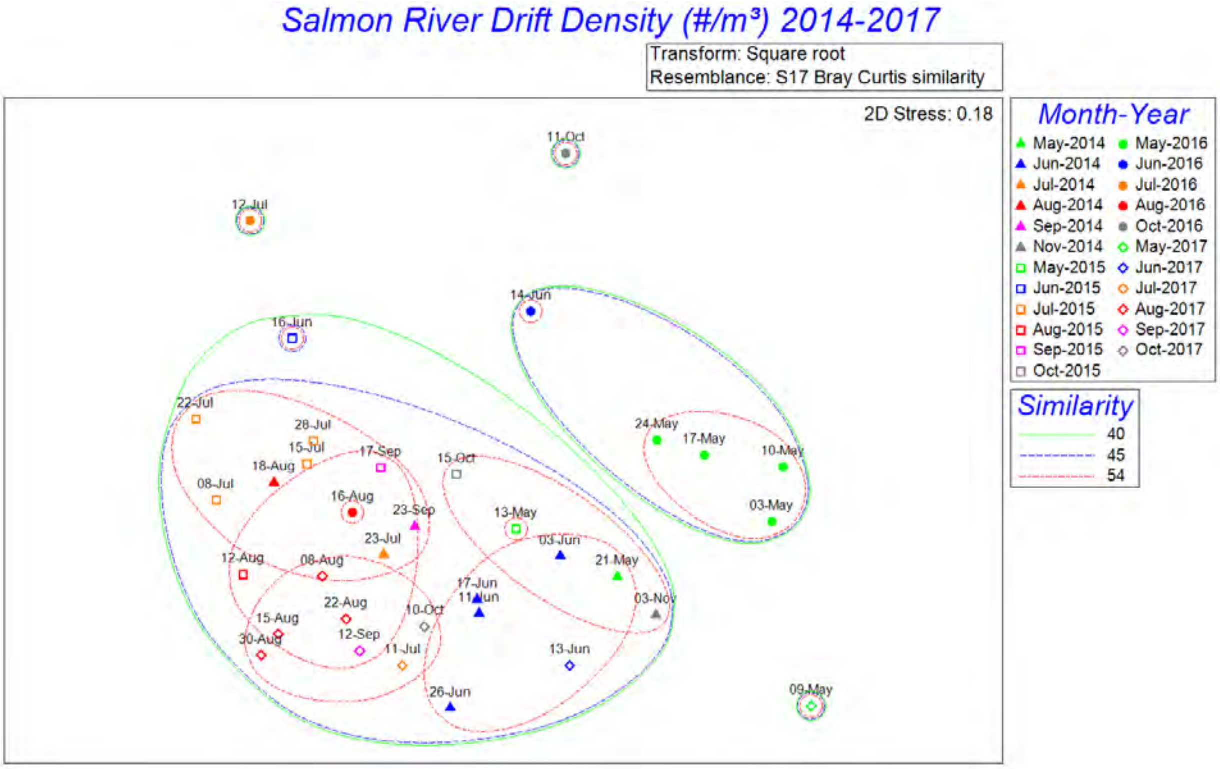


Figure 48. Salmon River non-metric, multi-dimensional scaling ordination plot by date.



3.4.2. Quinsam River Invertebrate Drift

3.4.2.1. Overview

The invertebrate drift density (individuals/m^3), biomass (mg/m^3), Simpson's family-level diversity index (1-λ), richness (# families), and CEFI at each site on each sample date are provided in Table 53. Mean, standard deviation and coefficients of variation values are shown for Year 1 (2014) data only, which is the only year when samples from all five drift nets were analyzed separately. Biomass results are also plotted in Figure 49. All values except for the CEFI (for which only aquatic taxa are considered) were calculated based on results for all taxa (aquatic, semi-aquatic, and terrestrial).

3.4.2.2. Density

The invertebrate drift density in the Quinsam River was variable across sampling dates. Density ranged from 1.18 individuals/m^3 (Oct 11) to 4.84 individuals/m^3 (Aug 9) (Table 53). Density measured at weekly intervals during August ranged from 2.38 – 4.84 individuals/m^3 (Table 53) with a coefficient of variation of 30%. Mean density in 2017 was within the range of values measured in previous years (0.65 – 6.88 individuals/m^3) (Table 53).

3.4.2.3. Biomass

The invertebrate drift biomass in the Quinsam River was generally highest early in the growing season (May and June), consistent with a weak trend of declining biomass throughout the growing season that was observed in the previous three years (Figure 49). The lowest biomass was observed on October 11 (0.06 mg/m^3) and the highest on May 10 (0.33 mg/m^3). Biomass was variable among the four weekly samples in August 2017 with a coefficient of variation of 49%. The range of biomass values measured in 2017 was consistent with the previous three years (Table 53).

3.4.2.4. Simpson's Family Level Diversity (1- λ)

Mean Simpson's family level diversity values varied throughout the season, with no clear trend (Table 53). Diversity ranged from 0.68 on August 16 to 0.85 on May 10. The coefficient of variation for the four weekly samples in August 2017 was 7%. Mean diversity in 2017 was within the range of values measured in previous years (0.64 – 0.93).

3.4.2.5. Richness (# of Families)

Mean family richness results show no apparent seasonal trend, with 28 families (Jun 14) to 46 families (Aug 9) recorded. Richness was consistent among the four weekly samples in August with a coefficient of variation of 15%. In 2017, mean richness was lower than in previous years (33 – 80 families).

3.4.2.6. Canadian Ecological Flow Index

Low CEFI values are described as <0.25 (Armanini *et al.* 2011) and all CEFI values in the Quinsam River were greater than this threshold (Table 51). CEFI values ranged from 0.33 in August to 0.37 in June. The coefficient of variation for the four weekly samples in August 2017 was 2%. CEFI values were generally lowest in mid-summer, indicating a shift to taxa that are less specific in their current velocity requirements (Armanini *et al.* 2011).

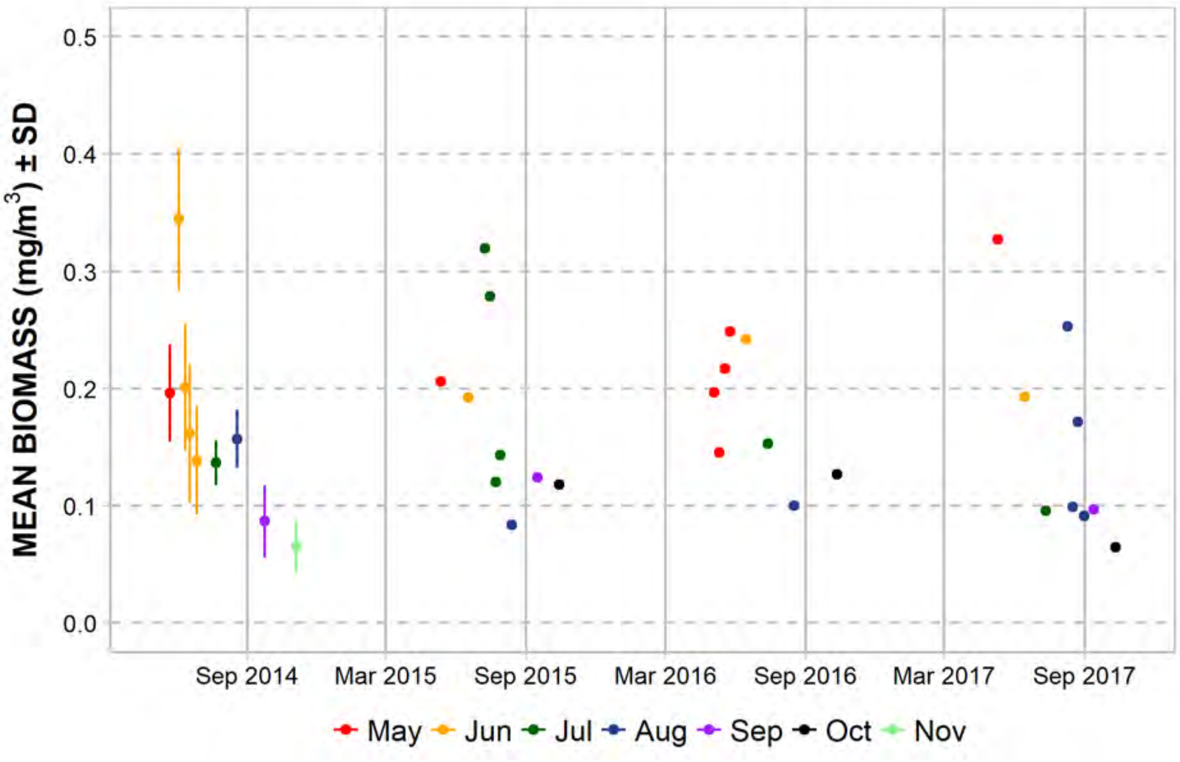
Table 53. Quinsam River invertebrate drift mean density, biomass, Simpson's diversity index (family level), richness and CEFI. Each drift net was analyzed separately in 2014, while nets were combined into one sample in subsequent years.

All Taxa (Aquatic, Semi-Aquatic, and Terrestrial)													
Year	Date	Number of Replicates	Density (#/m^3)			Biomass (mg/m^3)			CEFI Index†			Simspon's Diversity Index (1-λ)‡	Richness (# of Families)‡
			Mean	S.D.	C.V.	Mean	S.D.	C.V.	Mean	S.D.	C.V.		
2014	23-May	5	0.96	0.12	12.52	0.20	0.04	21.16	0.38	0.01	3.21	0.84	66
	4-Jun	5	2.74	0.22	8.06	0.34	0.06	17.49	0.37	0.02	4.71	0.80	66
	12-Jun	5	2.58	0.30	11.72	0.20	0.05	26.90	0.37	0.01	2.10	0.74	65
	18-Jun	5	3.12	0.64	20.61	0.16	0.06	36.78	0.37	0.01	1.77	0.76	63
	27-Jun	5	2.47	0.45	18.36	0.14	0.05	33.23	0.35	0.01	1.44	0.81	70
	22-Jul	5	4.19	0.73	17.47	0.14	0.02	14.07	0.36	0.00	0.40	0.82	60
	19-Aug	5	6.88	3.26	47.47	0.16	0.02	15.66	0.35	0.01	1.80	0.66	59
	24-Sep	5	2.36	0.85	35.86	0.09	0.03	35.64	0.33	0.02	5.11	0.81	52
	4-Nov	5	0.65	0.22	33.38	0.07	0.02	33.45	0.34	0.00	1.11	0.93	80
2015	12-May	1	1.38	-	-	0.21	-	-	0.35	-	-	0.78	52
	17-Jun	1	4.41	-	-	0.19	-	-	0.34	-	-	0.65	49
	9-Jul	1	6.38	-	-	0.32	-	-	0.34	-	-	0.74	61
	16-Jul	1	2.52	-	-	0.28	-	-	0.35	-	-	0.81	73
	23-Jul	1	4.38	-	-	0.12	-	-	0.33	-	-	0.76	52
	29-Jul	1	4.58	-	-	0.14	-	-	0.34	-	-	0.64	39
	13-Aug	1	4.34	-	-	0.08	-	-	0.31	-	-	0.78	42
	16-Sep	1	1.71	-	-	0.12	-	-	0.35	-	-	0.79	33
	14-Oct	1	2.07	-	-	0.12	-	-	0.34	-	-	0.87	50
2016	4-May	1	2.49	-	-	0.20	-	-	0.36	-	-	0.78	38
	11-May	1	1.87	-	-	0.15	-	-	0.36	-	-	0.79	43
	18-May	1	2.82	-	-	0.22	-	-	0.35	-	-	0.78	48
	25-May	1	3.72	-	-	0.25	-	-	0.34	-	-	0.82	59
	15-Jun	1	3.25	-	-	0.24	-	-	0.33	-	-	0.82	40
	13-Jul	1	5.33	-	-	0.15	-	-	0.31	-	-	0.66	41
	17-Aug	1	1.76	-	-	0.10	-	-	0.33	-	-	0.77	53
	12-Oct	1	1.71	-	-	0.13	-	-	0.36	-	-	0.92	53
2017	10-May	1	1.63	-	-	0.33	-	-	0.36	-	-	0.85	44
	14-Jun	1	4.13	-	-	0.19	-	-	0.37	-	-	0.71	28
	12-Jul	1	3.66	-	-	0.10	-	-	0.35	-	-	0.76	39
	9-Aug	1	4.84	-	-	0.25	-	-	0.34	-	-	0.75	46
	16-Aug	1	4.37	-	-	0.10	-	-	0.34	-	-	0.68	33
	23-Aug	1	3.29	-	-	0.17	-	-	0.33	-	-	0.81	40
	31-Aug	1	2.38	-	-	0.09	-	-	0.35	-	-	0.77	45
	13-Sep	1	2.46	-	-	0.10	-	-	0.34	-	-	0.80	31
	11-Oct	1	1.18	-	-	0.06	-	-	0.34	-	-	0.82	30

† Calculation considers only aquatic taxa

‡ Replicates were averaged where applicable prior to calculating metric

Figure 49. Quinsam River mean invertebrate drift biomass (mg/m³) ± 1 standard deviation (SD). SD was only calculated for 2014, when five drift nets were analyzed separately per site. Sampling occurred weekly during one month each year.



3.4.2.7. Top Five Families Contributing to Biomass

A summary of the top five families contributing to biomass in the invertebrate drift community on each sample date is provided in Table 54. Note that in some instances, a taxonomic level higher than family is listed (e.g., Ephemeroptera, Lepidoptera), as this was the lowest taxonomic level enumerated.

The invertebrate community was dominated (in terms of biomass) by mayflies (Baetidae, Ephemeroptera, and Heptageniidae) and true flies (Chironomidae, Bibionidae, Simuliidae, Dolichopodidae, and Empididae). Caddisflies (Limnephilidae and Hydropsychidae), gastropod (Planorbidae), beetles (Cantharidae, Elateridae, and Curculionidae), crustaceans (Ostracoda), true bugs (Gerridae and Aphididae), and ants (Formicidae) were also recorded within the top five families during sampling.

Considering all sample dates, mayflies and trueflies were most frequently among the top five contributors throughout the growing season, with both taxa among the top five taxa on all nine sample dates. The contribution to biomass of mayflies ranged from 10.0% to 39.8% and true flies ranged from 16.1% to 58.8%.

Table 54. Quinsam River: top five families contributing to invertebrate drift biomass.

QUN-IV	10-May-17	QUN-IV	14-Jun-17	QUN-IV	12-Jul-17	QUN-IV	9-Aug-17	Key
Family	% of Total Biomass	Family	% of Total Biomass	Family	% of Total Biomass	Family	% of Total Biomass	True Flies Mayflies
Bibionidae	24.0	Baetidae	39.8	Baetidae	25.6	Elateridae	21.0	Caddisflies
Baetidae	19.5	Limnephilidae	20.2	Chironomidae	18.2	Empididae	17.9	Beetles
Limnephilidae	10.9	Chironomidae	12.3	Dolichopodidae	12.0	Simuliidae	12.9	Crustacean
Cantharidae	8.8	Simuliidae	3.8	Simuliidae	11.7	Baetidae	12.2	Gastropod
Heptageniidae	7.1	Planorbidae	3.2	Empididae	4.3	Chironomidae	11.7	Ants
Sum	70.36	Sum	79.31	Sum	71.79	Sum	75.77	True Bugs

QUN-IV	16-Aug-17	QUN-IV	23-Aug-17	QUN-IV	31-Aug-17	QUN-IV	13-Sep-17	QUN-IV	11-Oct-17
Family	% of Total Biomass	Family	% of Total Biomass	Family	% of Total Biomass	Family	% of Total Biomass	Family	% of Total Biomass
Empididae	22.4	Empididae	20.4	Baetidae	16.8	Chironomidae	25.4	Ephemeroptera	22.5
Chironomidae	19.5	Chironomidae	9.6	Chironomidae	14.5	Simuliidae	17.5	Chironomidae	13.5
Simuliidae	16.9	Simuliidae	8.5	Simuliidae	11.9	Baetidae	11.3	Baetidae	10.6
Baetidae	10.1	Formicidae	7.7	Gerridae	8.7	Curculionidae	8.6	Simuliidae	9.8
Ostracoda	7.9	Curculionidae	5.7	Empididae	7.4	Aphididae	6.2	Hydropsychidae	6.2
Sum	76.83	Sum	52.08	Sum	59.34	Sum	69.04	Sum	62.55

3.4.2.8. Cluster Analysis

The results of the cluster analysis (based on density data) are provided in the dendrogram in Figure 50. Density data from the highest available taxonomic resolution were analyzed on each sample date. Results are presented for all samples collected to date. Black lines indicate branching of groups with a dissimilar community composition at a 5% significance level (SIMPROF test); red lines denote groups that are not significantly different in their community composition at a 5% significance level (SIMPROF test).

Similar to the Salmon River (Section 3.4.1.8), the analyses show seasonal differences in community composition with distinct groups that predominantly comprise samples from the early (May-June), mid (July-September) and late (October-November) growing season. Samples collected at weekly intervals during individual months (rotated each year) are generally similar; this indicates that single samples collected during individual months are representative of that specific month.

The multi-dimensional scaling (MDS) of the Bray Curtis similarity matrices (generated from density data at the highest taxonomic resolution available in the dataset) is shown in an ordination plot in Figure 51. The MDS plot was generated using density data from each sample date. The MDS has a stress value of 0.18. Stress values ≤0.1 correspond to a good ordination with negligible possibility of a misleading interpretation with respect to differences in community composition among samples (Clarke and Warwick 2001). Stress values between 0.1 and 0.2 provide a useful 2-dimensional MDS representation as long as there is agreement in groupings between dendrograms (Figure 50) and the MDS plot (Figure 51) (Clark and Warwick 2001). The relationships displayed by the MDS plot support those described above in relation to the dendrogram, with distinction between the samples collected during different periods in the growing season, even when results for multiple years are considered.

Figure 50. Quinsam River cluster analysis results on the Bray-Curtis similarity matrix.

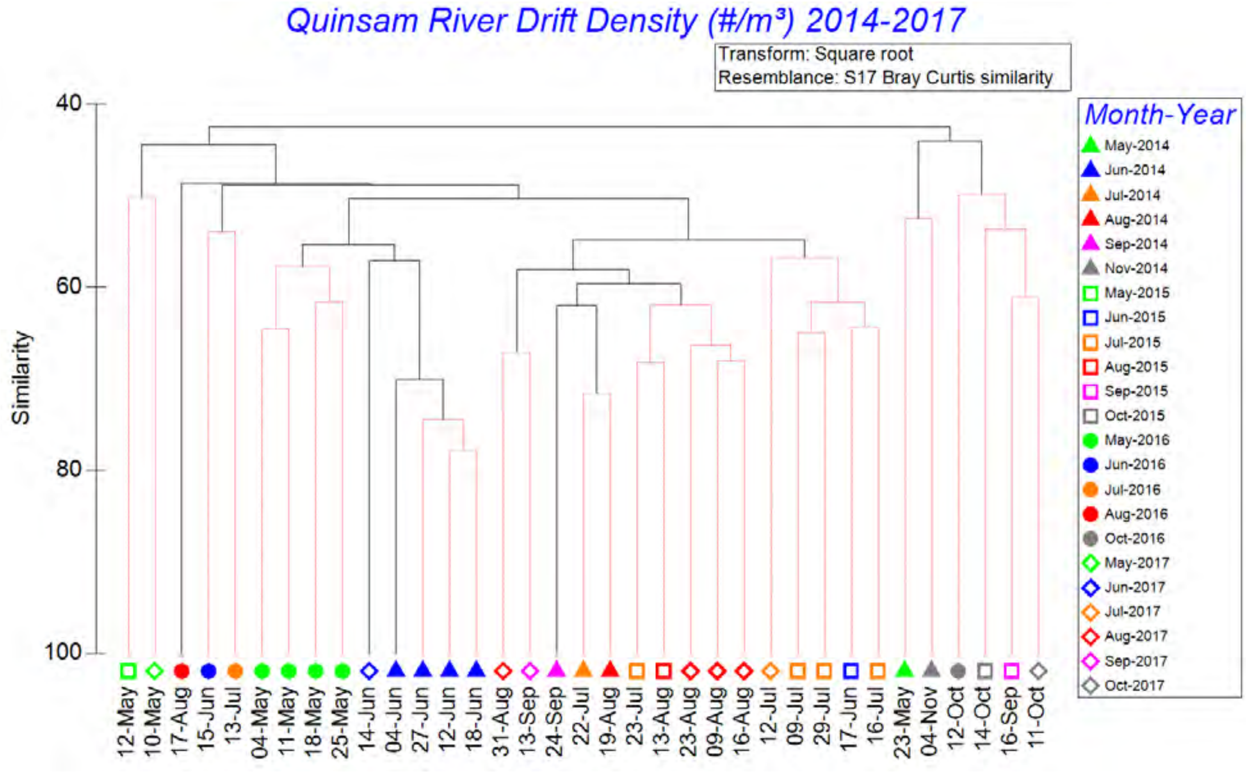
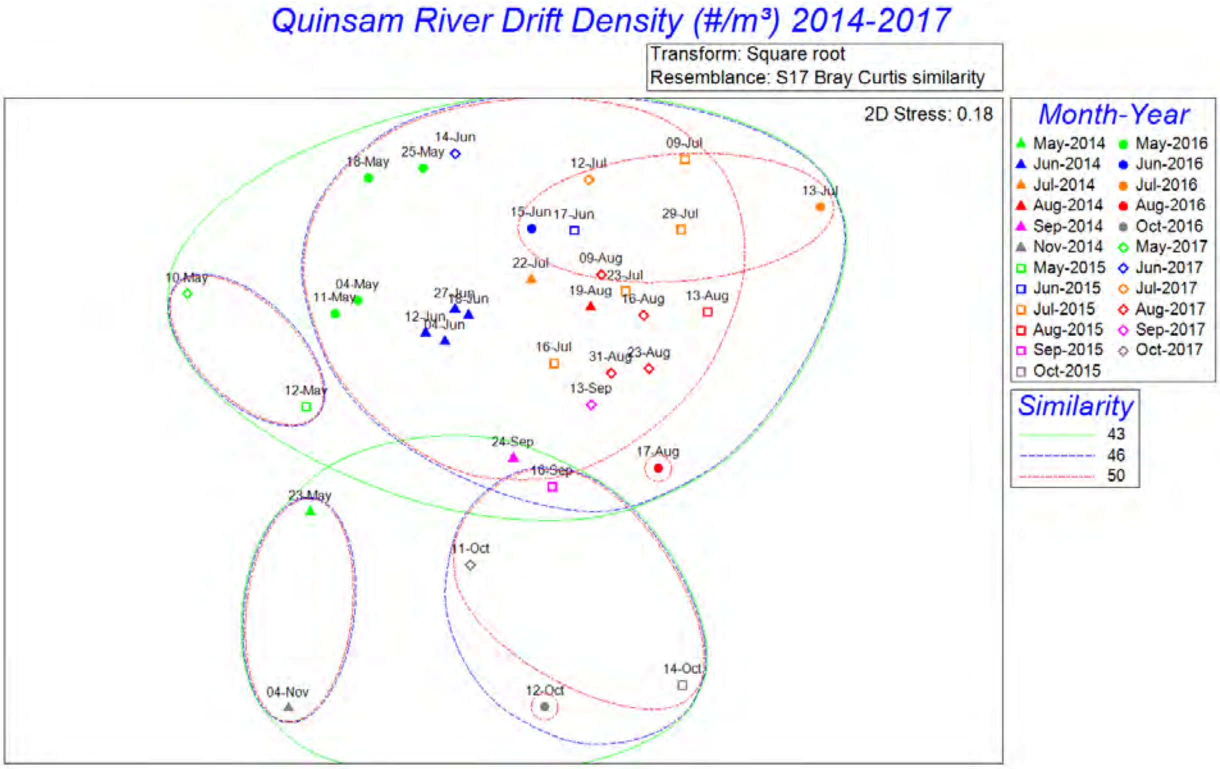


Figure 51. Quinsam River non-metric multi-dimensional scaling ordination plot by date.



3.4.3. Comparison of kick net and drift net sampling methods

Invertebrates collected using kick net sampling consisted almost exclusively of aquatic taxa (96.4-99.6% and 100% in the Salmon River and Quinsam River, respectively; Table 55). The kick net method involves holding the collection net completely under the stream surface for three minutes, so the dominance of aquatic taxa is to be expected. Invertebrates collected using drift net sampling were still dominated by aquatic taxa, but to a lesser extent (64.3–85.7% and 64.5–75.0% in the Salmon River and Quinsam River, respectively; Table 55). Drift nets are installed with the top of the net above the stream surface, so that any invertebrates suspended on the surface are collected, in addition to submerged invertebrates. These invertebrates are more likely to have entered the stream from terrestrial or semi-aquatic (riparian) habitats.

The contribution of individual families to invertebrate biomass differed between the two sampling methods. In the Salmon River, true flies (Chironomidae and Simuliidae) were dominant in drift net samples while mayflies (Heptageniidae, Baetidae, and Ameletidae) were dominant in kicknet samples (Table 56a). Also, caddisflies were top contributors to biomass using kick sampling but not drift sampling (Table 56a). In the Quinsam River, true flies (Chironomidae and Simuliidae) accounted for the majority of the biomass based on drift net sampling, while Hydropsychidae (caddisflies) and Astacidae (crustacea) were the dominant taxa based on kick sampling (Table 56b).

Table 55. Contribution of invertebrate taxa to total biomass by habitat type in Year 2 (2015) and Year 4 (2017) (data were not collected in 2014 and 2016).

Stream	Sample Date	Collection Method	Relative Contribution to Biomass (%)		
			Aquatic Taxa	Semi-Aquatic Taxa	Terrestrial Taxa
Quinsam River	16-Sep-2015	Driftnet	75.0	19.2	5.8
		Kicknet	100.0	0	0
	13-Sep-2017	Driftnet	64.5	15.7	19.8
		Kicknet	100.0	0	0
Salmon River	17-Sep-2015	Driftnet	85.7	5.4	8.8
		Kicknet	99.6	0.2	0.2
	12-Sep-2017	Driftnet	64.3	5.2	30.5
		Kicknet	96.4	0	3.6

Table 56. Top five families contributing to invertebrate biomass collected from a drift net and kick net in a) Salmon River, and b) Quinsam River.

a)

Salmon River

17-Sep-2015				12-Sep-2017			
Driftnet		Kicknet		Driftnet		Kicknet	
Family	% of Total Biomass	Family	% of Total Biomass	Family	% of Total Biomass	Family	% of Total Biomass
Simuliidae	38.6	Chironomidae	16.4	Baetidae	15.2	Heptageniidae	37.2
Chironomidae	25.5	Heptageniidae	14.8	Psocidae	11.9	Polycentropodidae	13.7
Baetidae	4.6	Baetidae	11.9	Aphididae	10.8	Tipulidae	8.5
Ceratopogonidae	3.8	Ameletidae	8.6	Chironomidae	9.4	Lepidostomatidae	7.3
Aphididae	3.1	Hydropsychidae	7.8	Hemerobiidae	7.5	Baetidae	4.4

Key
True Flies
Mayflies
Caddisflies
Barklice
True Bugs
Lacewings

b)

Quinsam River

16-Sep-2015				13-Sep-2017			
Driftnet		Kicknet		Driftnet		Kicknet	
Family	% of Total Biomass	Family	% of Total Biomass	Family	% of Total Biomass	Family	% of Total Biomass
Simuliidae	39.0	Hydropsychidae	16.5	Chironomidae	25.4	Astacidae	26.5
Chironomidae	15.5	Tipulidae	14.5	Simuliidae	17.5	Naididae	11.8
Ephemeroptera	13.7	Trichoptera	13.7	Baetidae	11.3	Gomphidae	10.8
Ameletidae	6.3	Chironomidae	7.3	Curculionidae	8.6	Elmidae	9.0
Sperchontidae	4.7	Lumbriculidae	5.9	Aphididae	6.2	Chironomidae	6.0

Key
True Flies
Mayflies
Caddisflies
Aquatic Worm
Crustacean
Dragonflies
True Bugs
Mites

4. DISCUSSION

A summary of the current status of each of the six hypotheses is provided below, including brief details of analyses that should be undertaken to test each hypothesis when data for more years are available. Interim analysis is scheduled for Year 5 and final analysis is scheduled for Year 10. Further details of the proposed data analysis methods are outlined in Section 1.4 and in Abell *et al.* (2015a).

$H_0$1: Annual population abundance does not vary with time (i.e., years) over the course of the Monitor

Although this study is at an early stage, JHTMON-8 results and historical data compiled so far show considerable inter-annual variability in juvenile fish abundance. Key results from Year 4 monitoring related to this hypothesis are:

- Adult steelhead counts in the Salmon River were low in 2017 relative to historical counts. The total count for the primary index reach (Lower Index; 54 fish) was the sixth lowest count out of the 20 years sampled and was approximately equal to the 25th percentile of the dataset. This count was higher than the count for Year 1 and Year 3 (39 and 50 fish respectively), but lower than the count for Year 2 (72 fish; see Section 3.1.1). The count for the reach that is surveyed upstream of the diversion dam (Rock Creek) was 0 fish. Year 4 was therefore only the third year when no fish have been observed upstream of the diversion dam out of the 11 years when surveys have been undertaken (historical range of counts:

0–70). The reason for absence of adult steelhead observations upstream of the dam is uncertain; e.g., there are no obvious reasons related to sampling conditions, survey timing, or reported passage issues.

- Juvenile steelhead fry abundance in the Salmon River (12 FPU) was well below the mean for the sampling period (1998–2017; 50 FPU). This value was also lower than the 2014 (49 FPU) and 2016 (36 FPU) values, but similar to the value obtained in 2015 (11 FPU). There was a clear difference in density between sites upstream and downstream of the diversion. On average, mean observed fry density upstream of the diversion (23 FPU) was almost half of the value measured downstream of the diversion (41 FPU). The depth-velocity adjusted densities further exaggerated this difference, with values downstream of the diversion approximately eight times higher than those above the diversion (66.0 FPU compared to 8.1 FPU). Nonetheless, the presence of 0+ steelhead fry upstream of the diversion dam means that steelhead successfully spawned upstream of the dam in Year 4, although the low abundance of juvenile fish is presumably related to low abundance of spawners. This indicates that that the steelhead fry habitat upstream of the diversion was below carrying capacity in Year 4.
- The range of juvenile Coho Salmon biomass estimated for the three sites downstream of the Salmon River Diversion (0.36 g/m^2 to 5.14 g/m^2) was comparable with Years 1 to 3. Estimated biomass values at the three sites upstream of the diversion were 0 g/m^2 to 2.3 g/m^2; values at these sites have varied considerably among years and sites.
- Data indicated that there were differences in the size of salmonid fry between sites upstream and downstream of the diversion dam. Coho Salmon 0+ fry sampled at sites downstream of the diversion had mean weight of 1.6 g to 4.9 g, whereas the mean weight of 0+ Coho Salmon 0+ fry sampled at sites upstream of the diversion was 1.5 g to 1.8 g. Although H_01 specifically relates to juvenile fish abundance and not size, these results indicate that there are systematic differences throughout the watershed in salmonid rearing conditions, reflecting variability in one or more environmental factors.
- Salmon escapement data for 2016 (i.e., Year 3) show that Pacific Salmon escapement was generally low in the Salmon River: Chinook Salmon escapement (68) was the second lowest in 64 years and Coho Salmon escapement (276) was the sixth lowest in the 63-year record. The low Coho Salmon count is likely to at least partly reflect that the final inspection (September 15) occurred before the reported spawning period (October 1 to December 15; Burt 2010). Pink Salmon (6,704) and Sockeye Salmon (2) escapement in 2016 were similar to the historical medians (7,554 and 2, respectively).
- In the Quinsam River, escapement of Coho Salmon (7,397) in 2016 approximated the historical median (9,263). Chinook Salmon escapement in 2016 (6,978) was double the

historical median (3,273). Pink Salmon escapement (51,032) in the Quinsam River in 2016 was slightly higher than the historical median (30,756).

- In the Quinsam River, total estimated outmigration of Pink Salmon fry in 2017 (Year 4) was 1.4 million, a decrease from record numbers in 2016 (9.2 million). Outmigration of Coho Salmon in 2017 (24,239 wild smolts and 29,920 colonized smolts) was comparable with Years 1 to 3. Estimated total outmigration of Chinook Salmon fry was high in 2017 (114,168 wild and 153,570 colonized smolts). Steelhead smolt outmigration in 2017 was estimated to be 4,992, approximately half of the value estimated in 2016. The accuracy of the estimates for Chinook and steelhead smolts is expected to be low because they were based on mark-recapture experiments conducted with another species (Coho Salmon), and observed counts were relatively low. Estimated survival of colonized juvenile Coho Salmon in Year 4 was 20%; this was the higher than Year 2 (13%) and similar to Year 1 (21%). Estimated survival of colonized juvenile Chinook Salmon in Year 4 was 74%, higher than both Year 3 (28%) and Year 2 (66%).

Proposed analysis methods to examine trends in juvenile fish abundance are described in Abell *et al.* (2015a, b; also see Lawson *et al.* 2004). Initial analysis should be undertaken in Year 5 with final analysis undertaken in Year 10. Analysis should examine variation in time of absolute values of juvenile abundance (e.g., FPU), in addition to variation in the relationship between juvenile fish abundance and the abundance of adult spawners. Analysis of variance in spawner-recruitment relationships will isolate variability in juvenile fish abundance that is due to variability in freshwater survival, from variability that is due to fluctuations in the abundance of adult fish. Such normalization is important to avoid misleading inferences about the role of environmental factors in driving population fluctuations (Walters and Ludwig 1981). Smolt to spawner ratios can be calculated using DFO adult escapement data and salmon counting fence records, with the intention to include data collected prior to JHTMON-8 in the analysis (see discussion of H_0*6* below).

$H_0$2: Annual population abundance is not correlated with annual habitat availability as measured by Weighted Usable Area (WUA)

Weighted Usable Area (in m^2) provides an index of habitat availability that is calculated using relationships developed between flow and the area of different habitats (Lewis *et al.* 2004). The metric is weighted based on Habitat Suitability Index scores; these provide a relative measure (between 0 and 1) of the suitability of a particular habitat for the species and life stage of interest.

To test this hypothesis, it will be necessary to analyze fish abundance data collected during this study, in concert with WUA determined as part of a separate study to derive relationships between habitat and flow for sites on the Quinsam River. For the Quinsam River, we expect that results of work already undertaken during the WUP process can be analyzed to provide information about flow-habitat relationships in the mainstem downstream of the diversion (BC Hydro 2013). The format and status of these data are uncertain; therefore, reviewing this has been identified as a task for Year 5 (see Section 5).

$H_0$3: Annual population abundance is not correlated with water quality

Year 4 water quality results were generally consistent with Year 1 though Year 3. Both study streams are typical of coastal BC watersheds with low nutrient concentrations (oligotrophic), near-neutral pH, and low turbidity during baseflow. Alkalinity and conductivity is low in the Salmon River and moderate in the Quinsam river, with these differences potentially reflecting the influence of lakes upstream in the Quinsam River and/or differences in watershed geology or land use.

Results show that measurements of some water quality variables were, at times, outside of the preferred ranges for fish species present in the watersheds. Specifically, water temperatures were recorded on both rivers that exceeded WQG-AL temperature ranges for suitable salmonid rearing conditions, while DO concentrations less than the provincial WQG-AL for the protection of buried embryos/alevins were recorded at times in the Quinsam River during the growing season. The low DO measurements were during reported incubation periods (Burt 2003) for resident Rainbow Trout and steelhead. Measurements also indicated that DO concentrations were below the WQG-AL range during the start of the Pink Salmon incubation period.

Analysis to test this hypothesis should be undertaken separately for individual species, water quality variables and watersheds. Initially, analysis should focus on the ten-year period of the monitor, although there are opportunities to use water temperature data collected by other parties to extend the time period over which the potential effects water temperature are considered (see Dinn *et al.* 2016). Analysis will initially involve evaluating scatter-plots, time series graphs, and correlation metrics to examine whether there is a link between variability in water quality variables and juvenile fish abundance. Based on an initial screening analysis of the water quality variables (Section 3.2.4), alkalinity or specific conductivity, DO, and water temperature were identified as predictor variables that may be the best candidates for inclusion in statistical models to quantify the effect of water quality on juvenile fish abundance. This analysis does not replace the requirement to consider all data at the end of the monitor when formal hypothesis tests will be conducted.

$H_0$4: Annual population abundance is not correlated with the occurrence of flood events

This hypothesis will be tested by quantifying high flow metrics separately for each watershed based on discharge measured at gauges maintained by the Water Survey of Canada. Relationships between the occurrence of floods and juvenile fish abundance will then be analyzed.

In Year 3, we conducted a review to identify hydrologic metrics to test this hypothesis. A range of metrics were identified based on a subset (Group 2) of the Indicators of Hydrologic Alteration (Richter *et al.* 1996). Metrics include measures of both high and low flows to provide an opportunity to extend the analysis to consider hydrologic variability more widely, reflecting that the occurrence of low summer flows can be a significant limiting factor for juvenile salmonid productivity (e.g., Grantham *et al.* 2012), in addition to the occurrence of floods. We plan to consider additional metrics in future years, e.g., that quantify the duration of high flows.

In Year 4, we calculated hydrologic metrics for 2014–2016, which were the study years for which quality-assured data were available. For all years, discharge was low during the summer low-flow period, with minimum mean daily discharge of <0.5 m^3/s measured in the mainstem of both rivers, downstream of the diversion facilities (when they were not operating). It was also notable that maximum discharge was particularly high during the incubation periods for Pacific Salmon species that emerged in 2015 and 2017, reflecting floods during December 2014 and November 2016.

For the Quinsam River, there is an opportunity to extend this analysis to historic years once historic data have been compiled to develop spawner–recruitment relationships.

$H_0$5: Annual population abundance is not correlated with food availability as measured by aquatic invertebrate sampling

Invertebrate drift data have now been collected for four growing seasons in both streams. Results show that invertebrate drift biomass generally tends to decline during the growing season and biomass is generally lower in the Salmon River (Figure 46) than the Quinsam River (Figure 49). Analysis of similarity in the invertebrate assemblages sampled to date shows consistent trends among years, with distinct communities present early in the growing season (May and June) relative to later in the growing season (Figure 48, Figure 51).

These trends have potential implications for juvenile salmonid productivity, although data for further years are required before relationships between aquatic invertebrate drift and fish abundance can be examined. Analysis to test this hypothesis will involve analyzing relationships between invertebrate biomass and juvenile fish abundance. Invertebrate biomass will be trialled as predictor variables in statistical models to quantify the effect (if any) of this variable on juvenile fish abundance and, potentially, fish condition. It is expected that other metrics of invertebrate productivity (e.g., invertebrate density) will also be trialled. As with water quality, the study is currently premised on the assumption that invertebrate drift measured at a single index site is representative of conditions experienced by fish in the wider watershed.

$H_0$6: Annual smolt abundance is not correlated with the number of adult returns (Quinsam River)

No analysis has been undertaken to test this hypothesis at this time. However, work is scheduled for Year 5 to collate and digitize historical data collected at the Quinsam Hatchery salmon counting fence since the 1970s. These data can then be related to salmon escapement data collected by DFO to extend the period over which the relationship between spawner abundance and recruitment can be analyzed.

5. ADDITIONAL TASKS FOR YEAR 5

A background review conducted at the start of the study identified individual analysis tasks to be undertaken during each year of JHTMON-8 to streamline final hypothesis testing in Year 10 (Abell *et al.* 2015a). This review was specific to the Salmon River watershed but the tasks are also relevant to the Quinsam River. In Year 4, we proposed to conduct initial screening of the suitability of water quality metrics for testing *$H_0$3*; this task was successfully completed and is presented in Section 3.2.4.

In Year 5, we propose to review existing habitat–flow data and propose a detailed approach to test $H_0 2$ (regarding habitat availability).

In addition, we developed a plan in Year 4 to collate and digitize historical data collected at the Quinsam Hatchery salmon counting fence since the 1970s. This plan has been approved by BC Hydro and will be implemented in Year 5. These additional tasks will provide an opportunity to substantially increase our ability to address the JHTMON-8 management questions for the Quinsam River by increasing the statistical power of the analysis.

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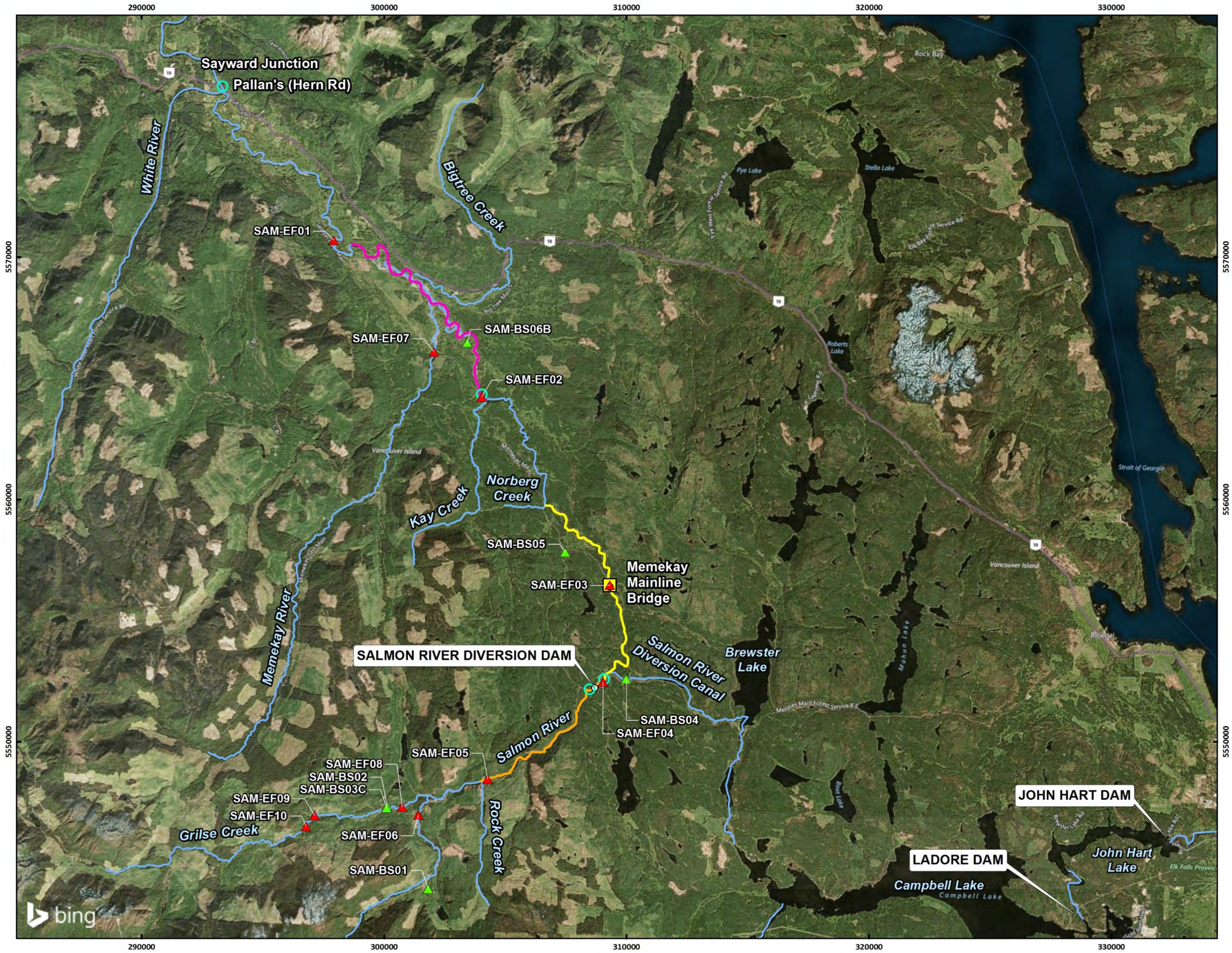
PROJECT MAPS



JHTMON Campbell River Water Use Plan

Overview of the Salmon River Watershed

Legend

- ○ Discharge Gauges
- ▲ Juvenile Steelhead Sampling Sites
- ▲ Juvenile Coho Salmon Sampling Sites
- 🟨 Invertebrate Sampling Site
- ● Water Quality Sampling Site
- ○ Salmon River Diversion Intake

Snorkel Reaches

- — Lower Index
- — Upper Index
- — Rock Creek

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 0.5 1 2 3 4 5 km

Scale: 1:150,000

NO.	DATE	REVISION	BY
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Date Saved: 26/02/2018
Coordinate System: NAD 1983 UTM Zone 10N

ECOFISH RESEARCH

Map 2

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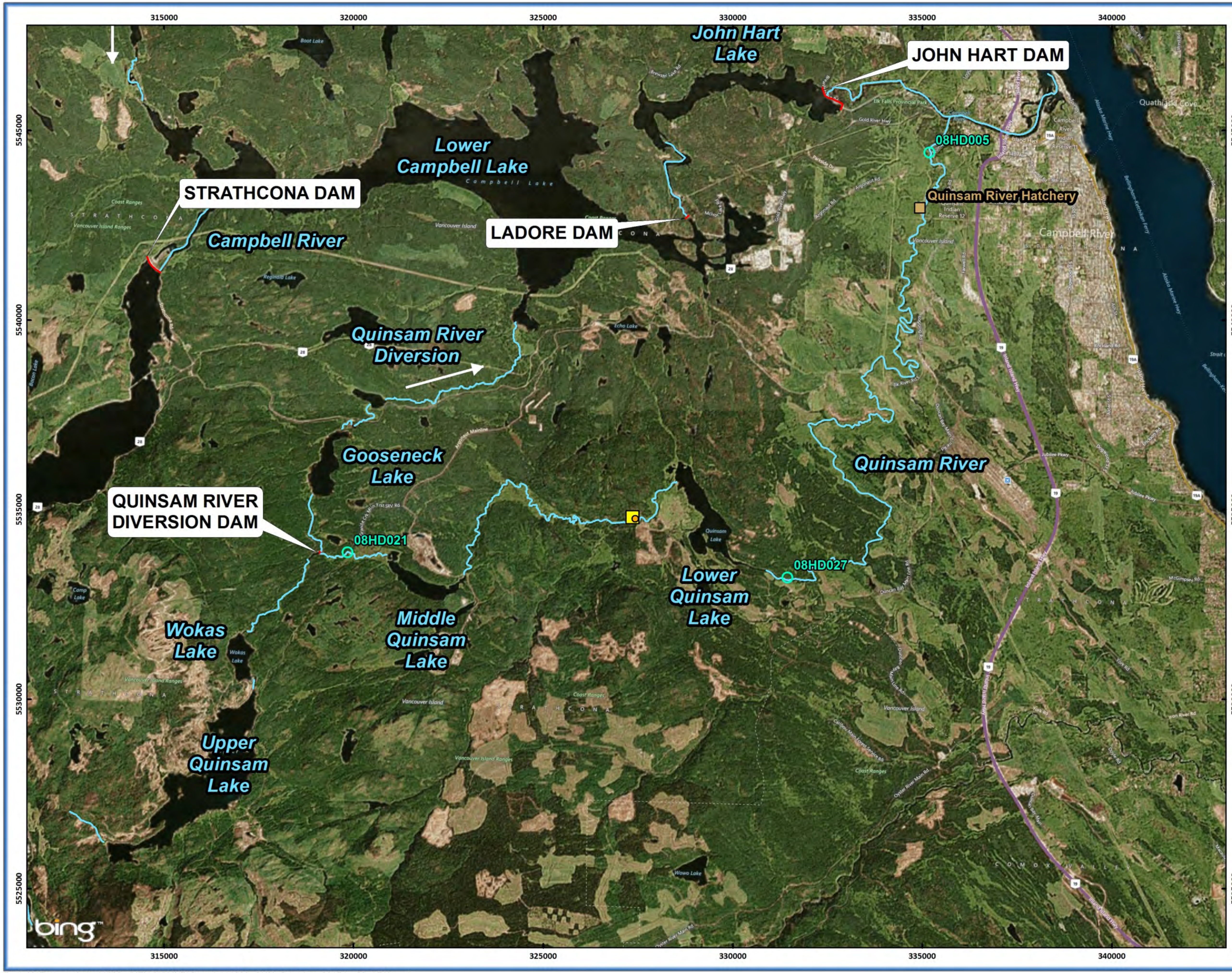

JHTMON Campbell River Water Use Plan

Overview of the Quinsam River Watershed

Legend

- ○ Discharge Gauges
- 🟨 Invertebrate Sampling Site
- ● Water Quality Sampling Site
- ― Dam
- ― Stream

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 0.5 1 2 3 4 5 km

Scale: 1:95,781

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ECOFISH RESEARCH

Map 3

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APPENDICES

Appendix A. Water Quality Guidelines, Typical Parameter Values, Previous Results, and Quality Control Results Summary

TABLE OF CONTENTS

LIST OF TABLES II

1. WATER QUALITY GUIDELINES AND TYPICAL PARAMETER VALUES 1

2. 2014 TO 2016 WATER QUALITY IN THE QUINSAM RIVER AND SALMON RIVER........ 5

3. QUALITY CONTROL/QUALITY ASSURANCE 13

LIST OF TABLES

Table 1. Water quality guidelines for the protection of aquatic life in British Columbia for parameters with less complex guidelines. 1

Table 2. Total suspended solids and turbidity guidelines for the protection of aquatic life in British Columbia. 2

Table 3. Dissolved oxygen guidelines for the protection of aquatic life in British Columbia. 2

Table 4. Total gas pressure guidelines for the protection of aquatic life in British Columbia. 3

Table 5. Typical values for water quality parameters in British Columbia waters. 4

Table 6. Salmon River (SAM-WQ) general water quality variables measured *in situ* during Years 1 to 3 (2014 to 2016). 5

Table 7. Salmon River (SAM-WQ) dissolved gases measured *in situ* during Years 1 to 3 (2014 to 2016). 6

Table 8. Salmon River (SAM-WQ) general water quality variables measured at ALS labs during Years 1 to 3 (2014 to 2016). 7

Table 9. Salmon River (SAM-WQ) low level nutrients measured at ALS labs during Years 1 to 3 (2014 to 2016). 8

Table 10. Quinsam River (QUN-WQ) general water quality variables measured *in situ* during Years 1 to 3 (2014 to 2016). 9

Table 11. Quinsam River (QUN-WQ) dissolved gases measured *in situ* during Years 1 to 3 (2014 to 2016). 10

Table 12. Quinsam River (QUN-WQ) general water quality variables measured at ALS labs during Years 1 to 3 (2014 to 2016). 11

Table 13. Quinsam River (QUN-WQ) low level nutrients measured at ALS labs during Years 1 to 3 (2014 to 2016). 12

Table 14. Hold time exceedances for water samples analyzed by ALS Environmental. 13

Table 15. Results of field blank and trip blanks for water samples analysed by ALS Environmental. 14

1. WATER QUALITY GUIDELINES AND TYPICAL PARAMETER VALUES

Table 1. Water quality guidelines for the protection of aquatic life in British Columbia for parameters with less complex guidelines.

Parameter	Unit	BC Guideline for the Protection of Aquatic Life[1]	Guideline Reference
Specific Conductivity	µS/cm	No provincial or federal guidelines	n/a
pH	pH units	When baseline values are between 6.5 and 9 there is no restriction on changes within this range (lethal effects observed below 4.5 and above 9.5)	McKean and Nagpal (1991)
Alkalinity	mg/L	No provincial or federal guidelines. However, waterbodies with <10 mg/L are highly sensitive to acidic inputs, 10 to 20 mg/L are moderatly sensitive to acidic inputs, > 20 mg/L have a low sensitivity to acidic inputs	n/a
Total Ammonia (N)	µg/L	Dependent on pH and temperature, too numerous to present, lowest maximum allowable concentration of 680 µg/L occurs at a pH of 9 and water temperature of 8ºC, lowest maximum average 30 day concentration of 102 µg/L occurs at a pH of 9 and water temperature of 20ºC	Nordin and Pommen (1986)
Nitrite (N)	µg/L	The lowest maximum allowable concentration occurs when chloride is ≤ 2 mg/L; instantaneous maximum allowable concentration is 60 µg/L and a maximum 30 day average of 20 µg/L is allowed when chloride is ≤ 2 mg/L	Nordin and Pommen (1986)
Nitrate (N)	µg/L	The 30 day average concentration to protect freshwater aquatic life is 3,000 µg/L[2] and the maximum concentration is 32,800 µg/L.	Meays (2009)
Orthophosphate	µg/L	No provincial or federal guidelines	n/a
Total Phosphate (P)	µg/L	Trigger ranges that would signify a change in the trophic classification: <4: ultra-oligotrophic, 4-10 oligotrophic, 10 -20 mesotrophic, 20-35 meso-eutrophic, 35-100 eutrophic, > 100 hyper-eutrophic	CCME (2004)

[1] Guideline for total phosphate is a federal guideline; provincial guidelines do not exist

[2] The 30-d average (chronic) concentration is based on 5 weekly samples collected within a 30-day period.

Table 2. Total suspended solids and turbidity guidelines for the protection of aquatic life in British Columbia.

Period	**British Columbia[1] Suspended Sediment and Turbidity Guidelines for the Protection of Aquatic Life**	
	Total Suspended Sediments (mg/L)	**Turbidity (NTU)**
Clear Flow Period (less than 25 mg/L or less than 8 NTU)	"Induced suspended sediment concentrations should not exceed background levels by more than 25 mg/L during any 24-hour period (hourly sampling preferred). For sediment inputs that last between 24 hours and 30 days (daily sampling preferred), the average suspended sediment concentration should not exceed background by more than 5 mg/L."	"Induced turbidity should not exceed background levels by more than 8 NTU during any 24-hour period (hourly sampling preferred). For sediment inputs that last between 24 hours and 30 days (daily sampling preferred) the mean turbidity should not exceed background by more than 2 NTU."
Turbid Flow Period (greater than or equal to 25 mg/L or greater than or equal to 8 NTU)	"Induced suspended sediment concentrations should not exceed background levels by more than 10 mg/L at any time when background levels are between 25 and 100 mg/L. When background exceeds 100 mg/L, suspended sediments should not be increased by more than 10% of the measured background level at any one time."	"Induced turbidity should not exceed background levels by more than 5 NTU at any time when background turbidity is between 8 and 50 NTU. When background exceeds 50 NTU, turbidity should not be increased by more than 10% of the measured background level at any one time."

[1] reproduced from Singleton (2001)

Table 3. Dissolved oxygen guidelines for the protection of aquatic life in British Columbia.

	BC Guidelines for the Protection of Aquatic Life[1]		
	Life Stages Other Than Buried Embryo/Alevin	**Buried Embryo/Alevin[2]**	**Buried Embryo/Alevin[2]**
Dissolved Oxygen Concentration	Water column mg/L O_2	Water column mg/L O_2	Interstitial Water mg/L O_2
Instantaneous minimum[3]	5	9	6
30-day mean[4]	8	11	8

[1] MOE (1997a) and MOE (1997b)

[2] For the buried embryo / alevin life stages these are in-stream concentrations from spawning to the point of yolk sac absorption or 30 days post-hatch for fish; the water column concentrations recommended to achieve interstitial dissolved oxygen values when the latter are unavailable. Interstitial oxygen measurements would supersede water column measurements in comparing to criteria.

[3] The instantaneous minimum level is to be maintained at all times.

[4] The mean is based on at least five approximately evenly spaced samples. If a diurnal cycle exists in the water body, measurements should be taken when oxygen levels are lowest (usually early morning).

Table 4. **Total gas pressure guidelines for the protection of aquatic life in British Columbia.**

Water Depth	Maximum Allowable ΔP (Total Gas Pressure - Barometric Pressure) for the Protection of Aquatic Life in BC[1]
> 1 m	76 mm Hg regardless of pO_2 levels
< 1 m	$\Delta P_{\text{initiation of swim bladder overinflation}} = 73.89 * \text{water depth (m)} + 0.15 * pO_2$ where $pO_2 = 157$ mm Hg (i.e., sea level normoxic condition) In its most conservative form (assuming water column depth = 0 m), the BC guideline for waters less than 1 m deep is that the maximum allowable ΔP should not exceed 24 mm Hg

[1] Fidler and Miller (1994)

Table 5. Typical values for water quality parameters in British Columbia waters.

Parameter	Unit	Typical range in British Columbia streams and rivers	Reference
Specific Conductivity	µS/cm	The typical value in coastal BC streams is 100 µS/cm	RISC (1998)
pH	pH units	Natural fresh waters have a pH range from 4 to 10, lakes tend to have a pH ≥ 7.0 and coastal streams commonly have pH values of 5.5 to 6.5	RISC (1998)
Alkalinity	mg/L	Natural waters almost always have concentrations less than 500 mg/L, with waters in coastal BC typically ranging from 0 to 10 mg/L; waters in interior BC can have values greater than 100 mg/L	RISC (1998)
Total Suspended Solids	mg/L	In BC natural concentrations of suspended solids vary extensively from waterbody to waterbody and can have large variation within a day and among seasons	Singleton (1985) in Caux *et al.* (1997)
Turbidity	NTU	In BC natural concentrations of suspended solids vary extensively from waterbody to waterbody and can have large variation within a day and among seasons	Singleton (1985) in Caux *et al.* (1997)
Dissolved Oxygen	mg/L	In BC surface waters are generally well aerated and have DO concentrations > 10 mg/L	MOE (1997a)
Dissolved Oxygen	% saturation	In BC surface waters are generally well aerated and have DO concentrations close to equilibrium with the atmosphere (i.e., close to 100% saturation)	MOE (1997a)
ΔP (Total Gas Pressure - Barometric Pressure)	mm Hg	In BC, dissolved gas supersaturation is a natural feature of many waters with ΔP commonly being between 50 – 80 mm Hg. (We often see values between -10 and 60)	Fidler and Miller (1994)
Total Ammonia (N)	µg/L	<100 µg/L for waters not affected by waste discharges	Nordin and Pommen (1986)
Nitrite (N)	µg/L	Due to its unstable nature, nitrite concentrations are very low, typically present in surface waters at concentrations of <1 µg/L	RISC (1998)
Nitrate (N)	µg/L	In oligotrophic lakes and streams, nitrate concentrations are expected to be <100 µg/L; in most streams and lakes not impacted by anthropogenic activities, nitrate is typically <900 µg/L.	Nordin and Pommen (1986); CCME (2012)
Orthophosphate (P)	µg/L	Coastal BC streams typically have concentrations <1 µg/L	Slaney and Ward (1993); Ashley and Slaney (1997)
Total Phosphorus (P)	µg/L	Oligotrophic water bodies have total phosphorus concentrations that are between 4 to 10 µg/L while concentrations are typically between 10 to 20 µg/L in mesotrophic water bodies.	CCME (2004)

2. 2014 TO 2016 WATER QUALITY IN THE QUINSAM RIVER AND SALMON RIVER

Table 6. Salmon River (SAM-WQ) general water quality variables measured *in situ* during Years 1 to 3 (2014 to 2016).

Year	Date	Conductivity µS/cm				Specific Conductivity µS/cm				pH pH units				Air Temperature °C				Water Temperature °C			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2014	21-May	-	-	-	-	28.2	28.2	28.2	0.0	6.91	6.91	6.91	0.00	-	-	-	-	9.1	9.1	9.1	0.0
	17-Jun	-	-	-	-	37.1	37.1	37.1	0.0	7.21	7.17	7.23	0.03	12	12	12	0	12.2	12.1	12.2	0.1
	23-Jul	-	-	-	-	46.7	46.7	46.7	0.0	7.03	7.03	7.03	0.00	14	14	14	0	15.5	15.5	15.5	0.0
	18-Aug	-	-	-	-	54.1	54.1	54.1	0.0	7.14	7.12	7.16	0.02	16	16	16	0	17.2	17.2	17.2	0.0
	23-Sep	-	-	-	-	54.7	54.7	54.8	0.1	7.22	7.21	7.23	0.01	17	17	17	0	14.6	14.6	14.6	0.0
	03-Nov	-	-	-	-	35.5	35.5	35.6	0.1	6.85	6.83	6.87	0.02	8	-	-	-	8.2	8.2	8.2	0.0
2015	13-May	-	-	-	-	41.5	41.5	41.5	0.0	7.36	7.34	7.39	0.03	11	11	11	0	10.8	10.8	10.8	0.0
	16-Jun	-	-	-	-	41.1	41.1	41.2	0.1	7.87	7.86	7.88	0.01	17	17	17	0	14.5	14.5	14.6	0.1
	22-Jul	-	-	-	-	52.6	52.6	52.6	0.0	7.60	7.58	7.62	0.02	16	16	16	0	16.5	16.5	16.5	0.0
	12-Aug	-	-	-	-	47.8	47.7	47.8	0.1	7.32	7.32	7.32	0.00	15	15	15	0	16.3	16.3	16.3	0.0
	17-Sep	-	-	-	-	47.4	47.4	47.4	0.0	7.09	7.08	7.09	0.01	11	11	11	0	11.2	11.2	11.2	0.0
	15-Oct	-	-	-	-	41.5	41.5	41.6	0.1	7.38	7.37	7.40	0.02	9	9	9	0	9.0	9.0	9.0	0.0
2016	17-May	29.6	29.6	29.6	0.0	42.6	42.6	42.6	0.0	6.41	6.37	6.45	0.04	14	14	14	0	9.8	9.8	9.8	0.0
	14-Jun	46.3	46.3	46.3	0.0	65.3	65.3	65.3	0.0	6.40	6.40	6.41	0.01	9	9	9	0	10.5	10.5	10.5	0.0
	12-Jul	56.6	56.4	56.7	0.2	73.8	73.7	73.9	0.1	6.47	6.43	6.51	0.04	14	14	14	0	13.3	13.3	13.3	0.0
	16-Aug	65.0	64.9	65.0	0.1	78.3	78.3	78.3	0.0	6.56	6.53	6.60	0.04	18	18	18	0	16.5	16.5	16.5	0.0
	13-Sep	61.6	61.5	61.6	0.1	83.3	83.3	83.3	0.0	7.17	7.17	7.17	0.00	8	8	8	0	12.0	11.9	12.0	0.1
	11-Oct	29.7	29.7	29.7	0.0	45.4	45.4	45.4	0.0	6.66	6.66	6.66	0.00	-	-	-	-	7.7	7.7	7.7	0.0

[1] Average of three replicates (n=3) on each date unless otherwise indicated. A single datum listed under Avg. indicates n=1.

Dashes (-) mean that no data were collected.

Table 7. Salmon River (SAM-WQ) dissolved gases measured *in situ* during Years 1 to 3 (2014 to 2016).

Year	Quarter	Dissolved Oxygen %				Dissolved Oxygen mg/L				Barometric Pressure mm Hg				TGP %				TGP mm Hg				ΔP mm Hg			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2014	21-May	102.6	102.6	102.6	0.0	11.68	11.67	11.68	0.01	748	748	748	0	102	102	102	0	761	761	761	0	13	13	13	0
	17-Jun	99.3	99.1	99.7	0.3	10.73	10.68	10.76	0.04	749	749	749	0	101	101	102	1	758	755	761	3	9	6	12	3
	23-Jul	101.8	101.8	101.9	0.1	10.20	10.20	10.20	0.00	747	747	747	0	101	101	101	0	755	755	755	0	8	8	8	0
	18-Aug	98.9	98.0	100.6	1.4	9.56	9.43	9.73	0.15	750	750	750	0	101	101	102	1	761	757	764	4	11	7	14	4
	23-Sep	88.2	87.1	88.8	0.9	8.80	8.71	8.86	0.08	760	760	760	0	98	98	99	1	749	748	751	2	-11	-12	-9	2
	03-Nov	95.7	95.1	96.5	0.7	11.08	11.02	11.18	0.09	763	762	763	1	100	100	100	0	763	761	764	2	0	-2	1	2
2015	13-May	93.7	93.7	93.8	0.1	10.38	10.37	10.39	0.01	742	742	742	0	-	-	-	-	-	-	-	-	-	-	-	-
	16-Jun	81.5	81.3	81.8	0.3	8.31	8.27	8.34	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	22-Jul	96.1	96.1	96.2	0.1	9.40	9.38	9.42	0.02	744	744	744	0	-	-	-	-	-	-	-	-	-	-	-	-
	12-Aug	92.0	91.9	92.1	0.1	9.02	8.98	9.06	0.04	747	747	747	0	-	-	-	-	-	-	-	-	-	-	-	-
	17-Sep	82.8	82.4	83.3	0.5	9.08	9.04	9.14	0.05	746	746	746	0	-	-	-	-	-	-	-	-	-	-	-	-
	15-Oct	99.1	98.9	99.3	0.2	11.46	11.44	11.48	0.02	750	750	750	0	-	-	-	-	-	-	-	-	-	-	-	-
2016	17-May	86.6	86.4	86.7	0.2	9.82	9.81	9.84	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	14-Jun	85.1	84.9	85.3	0.2	9.49	9.47	9.51	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	12-Jul	92.9	92.7	93.0	0.2	9.72	9.70	9.74	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	16-Aug	92.8	92.6	92.9	0.2	9.07	9.06	9.08	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	13-Sep	87.8	87.4	88.2	0.4	9.47	9.43	9.52	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	11-Oct	92.2	91.8	92.5	0.4	11.01	10.97	11.06	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

[1] Average of three replicates (n=3) on each date unless otherwise indicated.

Blue shading indicates that the more conservative provincial guideline (DO instantaneous minimum of 9 mg/L) for the protection of buried embryo/alevin has not been achieved. Note that the guideline for life stages other than buried embryo/alevin is met (DO instantaneous minimum of 5 mg/L).

Dashes (-) mean that no data were collected.

Table 8. Salmon River (SAM-WQ) general water quality variables measured at ALS labs during Years 1 to 3 (2014 to 2016).

Year	Date	Alkalinity, Total (as $CaCO_3$) mg/L				Specific Conductivity µS/cm				Total Dissolved Solids mg/L				Total Suspended Solids mg/L				Turbidity NTU				pH pH units			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2014	21-May	12.3	12.2	12.3	0.1	27.2	27.0	27.3	0.2	32	31	32	1	<1.0	<1.0	<1.0	0.0	0.30	0.22	0.38	0.11	7.38	7.35	7.40	0.04
	17-Jun	17.6	17.3	17.8	0.4	40.5	37.5	43.5	4.2	33	31	34	2	<1.0	<1.0	<1.0	0.0	0.22	0.17	0.26	0.06	7.57	7.55	7.59	0.03
	23-Jul	21.0	20.7	21.2	0.4	46.5	46.4	46.6	0.1	38	38	38	0	<1.0	<1.0	<1.0	0.0	0.92	0.71	1.12	0.29	7.58	7.53	7.62	0.06
	18-Aug	23.8	23.6	23.9	0.2	56.3	55.3	57.3	1.4	49	43	55	8	<4.6	<1.0	8.1	5.0	0.22	0.20	0.23	0.02	7.79	7.76	7.82	0.04
	23-Sep	23.9	23.8	23.9	0.1	53.1	52.8	53.4	0.4	46	41	51	7	<1.0	<1.0	<1.0	0.0	0.26	0.23	0.28	0.04	7.65	7.48	7.82	0.24
	03-Nov	16.6	16.5	16.6	0.1	37.2	36.7	37.7	0.7	53	37	69	23	<1.0	<1.0	<1.0	0.0	0.33	0.32	0.34	0.01	7.61	7.56	7.65	0.06
2015	13-May	15.8	15.3	16.2	0.6	33.5	33.3	33.6	0.2	25	23	27	3	<1.0	<1.0	<1.0	0.0	0.16	0.14	0.17	0.02	7.38	7.33	7.42	0.06
	16-Jun	21.6	20.8	22.4	1.1	47.8	47.7	47.8	0.1	32	31	33	1	<1.0	<1.0	<1.0	0.0	0.11	0.11	0.11	0.00	7.66	7.65	7.66	0.01
	22-Jul	23.1	22.6	23.5	0.6	59.9	55.0	64.8	6.9	32	31	32	1	<1.0	<1.0	<1.0	0.0	0.13	0.12	0.13	0.01	7.69	7.68	7.70	0.01
	12-Aug	22.6	21.7	23.4	1.2	51.4	51.2	51.6	0.3	47	45	48	2	<1.0	<1.0	<1.0	0.0	0.16	0.14	0.18	0.03	7.85	7.81	7.88	0.05
	17-Sep	20.4	20.4	20.4	0.0	47.2	47.1	47.3	0.1	32	32	32	0	<1.0	<1.0	<1.0	0.0	0.18	0.16	0.19	0.02	7.72	7.70	7.74	0.03
	15-Oct	18.2	18.1	18.2	0.1	40.7	40.6	40.8	0.1	37	36	37	1	<1.0	<1.0	<1.0	0.0	0.36	0.24	0.48	0.17	7.43	7.43	7.43	0.00
2016	17-May	12.9	12.8	12.9	0.1	26.4	26.3	26.5	0.1	19	18	20	1	<1.0	<1.0	<1.0	0.0	0.18	0.16	0.20	0.03	7.43	7.40	7.46	0.04
	14-Jun	14.8	14.8	14.8	0.0	35.4	35.1	35.6	0.4	28	27	28	1	<1.0	<1.0	<1.0	0.0	0.16	0.14	0.17	0.02	7.48	7.46	7.49	0.02
	12-Jul	17.9	17.6	18.1	0.4	37.0	36.9	37.0	0.1	31	30	32	1	<1.0	<1.0	<1.0	0.0	0.14	0.14	0.14	0.00	7.48	7.46	7.49	0.02
	16-Aug	21.5	21.3	21.6	0.2	50.3	50.1	50.4	0.2	32	28	36	6	<1.2	<1.0	1.4	0.3	0.13	0.12	0.13	0.01	7.33	7.32	7.34	0.01
	13-Sep	20.4	20.3	20.5	0.1	48.1	47.8	48.4	0.4	34	34	34	0	<1.0	<1.0	<1.0	0.0	0.18	0.15	0.20	0.04	7.74	7.65	7.82	0.12
	11-Oct	20.2	20.1	20.3	0.1	47.2	46.4	48.0	1.1	37	34	39	4	<1.1	<1.0	1.2	0.1	0.42	0.40	0.44	0.03	7.67	7.63	7.70	0.05

[1] Average of two replicates (n=2) on each date.

Parameters that have a concentration below the detection limit are assumed to have a concentration equal to the detection limit for calculation purposes.

Table 9. Salmon River (SAM-WQ) low level nutrients measured at ALS labs during Years 1 to 3 (2014 to 2016).

Year	Date	Ammonia, Total (as N) µg/L				Dissolved Orthophosphate (as P) µg/L				Nitrate (as N) µg/L				Nitrite (as N) µg/L				Total Phosphorus (P) µg/L			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2014	21-May	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	8.8	8.4	9.1	0.5	<1.0	<1.0	<1.0	0.0	3.2	3.1	3.2	0.1
	17-Jun	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	15.5	15.2	15.7	0.4	<1.0	<1.0	<1.0	0.0	<2.1	<2.0	2.1	0.1
	23-Jul	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	8.5	8.5	8.5	0.0	<1.0	<1.0	<1.0	0.0	2.4	2.2	2.5	0.2
	18-Aug	5.8	5.5	6.0	0.4	<1.1	<1.0	1.1	0.1	27.6	27.4	27.7	0.2	<1.0	<1.0	<1.0	0.0	<3.8	<2.0	5.6	2.5
	23-Sep	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	71.6	70.8	72.4	1.1	<1.0	<1.0	<1.0	0.0	<2.3	<2.0	2.5	0.4
	03-Nov	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	26.1	25.6	26.5	0.6	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
2015	13-May	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	12.2	12.1	12.3	0.1	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	16-Jun	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	52.8	52.8	52.8	0.0	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	22-Jul	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	25.0	24.6	25.4	0.6	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	12-Aug	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	96.6	95.9	97.3	1.0	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	17-Sep	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	40.0	39.9	40.0	0.1	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	15-Oct	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	20.1	20.0	20.1	0.1	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
2016	17-May	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	<5.6	<5.0	6.1	0.8	<1.3	<1.0	1.5	0.4	<2.7	<2.0	3.4	1.0
	14-Jun	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	14.4	14.1	14.7	0.4	<1.0	<1.0	<1.0	0.0	<3.5	<2.0	5.0	2.1
	12-Jul	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	23.6	23.5	23.6	0.1	<1.0	<1.0	<1.0	0.0	<2.8	<2.0	3.5	1.1
	16-Aug	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	81.9	81.4	82.4	0.7	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	13-Sep	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	40.4	40.2	40.5	0.2	<1.0	<1.0	<1.0	0.0	<2.2	<2.0	2.3	0.2
	11-Oct	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	32.7	32.4	32.9	0.4	<1.0	<1.0	<1.0	0.0	3.0	3.0	3.0	0.0

[1] Average of two replicates (n=2) on each date.

Parameters that have a concentration below the detection limit are assumed to have a concentration equal to the detection limit for calculation purposes.

Table 10. Quinsam River (QUN-WQ) general water quality variables measured *in situ* during Years 1 to 3 (2014 to 2016).

Year	Date	Conductivity µS/cm				Specific Conductivity µS/cm				pH[2] pH units				Air Temperature °C				Water Temperature °C				Salinity ppt			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2014	23-May	-	-	-	-	95.6	95.6	95.6	0.0	7.38	7.38	7.39	0.01	-	-	-	-	12.8	12.8	12.8	0.0	-	-	-	-
	18-Jun	-	-	-	-	143.1	143.1	143.1	0.0	7.58	7.57	7.58	0.01	14	14	14	0	17.1	17.1	17.1	0.0	-	-	-	-
	22-Jul	-	-	-	-	148.1	148.1	148.1	0.0	7.36	7.36	7.36	0.00	16	16	16	0	17.7	17.7	17.7	0.0	-	-	-	-
	19-Aug	-	-	-	-	152.3	152.2	152.4	0.1	7.38	7.36	7.43	0.04	19	19	19	0	20.2	20.2	20.2	0.0	-	-	-	-
	24-Sep	-	-	-	-	109.9	109.9	109.9	0.0	7.30	7.23	7.36	0.07	14	14	14	0	16.1	16.1	16.1	0.0	-	-	-	-
	04-Nov	-	-	-	-	69.4	69.4	69.4	0.0	7.01	7.01	7.02	0.01	7	7	7	0	9.6	9.6	9.6	0.0	-	-	-	-
2015	12-May	-	-	-	-	144.4	144.4	144.5	0.1	7.68	7.68	7.68	0.00	14	14	14	0	14.2	14.2	14.2	0.0	-	-	-	-
	17-Jun	-	-	-	-	98.1	14.0	140.2	72.8	7.71	7.71	7.71	0.00	15	15	15	0	18.2	18.2	18.2	0.0	-	-	-	-
	23-Jul	-	-	-	-	190.7	190.7	190.7	0.0	7.49	7.49	7.49	0.00	17	17	17	0	17.0	17.0	17.0	0.0	-	-	-	-
	13-Aug	-	-	-	-	197.7	197.6	197.7	0.1	7.41	7.40	7.41	0.01	17	17	17	0	18.5	18.5	18.5	0.0	-	-	-	-
	16-Sep	-	-	-	-	185.7	185.7	185.7	0.0	7.50	7.50	7.50	0.00	12	12	12	0	14.1	14.1	14.1	0.0	-	-	-	-
	14-Oct	-	-	-	-	131.9	131.8	131.9	0.1	7.52	7.50	7.54	0.02	11	11	11	0	9.5	9.5	9.6	0.1	-	-	-	-
2016	18-May	119.1	119.1	119.2	0.1	150.1	150.0	150.2	0.1	7.18	7.16	7.20	0.02	12	12	12	0	14.7	14.7	14.7	0.0	0.07	0.07	0.07	0.00
	15-Jun	112.1	112.0	112.1	0.1	143.5	143.4	143.6	0.1	6.86	6.86	6.87	0.01	9	9	9	0	14.0	14.0	14.0	0.0	0.07	0.07	0.07	0.00
	13-Jul	125.5	125.4	125.6	0.1	154.2	154.1	154.4	0.2	7.68	7.67	7.68	0.01	15	15	15	0	15.7	15.7	15.7	0.0	0.07	0.07	0.07	0.00
	17-Aug	139.4	139.4	139.4	0.0	157.4	157.4	157.4	0.0	7.25	7.24	7.25	0.01	19	19	19	0	19.3	19.3	19.3	0.0	0.07	0.07	0.07	0.00
	14-Sep	138.5	138.5	138.5	0.0	172.6	172.6	172.7	0.1	7.40	7.39	7.40	0.01	12	12	12	0	15.1	15.1	15.1	0.0	0.08	0.08	0.08	0.00
	12-Oct	115.2	114.9	115.5	0.3	175.9	175.5	176.1	0.3	7.70	7.69	7.71	0.01	5	5	5	0	7.7	7.7	7.7	0.0	0.08	0.08	0.08	0.00

[1] Average of three replicates (n=3) on each date unless otherwise indicated.

[2] pH measured in the laboratory is presented for the July and October sampling dates because the pH meter malfunctioned on these dates.

Dashes (-) mean that no data were collected.

Table 11. Quinsam River (QUN-WQ) dissolved gases measured *in situ* during Years 1 to 3 (2014 to 2016).

Year	Date	Dissolved Oxygen %				Dissolved Oxygen mg/L				Barometric Pressure mm Hg				TGP %				TGP mm Hg				ΔP mm Hg			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2014	23-May	101.8	101.4	102.6	0.7	10.74	10.69	10.82	0.07	744	743	745	1	100	100	100	0	744	744	745	1	0	0	1	1
	18-Jun	91.3	90.9	91.9	0.5	8.84	8.80	8.87	0.04	748	748	749	1	101	101	101	0	755	753	757	2	7	5	8	2
	22-Jul	95.8	95.8	95.9	0.1	9.13	9.12	9.13	0.01	747	747	748	1	101	101	101	0	753	753	753	0	6	5	6	1
	19-Aug	77.9	77.7	78.3	0.3	7.01	6.99	7.03	0.02	745	744	745	1	99	99	99	0	735	735	735	0	-10	-10	-9	1
	24-Sep	91.7	90.1	92.7	1.4	8.78	8.53	8.91	0.21	753	752	753	1	98	98	98	0	739	739	740	1	-13	-14	-13	1
	04-Nov	88.5	88.4	88.5	0.1	9.95	9.94	9.96	0.01	761	761	762	1	99	99	99	0	755	755	755	0	-6	-7	-6	1
2015	12-May	96.2	96.2	96.3	0.1	9.89	9.88	9.89	0.01	741	741	741	0	-	-	-	-	-	-	-	-	-	-	-	-
	17-Jun	83.7	83.6	83.9	0.2	7.90	7.89	7.91	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	23-Jul	84.2	84.1	84.4	0.2	8.14	8.13	8.14	0.01	744	744	744	0	-	-	-	-	-	-	-	-	-	-	-	-
	13-Aug	84.2	84.1	84.4	0.2	7.89	7.88	7.91	0.02	746	746	746	0	-	-	-	-	-	-	-	-	-	-	-	-
	16-Sep	78.1	77.8	78.5	0.4	8.03	8.00	8.05	0.03	743	743	743	0	-	-	-	-	-	-	-	-	-	-	-	-
	14-Oct	87.0	86.8	87.3	0.3	9.88	9.87	9.89	0.01	754	754	754	0	-	-	-	-	-	-	-	-	-	-	-	-
2016	18-May	81.9	81.7	82.0	0.2	8.30	8.30	8.30	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	15-Jun	80.0	79.9	80.2	0.2	8.23	8.22	8.24	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	13-Jul	79.4	79.3	79.5	0.1	7.89	7.87	7.92	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	17-Aug	84.4	84.1	84.6	0.3	7.77	7.75	7.79	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	14-Sep	81.0	80.9	81.2	0.2	8.16	8.15	8.17	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	12-Oct	98.0	97.6	98.5	0.5	11.70	11.63	11.75	0.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

[1] Average of three replicates (n=3) on each date unless otherwise indicated.

Blue shading indicates that the more conservative provincial guideline (DO instantaneous minimum of 9 mg/L) for the protection of buried embryo/alevin has not been achieved. Note that the guideline for life stages other than buried embryo/alevin is met (DO instantaneous minimum of 5 mg/L).

Dashes (-) mean that no data were collected.

Table 12. **Quinsam River (QUN-WQ) general water quality variables measured at ALS labs during Years 1 to 3 (2014 to 2016).**

Year	Date	Alkalinity, Total (as CaCO$_3$) mg/L				Specific Conductivity µS/cm				Total Dissolved Solids mg/L				Total Suspended Solids mg/L				Turbidity NTU				pH pH units			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2014	23-May	31.7	31.5	31.8	0.2	94.8	94.1	95.4	0.9	69	68	70	1	<1.0	<1.0	<1.0	0.0	0.59	0.52	0.65	0.09	7.77	7.77	7.77	0.00
	18-Jun	41.0	40.8	41.1	0.2	139.5	139.0	140.0	0.7	96	96	96	0	<1.0	<1.0	<1.0	0.0	0.42	0.40	0.44	0.03	7.87	7.87	7.87	0.00
	22-Jul	42.4	42.4	42.4	0.0	140.0	139.0	141.0	1.4	103	101	105	3	<1.0	<1.0	<1.0	0.0	0.46	0.44	0.47	0.02	7.73	7.65	7.81	0.11
	19-Aug	42.1	41.9	42.3	0.3	156.0	146.0	166.0	14.1	96	95	96	1	<1.0	<1.0	<1.0	0.0	0.70	0.47	0.93	0.33	7.81	7.57	8.05	0.34
	24-Sep	35.0	35.0	35.0	0.0	109.0	109.0	109.0	0.0	71	67	74	5	<1.0	<1.0	<1.0	0.0	0.56	0.50	0.62	0.08	7.55	7.52	7.58	0.04
	04-Nov	23.7	23.5	23.8	0.2	71.3	70.7	71.8	0.8	59	53	64	8	<1.0	<1.0	<1.0	0.0	0.74	0.71	0.77	0.04	7.61	7.59	7.63	0.03
2015	12-May	40.8	40.6	41.0	0.3	143.0	143.0	143.0	0.0	91	89	93	3	<1.0	<1.0	<1.0	0.0	0.38	0.37	0.39	0.01	7.79	7.78	7.80	0.01
	17-Jun	43.9	43.8	43.9	0.1	157.0	157.0	157.0	0.0	97	94	100	4	<1.0	<1.0	<1.0	0.0	0.41	0.40	0.42	0.01	7.91	7.90	7.92	0.01
	23-Jul	52.9	51.7	54.0	1.6	206.0	206.0	206.0	0.0	120	120	120	0	<1.0	<1.0	<1.0	0.0	0.49	0.49	0.49	0.00	8.00	7.99	8.01	0.01
	13-Aug	48.8	48.0	49.6	1.1	175.0	173.0	177.0	2.8	124	120	127	5	<1.0	<1.0	<1.0	0.0	0.36	0.30	0.42	0.08	7.78	7.70	7.85	0.11
	16-Sep	46.2	46.0	46.3	0.2	178.0	177.0	179.0	1.4	145	116	173	40	<1.0	<1.0	<1.0	0.0	0.40	0.38	0.42	0.03	7.94	7.94	7.94	0.00
	14-Oct	34.0	33.9	34.1	0.1	130.0	129.0	131.0	1.4	94	92	96	3	<1.3	<1.0	1.6	0.4	0.47	0.40	0.53	0.09	7.55	7.52	7.58	0.04
2016	18-May	35.4	35.1	35.6	0.4	131.5	131.0	132.0	0.7	85	85	85	0	<1.0	<1.0	<1.0	0.0	0.49	0.38	0.59	0.15	7.83	7.80	7.86	0.04
	15-Jun	34.3	33.9	34.7	0.6	130.5	130.0	131.0	0.7	87	86	88	1	<1.0	<1.0	<1.0	0.0	0.45	0.44	0.46	0.01	7.78	7.77	7.78	0.01
	13-Jul	36.6	36.5	36.7	0.1	110.0	109.0	111.0	1.4	70	67	72	4	<1.3	<1.0	1.5	0.4	1.17	1.14	1.19	0.04	7.68	7.67	7.68	0.01
	17-Aug	35.5	35.4	35.5	0.1	137.5	137.0	138.0	0.7	87	86	88	1	<1.1	<1.0	1.1	0.1	0.46	0.44	0.47	0.02	7.51	7.50	7.51	0.01
	14-Sep	35.3	35.1	35.4	0.2	139.0	139.0	139.0	0.0	84	83	84	1	<1.0	<1.0	<1.0	0.0	0.46	0.45	0.46	0.01	7.71	7.70	7.72	0.01
	12-Oct	30.6	30.4	30.8	0.3	118.5	114.0	123.0	6.4	83	81	84	2	<1.0	<1.0	<1.0	0.0	0.72	0.72	0.72	0.00	7.70	7.69	7.71	0.01

[1] Average of two replicates (n=2) on each date.

Parameters that have a concentration below the detection limit are assumed to have a concentration equal to the detection limit for calculation purposes.

Table 13. Quinsam River (QUN-WQ) low level nutrients measured at ALS labs during Years 1 to 3 (2014 to 2016).

Year	Date	Ammonia, Total (as N) µg/L				Orthophosphate (as P) µg/L				Nitrate (as N) µg/L				Nitrite (as N) µg/L				Total Phosphorus (P) µg/L			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2014	23-May	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	13.8	13.5	14.0	0.4	<1.0	<1.0	<1.0	0.0	3.9	3.8	3.9	0.1
	18-Jun	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	29.7	29.2	30.1	0.6	<1.0	<1.0	<1.0	0.0	2.8	2.7	2.9	0.1
	22-Jul	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	31.6	31.3	31.9	0.4	<1.0	<1.0	<1.0	0.0	2.9	2.6	3.2	0.4
	19-Aug	<5.2	<5.0	5.3	0.2	<1.0	<1.0	<1.0	0.0	17.1	17.0	17.1	0.1	<1.0	<1.0	<1.0	0.0	4.8	4.6	5.0	0.3
	24-Sep	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	21.2	20.7	21.6	0.6	<1.0	<1.0	<1.0	0.0	4.3	3.9	4.6	0.5
	04-Nov	5.1	5.1	5.1	0.0	<1.0	<1.0	<1.0	0.0	24.6	24.0	25.1	0.8	<1.0	<1.0	<1.0	0.0	3.7	2.9	4.4	1.1
2015	12-May	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	23.0	22.9	23.1	0.1	<1.0	<1.0	<1.0	0.0	2.9	2.5	3.3	0.6
	17-Jun	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	23.8	23.6	23.9	0.2	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	23-Jul	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	29.9	29.3	30.5	0.8	<1.0	<1.0	<1.0	0.0	<2.1	<2.0	2.1	0.1
	13-Aug	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	41.0	40.6	41.3	0.5	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	16-Sep	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	14.0	13.9	14.1	0.1	<1.0	<1.0	<1.0	0.0	<2.2	<2.0	2.3	0.2
	14-Oct	9.0	8.8	9.2	0.3	<1.0	<1.0	<1.0	0.0	36.0	35.6	36.3	0.5	<1.0	<1.0	<1.0	0.0	4.6	4.4	4.8	0.3
2016	18-May	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	16.3	16.1	16.4	0.2	<1.0	<1.0	<1.0	0.0	3.5	3.0	3.9	0.6
	15-Jun	<5.0	<5.0	<5.0	0.0	1.45	1.2	1.7	0.4	15.2	14.4	16.0	1.1	<1.0	<1.0	<1.0	0.0	3.3	2.7	3.9	0.8
	13-Jul	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	16.7	16.3	17.1	0.6	<1.0	<1.0	<1.0	0.0	4.6	4.2	4.9	0.5
	17-Aug	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	24.0	23.9	24.1	0.1	<1.0	<1.0	<1.0	0.0	3.8	3.0	4.6	1.1
	14-Sep	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	18.5	18.4	18.5	0.1	<1.0	<1.0	<1.0	0.0	2.6	2.5	2.7	0.1
	12-Oct	9.5	9.2	9.8	0.4	<1.0	<1.0	<1.0	0.0	38.8	38.6	39.0	0.3	<1.0	<1.0	<1.0	0.0	5.5	5.4	5.5	0.1

[1] Average of two replicates (n=2) on each date.

Parameters that have a concentration below the detection limit are assumed to have a concentration equal to the detection limit for calculation purposes.

3. QUALITY CONTROL/QUALITY ASSURANCE

Table 14. **Hold time exceedances for water samples analyzed by ALS Environmental.**

Description	Site	Sampling Date	Recommended Hold Time (days)	Actual Hold Time (days)
Physical Tests				
Total Suspended Solids	SAM-WQ	17-May-16	7	8
Anions and Nutrients				
Nitrite in Water by Ion Chromatography	QUN-WQ	19-Aug-14	3	8
Total Dissolved P in Water by Colour	SAM-WQ	17-Jun-14	3	6

All samples for all sites and sample dates exceeded the recommended hold time for pH of 0.25 hours; however, laboratory measurements of pH are still considered more accurate than field measurements.

Table 15. Results of field blank and trip blanks for water samples analysed by ALS Environmental.

Year	Date	Site	Type of Sample	Alkalinity, Total (as CaCO3) mg/L	Ammonia, Total (as N) µg/L	Conductivity µS/cm	Orthophosphate (as P) µg/L	Nitrate (as N) µg/L	Nitrite (as N) µg/L	Total Dissolved Solids mg/L	Total Phosphorus (P) µg/L	Total Suspended Solids mg/L	Turbidity NTU	pH pH units
2014	21-May	SAM-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.60
		SAM-WQ	Trip Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.54
	23-May	QUN-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.60
		QUN-WQ	Trip Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.64
	17-Jun	SAM-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.44
		SAM-WQ	Trip Blank	<2.0	6.08	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.48
	18-Jun	QUN-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.47
		QUN-WQ	Trip Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.45
	22-Jul	QUN-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.69
		QUN-WQ	Trip Blank	<2.0	2.71	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.76
	23-Jul	SAM-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.50
		SAM-WQ	Trip Blank	<2.0	50.2	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.47
	18-Aug	SAM-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	6.50
		SAM-WQ	Trip Blank	<2.0	88.5	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	6.05
2014	19-Aug	QUN-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.91
		QUN-WQ	Trip Blank	<2.0	38.7	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	6.17
	23-Sep	SAM-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.28
		SAM-WQ	Trip Blank	<2.0	81.6	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	6.03
	24-Sep	QUN-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.45
		QUN-WQ	Trip Blank	<2.0	55.1	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.41
	03-Nov	SAM-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.75
		SAM-WQ	Trip Blank	<2.0	87.7	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.73
	04-Nov	QUN-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.70
		QUN-WQ	Trip Blank	<2.0	99.5	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.75

Table 15. Continued.

Year	Date	Site	Type of Sample	Alkalinity, Total (as CaCO3) mg/L	Ammonia, Total (as N) µg/L	Conductivity µS/cm	Orthophosphate (as P) µg/L	Nitrate (as N) µg/L	Nitrite (as N) µg/L	Total Dissolved Solids mg/L	Total Phosphorus (P) µg/L	Total Suspended Solids mg/L	Turbidity NTU	pH pH units
2015	12-May	QUN-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.84
		QUN-WQ	Trip Blank	<2.0	11.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.80
	13-May	SAM-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.50
		SAM-WQ	Trip Blank	<2.0	18.8	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	6.77
	16-Jun	SAM-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	6.32
		SAM-WQ	Trip Blank	<2.0	43.6	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	6.22
	17-Jun	QUN-WQ	Field Blank	<2.0	<5.0	3.2	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	6.22
		QUN-WQ	Trip Blank	<2.0	58.5	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.91
2016	17-May	SAM-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.70
		SAM-WQ	Trip Blank	<2.0	12.1	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.74
	18-May	QUN-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.62
		QUN-WQ	Trip Blank	<2.0	5.90	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.58